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The Food Problem and the Evolution of International Income Levels

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ABSTRACT
In most poor countries, large fractions of land, labor, and other productive resources are devoted to producing food for subsistence needs. We show that a model incorporating the “food problem” can provide new and useful insights into the evolution of international income levels. In particular, we find that the food problem can explain why some countries started to realize increases in per capita output more than 250 years later in history than others. We also show that the food problem has important implications for growth miracles and the speed at which a country converges to its balanced growth path.

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1. Introduction

Many poor economies suffer from what T.W. Schultz (1953) characterized as the “food problem.” Simply put, Schultz argued that many poor countries are in a situation of “high food drain,” in which they have “a level of income so low that a critically large proportion of the income is required for food.” Schultz took it as given that countries in this situation must produce the bulk of their own food to satisfy subsistence needs, presumably because imports are prohibitively costly and because these countries have few goods or resources to exchange for food. Until they can meet their subsistence needs, Schultz said, they are unable to begin the process of modern economic growth. Schultz’s view was later echoed in a large literature that held that an agricultural surplus is a necessary precondition for a country to begin the development process. This hypothesis was a central argument of Johnston and Mellor (1961), Johnston and Kilby (1975) and Timmer (1988), among others. More recently, it has figured prominently in the writing of non-economists such as Diamond (1997) and remains a major theme of Timmer (2002).

This paper explores the quantitative implications of Schultz’s hypothesis. In particular, it presents a model of economic development and growth that incorporates Schultz’s idea, and then uses the model to analyze the evolution of international incomes over the last three centuries. We show that a model incorporating the food problem provides new and useful insights into the evolution of international income levels. First, it offers a plausible explanation for why some countries started to realize increases in per capita output more than 250 years later than others. Second, the food problem acts as a drag on the industrialization process, reducing the speed at which a country converges to its balanced growth path. Third, the model offers insights as to why, once underway, the
process of industrialization occurs at different rates in different countries, and why growth miracle experiences have not all been alike.

Our model is an extension of the neoclassical growth model that includes an explicit agricultural sector. In both sectors, technology grows exogenously. We implement Schultz’s idea by imposing a subsistence requirement for food consumption. Consumers in the model economy care only about consuming food until they reach the subsistence threshold. This preference specification implies that all of an economy’s resources will be used to produce food if productivity in agriculture is sufficiently low. This can result in a potentially long period of constant living standards in which subsistence agriculture is the sole economic activity. Once productivity in the agricultural sector reaches the level needed to meet the food requirements of the population, productive resources begin to move out of agriculture and into industry, per capita output begins to grow.

The agricultural sector remains important in the model economy for a long time after the beginning of industrialization. The movement of labor out of agriculture and into industry – the “structural transformation” of the economy – is constrained by the continued need to satisfy the economy’s food demands. Initially, the pace of the structural transformation is determined entirely by the advancement of technology in agriculture. Subsequently, capital produced in the industrial sector is employed in agriculture, i.e., farming becomes mechanized. This allows an acceleration of the structural transformation. Asymptotically, agriculture’s share of economic activity declines to zero and the model behaves like the standard one-sector neoclassical growth model.
We calibrate the model to the structural transformation and economic growth of the United Kingdom between 1750 and 2000. We then use the calibrated structure to examine the theory’s implications for the evolution of international incomes. We focus on the potential importance of cross-country differences in both agricultural total factor productivity (TFP) and non-agricultural total factor productivity, which we interpret as resulting from differences in both policy regimes and geoclimatic endowments (e.g., land quality, location, climate, and disease/pest burdens).

Unsurprisingly, as in many one-sector growth models, differences in non-agricultural TFP are important in accounting for disparities in income levels across countries. Indeed, asymptotically these differences are the only source of disparities in countries’ relative income level. A key contribution of this paper, however, is to show that differences in agricultural TFP are also be important. Specifically, in our model, agricultural TFP differences account entirely for differences in the starting date of economic growth, and largely in consequence these differences in agricultural TFP also have a significant effect -- for hundreds of years -- on cross-country differences in relative incomes. This is true even though asymptotically, agricultural TFP differences cannot explain any differences in relative incomes or growth rates. This explanation for cross-country income disparities differs from those commonly given in the growth literature, which instead focuses on differences in aggregate or non-agricultural TFP.

Unlike most one-sector growth models and models of long-run growth, our model offers an explanation for why some economies have failed to benefit from the dramatic increase in the stock of worldwide knowledge, as well as for why policy reforms and institutional improvements in the non-agricultural sector – undertaken in many poor
countries in an effort to bring growth – might prove ineffectual. In our model, economies that are bedeviled by the food problem will benefit little or not at all from changes in the level or growth of efficiency in the non-agricultural sector.

Our model also offers new insights into growth miracles. In our model, the source of a growth miracle can either be agriculture or non-agriculture, and the nature of the miracle depends on the source. An agricultural induced growth miracle occurs when a country overcomes its food problem by realizing a large increase in agricultural TFP. This Green Revolution – achieved through the introduction of new seeds, for example, or through policy reforms, has a dramatic and immediate effect on the country’s income level, accelerating its industrialization and convergence to its long-run relative income level. It does not, however, change the country’s long-run relative income. In contrast, a non-agricultural induced growth miracle occurs when a country that has barely solved its food problem realizes a large increase in non-agricultural TFP. This Industrial Revolution will have a smaller short-run impact – but larger long-run impacts on relative income levels.

Our paper clearly owes a major intellectual debt to the early (but generally less formalized) literature on agricultural development.\(^1\) It is also related to a set of recent papers that seek to account for the process of economic development and growth in the very long run. Most of these papers seek to encompass, in a model with a single final good, the fact that living standards in most economies were low and relatively constant for long periods of time, followed by a transition period with modest and irregular

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growth, followed in turn by a period of modern economic growth. This set of papers includes: Galor and Weil (2000), Goodfriend and McDermott (1995), Hansen and Prescott (2002), King and Rebelo (1993), Laitner (2000), and Lucas (2001). These papers differ fundamentally from our paper in that they do not focus on prolonged periods of structural transformation.

Our paper also relates to a set of recent papers that incorporate agriculture into growth models. Unlike us, Echevarria (1995, 1997), Kongsamut, Rebelo and Xie (2001), Irz and Roe (2001), Glomm (1992), Matsuyama (1992), and Lucas (2004) do not examine the role of agriculture in the evolution of international income differences. Case lli and Coleman (2001), and Gollin, Parente and Rogerson (2004) each examines the role of agriculture in the evolution of international or regional income differences, but focus on different factors that prevent an economy from moving resources out of agriculture too quickly. In Caselli and Coleman (2001) this factor is a skill needed to work in non-agriculture, and in Gollin, Parente and Rogerson (2004) this factor is home production. Similar to us, Restuccia et al (2004) stress the importance of differences in agricultural TFP in accounting for cross-country differences in living standards. But whereas we focus on the implications of these differences for how an economy develops over time, these authors focus on understanding the factors that lead to low TFP in agriculture. We view this work as complementary to our analysis.

Our model is most closely related to Gollin, Parente, and Rogerson (2002), and Kogel and Prskawetz (2001). These papers similarly impose a subsistence constraint and allow for exogenous technological change in the agricultural sector. The main difference

particularly interesting early numeric simulation of a two-sector model can be found in Kelley, Williamson and Cheatham (1972).
between our paper and these is that the earlier papers do not allow a feedback from industry to agriculture corresponding to the mechanization of farming.

The paper is organized as follows. Section 2 provides some empirical support for the food problem hypothesis. Section 3 describes the model economy and characterizes the equilibrium properties. Section 4 calibrates the model to the structural transformation of the United Kingdom over the period from 1700 to 2000. Section 5 then uses the calibrated model to organize and interpret the evolution of international incomes levels over the last 300 years. Finally, Section 6 concludes the paper.

2. Empirical Support

The central tenet of our theory is that improvements in agricultural productivity allow resources to be released to other activities. Before proceeding, it is instructive to ask what the empirical support is for this proposition. In this section we document two facts about the agricultural transformation. First, in most poor countries, large amounts of labor and land are devoted to the production of basic foods for domestic consumption – in other words, to meeting subsistence needs. Second, increases in the productivity of the agricultural sector are associated with a structural transformation: the shifting of resources away from agriculture and into non-agriculture. We consider these two facts in turn.

Subsistence needs

In most poor countries, agriculture accounts for very large fractions of employment and value added. For all developing countries in 2000, the United Nations Food and
Agriculture Organization (FAO) estimates that agriculture accounted for 55 percent of employment, and for 65 countries designated as “low-income,” agriculture employed 58 percent of the total workforce (FAOSTAT data, 2004). For a number of countries (including Rwanda, Burundi, Burkina Faso, and Nepal), over 90 percent of workers are employed in agriculture. Agriculture’s share of value added is also high – reaching 40-50 percent in some poor countries.

Some agriculture is devoted to producing non-food crops and export crops, which might challenge our underlying assumption that the agriculture sector essentially produces food for domestic consumption. But it turns out that in most poor countries, agricultural land and labor are overwhelmingly devoted to food production – and specifically, to meeting the subsistence needs of the population. For example, FAO reports that in 2000, 68.6 percent of arable land in 159 developing countries was devoted to staple food crops: grains, pulses (beans, peas, lentils, etc.), roots and tubers (FAOSTAT data, 2004). Of the resulting production, almost all was devoted to domestic consumption: only a handful of developing countries were net exporters of grain (Argentina, Guyana, India, Paraguay, Thailand, Uruguay, and Vietnam). Of these, only Argentina exported more than a quarter of its grain production (FAOSTAT 2001). A similarly small set of countries were significant net exporters of roots and tubers, with only eight countries having net exports equal to more than 5 percent of production (Costa Rica, Dominican Republic, Guatemala, Lebanon, St. Vincent, Swaziland, Thailand, and Vietnam).

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2 The United Nations Food and Agriculture Organization (FAO) includes data for 159 developing countries. The major countries missing from the data are the countries of the former Soviet Union.

3 A number of countries from the former Soviet Union, not included in the land use data above, are modest exporters of grain, including Ukraine and Kazakhstan.
Moreover, FAO data show that most poor countries meet essentially all of their food needs from domestic sources. Contrary to popular perceptions, food imports and food aid are not a major source of food at the macro level for poor countries. Taking all low-income countries together, net imports of food supplied around 5 percent of total calorie consumption in 2000 (FAOSTAT data, 2004). Using another measure of import dependence, in 2000, there were exactly 100 countries with populations over 5 million and available FAO data on food consumption. Of these, only 14 imported more than 15 percent of their total food grain, and only 7 of these were developing countries (Angola, Belarus, Cuba, Dominican Republic, Libya, Malaysia, and Saudi Arabia). Including small countries as well as large, approximately 5.6 billion of the world’s 6.2 billion people live in countries that depend on imports for less than 15 percent of food grain consumption.

To summarize, the above discussion support three conclusions. First, in today’s poor countries, at least in a stylized sense, most of the resources in agriculture are used for meeting domestic food needs, and most food needs are met from domestic resources. Second, the resources required are large relative to the aggregate economy. Third, it is reasonable to view most economies as closed, from the perspective of trade in food.

*Agricultural productivity growth and the structural transformation*

On average, countries that have succeeded in increasing productivity in agriculture have experienced relatively sharp declines in agriculture’s share of GDP. In other words, growth in agricultural productivity has been associated with a diminishing role for agriculture. This result is fairly robust to the ways in which we measure agricultural productivity, and it mirrors results reported by Timmer (1988), among others.
Our analysis is based on data on a set of 92 countries for which all relevant data were available. For these countries, we regressed a measure of the change in agriculture’s share of the workforce on a constant and a measure of agricultural productivity growth. In particular, the dependent variable was the change in log of agriculture’s share of the economically active population, from 1960-2000. These numbers were taken from FAO online data. The independent variable was a measure of the growth rate of real output per worker in agriculture. We derived this number from the FAO data on agriculture’s share of the workforce, along with data from the Penn World Tables on real output per worker and data on agriculture’s share of GDP from the World Bank’s World Development Indicators 2001 and the International Historical Statistics, various volumes (Mitchell 1992, 1993, 1995). For 56 countries, we were able to compute this measure for the period 1960 to 2000. For other countries, we used other starting or ending years.

Table 1 reports the results of an OLS regression on the data, for the 1960-2000 period. The results show a strongly negative relationship between the change in agriculture’s share of employment and the change in agricultural output per worker. A similar result obtains even if we use agricultural output per person on the right-hand side. These results are consistent with the notion that countries experiencing increases in agricultural productivity are able to release labor from agriculture into other sectors of the economy.

3. A Model of the Structural Transformation

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4 We recognize that this measure of agriculture’s share of GDP may be imperfect since it presumably uses nominal prices. This may affect our measures of agricultural output per worker, but we believe the results reported here would be robust to other measures of agricultural productivity change.
3.1 The Economy

The basic structure of our model is that of the one-sector neoclassical growth model, extended to allow for an explicit agricultural sector. The extension is done in such a way that the process of development is associated with a structural transformation of economic activity, characterized by a declining share of economic activity accounted for by agriculture. Asymptotically, agriculture’s share of the labor force shrinks to zero, and the model essentially becomes identical to the standard one-sector neoclassical growth model.

We assume economies are closed. This assumption precludes a poor country that is relatively unproductive at producing food from simply importing it, a restriction that can be significant for some specifications of our model. However, as documented in Section 2, this assumption is consistent with the data. Thus, we believe it is empirically reasonable to treat our model economy as closed to trade in food.

Preferences

The model economy is populated by an infinitely-lived representative family. For simplicity, we hold family size constant and normalized to one. This ignores the admittedly important demographic transitions associated with long-run growth – even though fertility may in turn be related to food availability. Nevertheless, we abstract from population growth in order to better isolate the effect of the food problem on an economy’s industrialization.

Instantaneous utility is defined over two consumption goods: a non-agricultural good denoted by $c_t$, and an agricultural good denoted by $a_t$. To account for the secular
decline in agriculture’s share of economic activity we follow the convention of assuming 
a utility function with non-homothetic preferences, such that the budget share of 
agricultural goods will decline with income growth. To keep the analysis simple, we 
adopt a rather extreme case, namely:

\[
U(c_t, a_t) = \begin{cases} 
    a_t & \text{if } a_t \leq \bar{a} \\
    c_t^{\sigma} + \frac{\bar{a}}{\sigma} & \text{if } a_t > \bar{a}
\end{cases}, \quad 0 < \sigma < 1 
\]

(1)

The restriction that \(0 < \sigma < 1\) ensures that utility is strictly concave and that it increases 
when the household’s consumption of the non-agricultural good goes from zero to a 
small positive amount. Lifetime utility is given by:

\[
\sum_{t=0}^{\infty} \beta^t U(c_t, a_t),
\]

(2)

where \(\beta\) is the subjective time discount factor.

These preferences imply that a family will never consume the agricultural good 
beyond \(\bar{a}\) no matter how cheap agricultural goods may be relative to nonagricultural 
goods. In equilibrium this will imply that any labor not needed to produce \(\bar{a}\) units of 
agricultural output will flow into the non-agriculture sector, regardless of productivity 
levels in that sector.

**Endowments**

The representative family is endowed with one unit of time each period. Additionally, 
the family is endowed with the economy’s stock of land, denoted by \(L\), which is
normalized to 1. Land does not depreciate in the model. The family is not endowed with any initial holdings of capital. It will, however, come to own capital at some date.

**Technologies**

**Non-Agriculture**

Following the tradition in the literature, we associate the nonagricultural sector with the “manufacturing” or “industrial” sector, though in fact it is meant to capture the full range of activities in manufacturing, mining, services, and other nonagricultural sectors. We use the subscript $m$ to refer to non-agricultural variables. The nonagricultural sector produces output ($Y_t$) using capital ($K_{mt}$) and labor ($N_{mt}$) as inputs according to the following constant returns to scale technology:

$$Y_t = E_m [(1 + \gamma_m)^{1-\theta} N_{mt}^{1-\theta} + \varepsilon N_{mt}].$$

(3)

In equation (3), $E_m$ is an efficiency parameter that determines total factor productivity in the non-agriculture technology, and $\gamma_m$ is the constant exogenous rate of technological change. This technology is standard except for the term $\varepsilon N_{mt}$. This term is added to the production function so that an economy with no physical capital can start manufacturing and accumulate capital. In the numerical work that follows we will pick $\varepsilon$ to be a small number.

The efficiency parameter, $E_m$, is assumed to be country-specific, being determined by policies and institutions that impact on activity in the non-agriculture sector.\(^5\) It can be interpreted as the fraction of the exogenous stock of knowledge in the world that a

\(^5\) See Parente and Prescott (2000) for an explicit discussion of a mapping from policies into aggregate efficiency. Certainly, an important issue and one we do not address here is to identify those policies that are most responsible for generating cross-country differences in efficiency.
country would use, given its institutions, were it to produce the non-agricultural good. In contrast, the parameters, $\gamma_m$ and $\varepsilon$ are identical across countries and over time. To be sure, the growth rate of productive knowledge has not been constant through history. The assumption of a constant rate of technological change, however, is not critical to the results we establish in this paper. Additionally, much of the stock of useful knowledge owes its creation to research and development in the rich countries. Poor countries are generally not in the business of creating ideas, and so from their perspective, the assumption of exogenous technological change is reasonable.

Output from the manufacturing sector can be used for consumption or to augment the capital stock. The non-agriculture resource constraint is thus,

$$c_t + x_t \leq Y_t,$$  \hfill (4)

and the law of motion for the stock of capital in the economy is

$$k_{t+1} = (1 - \delta)k_t + x_t.$$  \hfill (5)

Agriculture

We distinguish between three technologies to produce the agricultural good. The first of these, which is indexed by 0, corresponds to a traditional, or Malthusian, technology. For this technology, we think of the household itself as the production unit, consuming all that it produces. The key features of this technology are that it is not subject to exogenous technological change and it is not affected by policy. The inputs to the traditional technology are labor services ($N_0t$) and land services ($L_0t$). The amount of output produced from the traditional technology ($A_0t$) is given by

$$A_0t = N_0^\alpha L_0^{1-\alpha}.$$  \hfill (6)
Implicitly, TFP in the traditional agricultural technology has been normalized to 1.

The other two agricultural technologies, indexed by the numbers 1 and 2, are both subject to exogenous technological change and are affected by policy. The key difference between them is that Technology 2 uses land, labor, and capital produced in the manufacturing sector whereas Technology 1 uses only land and labor.

We think of Technology 1 as essentially an intensification of traditional agriculture, in the sense described in the early development literature by Boserup (1965) and Geertz (1966). We associate Technology 1 with the family farm that produces more than its members working on the farm consume. Intensification occurs in this stage through shortening of fallows, improved manipulation of crop rotations, manures and organic fertilizers, and construction of terraces, bunds, drains, and other land modifications.\footnote{Hayami and Ruttan (1985) argue that in England’s Agricultural Revolution this stage of technological advance led to “[s]ubstantial growth in both total agricultural output and output per acre.” They further note that “[t]he inputs used in this conservation system of farming were largely supplied by the agricultural sector itself.”}

By contrast, Technology 2 involves the use in agriculture of manufactured capital goods. We think of this technology as reflecting the introduction of manufactured farm implements, transport equipment, processing machinery, etc. To some degree, we also think of the introduction of chemical fertilizers as a kind of capital, in the sense that they allowed farmers to build up soil fertility (or to reduce nutrient loss) on continuously farmed land.

Agricultural output from Technology 1 ($A_{1t}$) is given by

$$A_{1t} = E_a (1 + \gamma_a)^t N_a L^{1-a}_{1t},$$

whereas agricultural output produced using Technology 2 ($A_{2t}$) is given by

$$\text{Hayami and Ruttan (1985) argue that in England’s Agricultural Revolution this stage of technological advance led to “[s]ubstantial growth in both total agricultural output and output per acre.” They further note that “[t]he inputs used in this conservation system of farming were largely supplied by the agricultural sector itself.”}$$
\[ A_{2t} = E_a (1 + \gamma_a)^{1 - \gamma_a} K^\phi N^\xi L^{1-\phi-\mu} . \]

In equations (7) and (8), \( E_a \) is an efficiency parameter, which is country-specific. As was the case with the manufacturing technology, one source of cross-country differences in this parameter is policies and or institutional features that impact on agricultural activity. However, another very important source of variation is differences in the amount or quality of land per person, and climate. In particular, technological innovations that are useful for a specific crop in a given climate may not be particularly relevant for other crops in other parts of the world, thus generating large differences in cross-country productivity levels that are independent of policy.

The parameter \( \gamma_a \) denotes the rate of exogenous technological change in the modern agricultural technologies. Though it is easy to imagine circumstances in which (because technological innovations are not applicable in all countries) growth rates of technology may differ across countries, for the purposes of our analysis here, we assume that this value is common to all countries.

There are several reasons why we use two “modern” agricultural technologies rather than one. The first reason is purely technical. We need to allow for some mechanism by which the structural transformation can begin. If the agricultural technology given by equation (7) did not exist, no economy would ever be able to move resources out of agriculture and grow. Second, as evidenced both by England’s historical experience and by the more recent experience of the Green Revolution in developing countries, major increases in output can be realized without significant manufactured inputs. For example, in the Green Revolution, large increases in rice harvests followed the introduction of new
seed varieties – even in places where farmers continued to use animal power and hand tools.

In the model economy, output from the agriculture sector can only be used for consumption purposes. Thus, the agriculture resource constraint for the economy is,

\[ a_i = \sum_{i=0}^{\infty} A_i. \]

### 3.2 Solving for Equilibrium

We do not allow any members of the household to work outside of agriculture as long as its subsistence requirement is not met. Thus, as long as \( E_a (1 + \gamma_a)' < \bar{a} \), an economy will specialize in agriculture using the traditional technology. The economy will switch into agricultural Technology 1 in the first period for which \( E_a (1 + \gamma_a)' \geq \bar{a} \), and will begin manufacturing in the first period in which \( E_a (1 + \gamma_a)' > \bar{a} \).

Denote the first period in which the economy can move resources into manufacturing by \( T \). The competitive equilibrium allocations solve the following planner’s problem starting with \( T \):

\[
\max \sum_{t=T}^{\infty} \beta^{t-T} \left[ \frac{c_t^{\sigma}}{\sigma} + \bar{a} \right]
\]

subject to

i. \( c_t + k_{t+1} \leq E_m (1 + \gamma_m)' K_m^\theta N_m^{1-\theta} + \varepsilon E_m N_m + (1 - \delta) k_t \)

ii. \( E_a (1 + \gamma_a)' N_a^{\alpha} L_t^{1-\alpha} + E_a (1 + \gamma_a)' K_2^\phi N_2^{1+\phi} L_2^{1+\phi} \geq \bar{a} \)

iii. \( K_m + K_2 \leq k_t \)
iv. \( N_{mt} + N_{1t} + N_{2t} \leq 1 \)

v. \( L_{1t} + L_{2t} \leq 1 \)

vi. \( k_t = 0 \).

The maximization is over the sequence of choices \( \{c_t, K_{mt}, K_{2t}, N_{mt}, N_{1t}, N_{2t}, k_{t+1}\}_{t=T}^{\infty} \).

Let the numéraire for the economy be the agricultural good. Prices can be determined as follows. First, the rental prices of land and labor are just the marginal physical products from the agricultural technology that is used. Second, the price of the manufactured good can be determined by using the marginal physical product of labor from agriculture with the marginal physical product of labor from manufacturing. The rental price of capital is just the marginal product of capital in agricultural Technology 2 as long as that technology is used. Otherwise, it is the price of the manufactured good times the marginal physical product of capital in manufacturing.

Computationally, we exploit the fact that in the limit the economy converges to the one-sector neoclassical growth model. We employ a shooting algorithm in which only a guess for the value of \( k_{T+1} \) is needed to compute the entire path of allocations for the economy from \( t = T \) to \( t = T + 350 \). As part of this algorithm, we determine, for any \( k_t \), the corresponding optimal allocations of capital, labor and land service inputs for all technologies.

4. Model Calibration
In this section we calibrate the model to the experience of the United Kingdom over the last 200 years and show that the model replicates the long-run pattern of economic development and growth. Namely, we show that the model can account for the long initial period of constant living standards, followed by a transition period with small but increasing growth rate of per capita income, followed by a period of modern economic growth with higher and constant growth rate of per capita income.

4.1 Parameter Values

The empirical counterpart of the model period is a year. The strategy of the calibration exercise is to restrict the values of the preference parameters and the parameters associated with the manufacturing side of the economy to match twentieth century observations of the United Kingdom. The values of the parameters associated with the agricultural side of the economy are restricted so that the model matches the structural transformation of the United Kingdom and is consistent with widely used estimates of agricultural production functions. Table 2 reports the values of the calibrated parameters. It also provides a brief comment on how the value of each parameter was selected. For most parameters, the brief comments are sufficient. For a few parameters, namely, $\ddot{a}$, $\epsilon$, $E_m$, and $\theta$, we offer more detailed explanation.

The subsistence parameter $\ddot{a}$ is set so that were the economy to specialize in the traditional technology it produces exactly $\ddot{a}$ units of the agricultural good. Given our
normalization of the family’s endowment of time and land, the restriction implies $\bar{a} = 1$.\footnote{We note that there are reasons to believe that a value close to $\bar{a}$ is appropriate. Models in which fertility is endogenous suggest that output per capita will be close to subsistence levels for economies that have not begun the process of industrialization.}

The labor productivity parameter in the non-agricultural technology, $\varepsilon$, is set to a number close to zero so that the economy can (and will) begin to operate the non-agricultural technology even though it initially holds no capital, but is quantitatively unaffected by this “extra” productivity term in the limit. The efficiency parameter in the non-agricultural technology, $E_m$ is set so that the mechanization of agriculture in the model occurs in the year 1800. As the value of the non-agricultural efficiency parameter affects the rate at which the structural transformation occurs, it also affects the date at which the economy first begins using the mechanized agricultural production technology.

The economic history literature offers conflicting views on when the mechanization of agriculture in the United Kingdom actually occurred. It is clear that some manufactured capital goods have been used in agriculture for a very long time, but the major transformation of the technology – to one making routine and extensive use of manufactured capital goods – appears to have happened after the late 1700s and to have been complete by the middle of the 19th century. Allen (1999) has argued convincingly that 1800 marks an important break-point in the English historical data, with a “post-1800 surge in productivity” in agriculture contributing significantly to overall economic growth after 1815. A key part of this productivity surge appears to be the contribution of early mechanization, such as the rapid improvement in plough designs documented by Brunt (2003), who notes that by 1850, “agricultural implements were an important part of England’s inventory of advanced machinery, which was the envy of the world.” In our
calibration exercise, then, we take 1800 as the date of the UK’s transition to Technology 2.

The value of the capital share parameter in the non-agricultural production function, $\theta$ is not well restricted by the National Income and Product Accounts (NIPA). The reason for this is that NIPA does not measure investments in intangible capital. Intangible capital, which takes the form of knowledge and skills embodied in people (human capital) and in production units (organizational capital), has recently been recognized as an important input in the production process of industrialized countries. Evidence at the micro level suggests intangible capital investments may well be as large as physical capital investments, which are measured in the NIPA.  

This suggests a capital share parameter value that is well above the value of one-third used in the real business cycle literature based on a narrow measure of the capital stock. In the calibration we set $\theta$ equal to .50.

With this higher capital share, total output in the model no longer corresponds to NIPA GDP. Therefore, in making comparisons between the model and the data, it is necessary to subtract the value of investment in intangible capital from total output. Let $x_{it}$ denote the amount of investment in intangible capital and let $x_{pi}$ denote the amount of investment in physical capital. Then, NIPA GDP corresponds to

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8 See Parente and Prescott (1994, 2000) for a formal discussion of the size of the intangible capital stock and its implications for total capital’s share.

9 With capital’s share in the non-agricultural technology not well-restricted, there is the question how sensitive our results are to its value. The good news is that the model’s ability to match the structural transformation of the United Kingdom is not sensitive to its value. Additionally, the model’s prediction for the date at which an economy starts its structural transformation is completely independent of the non-agricultural capital share parameter. The asymptotic difference in relative income levels associated with any difference in relative non-agricultural efficiency does, however, depend on the values of the capital share parameter, with a larger value implying a larger relative income level difference. Non-agricultural growth miracles are sensitive to its value as well. The importance of the capital share parameter for relative income level differences and growth miracles is essentially the same as in the one-sector growth model.
\( \bar{a} + p_t(Y_t - x_t) \) in the model. It is possible to impute the size of intangible capital by exploiting the fact that the production function with a single capital input is isomorphic to a production function with two capital stocks that depreciate at the same rate. The capital share parameter in the one-capital stock production function, \( \theta \), equals the sum of the separate capital share parameters in the two-capital stock production function, \( \theta_i \) and \( \theta_p \). Similarly, investment in the one-capital stock production function is the sum of investment in intangible and physical capital in the two-capital model, i.e. \( x_t = x_{it} + x_{pt} \).

The total capital share can be decomposed into its two sub-components by requiring that the model generate an investment in physical capital to measured output ratio, \( p_t x_{pt} / [\bar{a} + p_t(Y_t - x_t)] \), that matches the UK’s investment to GDP ratio of roughly 20 percent in the postwar period. The implied value of \( \theta_p \) is 0.24 and the implied investment in intangible capital to measured output is 20 percent.\(^{10}\) The decomposition of the capital share parameter allows one to decompose total investment into its intangible and physical capital components at any date along the equilibrium path.

### 4.2 Economic Development and Growth

Although our paper does not aim to provide a detailed model of the UK’s historical growth experience, we use the success of the calibration to argue that the model offers a useful tool for thinking about economies as they develop and grow over very long time horizons. In this vein, we review several predictions of the model and compare them to the data for the UK economy.

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\(^{10}\) This second implications is the main reason why we set \( \theta = .50 \) in the calibration.
The calibration implies a starting date of 1708 for the UK structural transformation. Prior to 1708, the model predicts a constant living standard at a subsistence level, which (like many other points) is a subject of some debate in the literature on English economic history, but which seems a reasonable abstraction. After 1708, the model economy shows a steady but modest intensification of agriculture, with rising output per worker, and the beginning of non-agricultural production. The model predicts that the mechanization of agriculture is completed by 1805, which is probably somewhat too early relative to historical estimates.

The model matches the UK development experience fairly well along most other dimensions of the data. Figure 1 displays agriculture’s employment share for the model and for the United Kingdom as reported by Kuznets (1966). By construction, the calibrated model trivially matches agriculture’s share of employment in the United Kingdom for the years 1800 and 1950. However, the model also tracks the data quite well in the periods before and after these dates. In general, the model captures the long-run trend in agriculture’s share of the workforce over time. In the same spirit, Figure 2 displays the path of real per capita GDP over the 1820-1990 period, in relation to its 1820 value, for both the model and actual economies. As can be seen the model matches the path of UK per capita GDP reported by Maddison (1995) fairly closely except for the period beginning with World War I and ending with World War II. Although the non-agricultural growth rate for the 20th century is calibrated to match the data, there is no

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11 For example, Allen (1999) writes that “[c]onsumption of agricultural goods per head fell in the sixteenth and seventeenth centuries and then rebounded, but the level reached in the early eighteenth century was no higher than that of the sixteenth.”

12 The measure uses the year 2000 price of the non-agricultural good as the base year price and does not include the imputed value of intangible capital. More specifically, model real $GDP_t$ is calculated as $rGDP_t = \bar{a} + p_t(Y_t - x_t)$. 

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22
guarantee that the model should do well in matching aggregate real output for the longer
time period. But the calibrated model in general captures both the level and trend in per
capita income over the entire period. Another dimension in which the model matches
the data reasonably well is in agriculture’s share of output at each date, measured in date \( t \)
prices (Figure 3). Here, too, the model, despite its rather simple structure, does a fairly
good job at matching the pattern of structural transformation in the United Kingdom, as
documented by Kuznets (1966). Again, the calibration does not guarantee that the model
matches the sector’s share of GDP, especially since changes in agriculture’s share of
output embody price changes as well as changes in the composition of output.

Examining the relative price data in more detail, Figure 4 shows the relative price of
the non-agriculture good to the agricultural good for both the model economy and the
actual economy during the major period of structural transformation, from 1725 to 1860.
We focus on this period because a relatively consistent price series is available through
1860 from Clark (2004). We deviate from Clark’s measures only in normalizing the
1860 prices of both goods to 1. Figure 4 then shows the relative price changes over time
in the model economy and the data. We note that the data does not display so rapid a
decline as the model in the relative price of non-agricultural good at the beginning of this
period, but after 1750, the model’s predictions are remarkably close to the data.

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13 The model does less well in matching the data for per capita output in the interwar period. We do not find
this worrisome; it is well known that the British economy grew well below trend values during the interwar
period, a phenomenon that is still subject to some debate and one that our calibration does not attempt to
capture.

14 The price series includes prices going back to approximately 1200, but we are only interested in the
prices from 1725 onward, since that is essentially the date at which the structural transformation begins. In
this price data, we take Clark’s reported price of clothing as a proxy for the price of the non-agricultural
good, and we use a weighted basket of prices for grain, potato, meat dairy, sugar and drink for the
agricultural price measure, using the weights that Clark gives for those commodities in a consumption
basket for manual workers (Clark 2004, p. 51).
The model is also consistent with the secular rise in the investment to output ratio experienced by the United Kingdom and other currently rich countries. According to Feinstein (1981), the UK investment to output ratio was 8 percent in 1761, and 14 percent in 1800, and 13 percent in 1850. The model predicts a physical capital investment to output ratio (i.e., \( p_t x_{pt} / [a + p_t (Y_t - x_t)] \)), equal to 5 percent in 1725, 10 percent in 1761, and 15 percent in 1800, 18 percent in 1850.\(^{15}\) The model predicts very little decline in the nominal interest rate after 1800; between 1800 and 2000 the real interest rate predicted by the model declines from 5.8 to 5.0 percent. Between 1725 and 1800, the decline of the real rate of interest is much larger, going from 13 percent to 6 percent in this period. The roughly constant nature of the real interest rate going back to 1800 is consistent with Homer’s claim (1963) that real interest rates have been constant over the last two centuries. The model is also consistent with the secular increase in the real wage and the lack of any trend in the rental price of land in the United Kingdom as reported by Clark (1998). The real wage increases by a factor 27 between 1725 and 2000. The rental price of land for obvious reasons is equal to .30 in all periods.

The conclusion we draw from these comparisons is that the model, despite its simplicity, successfully captures the historical development experience of the United Kingdom fairly well. Having passed this “test” we now proceed to examine the models’ implications for the evolution of international incomes.

\(^{15}\) Feinstein (1981) does not provide estimates for gross total investment to GNP for earlier dates. Deane and Cole (1969) report a net investment to output ratio between 3 and 6 percent in 1688.
5. The Evolution of International Income Levels

In this section we use the model to organize and interpret the evolution of international income levels over the last three centuries. In particular, we use the model to account for the following aspects of the evolution of international income levels:

- Economic growth started in different countries at different times with some countries starting to grow approximately 250 years after the United Kingdom started.

- Late starters’ experiences have differed dramatically once economic growth began. Some countries – particularly those in Latin America – started economic growth around 1900, and subsequently maintained the same level of income relative to the leader. Other countries – particularly those in South East Asia – started to grow later but subsequently eliminated much of the gap with the leader. A third set of countries, particularly sub-Saharan countries, started growth only after 1950, and subsequently lost ground relative to the leader.

- Some of the late starters that eliminated much of their income gap with the leader have done so in an incredibly short time, doubling their per capita income in a decade. These growth miracle experiences are a very recent phenomenon and are limited to countries that were poor at the time their miracle started.

We now interpret each of these facts in light of the model, and in doing so, point out the relevance of the food problem for these facts.
5.1 Late Starts to Development

According to the model, the date at which an economy begins to industrialize is determined solely by the agriculture efficiency parameter. Consequently, we interpret delays in the starting date of economic growth as the outcomes of low efficiency in the agricultural sector. Table 3 reports the implied value of agricultural efficiency that would give rise to an 1800, 1850, 1900, 1950, and 2000 starting date for the structural transformation. Recall that the calibration implies a 1708 starting date for the leader. Table 3 also reports the real per capita GDP (relative to the world leader) for each late starter at the moment when its structural transformation begins. It is not obvious how to make these GDP comparisons, since prices differ across economies. In the spirit of such modern day comparisons as the Penn World Tables, however, we compute real per capita GDP for each economy at all dates by valuing its output of agricultural and non-agricultural goods using year 2000 prices from the benchmark economy. More specifically, a country’s real per capita GDP in year \( t \) equals
\[
an_t + p_{2000}^g (Y_t - x_{p_t}),
\]
where \( p_{2000}^g \) is the year 2000 price of the non-agricultural good in the benchmark economy. We emphasize that for the moment the only parameter that differs between economies is the agricultural productivity level, \( E_a \).

According the model, a country’s “takeoff” into growth would be delayed from 1708 until 1950 if its efficiency level in agriculture is 20 percent of the leader. At the point of its takeoff, in 1950, this economy will have a per capita income level that is 5 percent of the leader. An economy with even lower productivity in agriculture – 10 percent of the leader – will not begin its takeoff until 2000, at which point its real per capita income will be 3 percent of the leader’s. To our knowledge, estimates of
agricultural efficiency for individual countries do not exist. However, the required difference in agricultural efficiency implied by the model to account for a 250 year delay in the start of economic growth is in line with estimates of Solow residuals based on aggregate production functions for a cross section of countries (see for example, Hall and Jones 2000). On this basis, we would argue for the plausibility of the model as an explanation for the delayed development of some countries.

From a quantitative perspective, these experiments seem to support the longstanding idea in the development literature that agricultural productivity differences – whether induced by nature or by policy – are a major reason that some countries are so poor today. Note that the food problem is important for this result. In general, in a neoclassical environment, if one economic activity is hindered by low productivity or policy distortions, economic agents will devote fewer resources to that activity and more to alternative activities, thereby lessening the impact of the “problem.” However, in our model, agricultural consumption is necessary and the economy cannot substitute away from it. If productivity in agriculture falls, there will actually be an increase in the resources devoted to that activity.

Note further that all of these economies will ultimately converge to the income level of the leader. Since asymptotic real incomes, relative to the leader, are determined entirely by the non-agricultural efficiency level, and since these economies are identical to the leader in that respect, these economies will grow rapidly once they have begun their takeoff, eventually catching up to the leaders, in the spirit of Lucas (2001). Thus, if agricultural productivity differences are the driving force behind cross-country income differences, the model suggests a relatively hopeful path for the future. However, there
are other potential sources of differences across countries; agricultural productivity differences are a sufficient explanation, in the model, for the poverty of some economies. But they are not a necessary explanation.

5.2 Development Subsequent to Late Start

Although a country’s efficiency in non-agriculture is unimportant for determining the date at which its begins its structural transformation and starts to grow, it is critical for determining its subsequent path of development – and in particular for determining whether it continues to lose ground or gain ground relative to the leader. Accordingly, we interpret the very different development experiences of late starters (subsequent to starting the process of economic development) to be the result of different non-agricultural efficiencies.

We now consider the impact of non-agricultural efficiency on a country’s subsequent development and structural transformation. Towards this end, we compute the equilibrium for several economies which are assumed to begin the process of industrialization in 1950 but which differ in non-agricultural efficiency. For simplicity, the values of \( E_m \) we consider are one-eighth, one-quarter, and one-half the level of the benchmark economy. Figure 5 compares the relative per capita GDPs of these economies over the 1950-2050 period. For each economy, real per capita GDP in year \( t \) is calculated using year 2000 prices in the benchmark economy as described above. Relative GDPs at date \( t \) are computed as a ratio of the per capita GDP of the benchmark economy in year \( t \).

A country’s relative efficiency in non-agricultural has important implications for its development path once its structural transformation has begun. For the economy with \( E_m \)
at one-eighth the leader’s level, relative per capita GDP continues to fall over the industrialization process. For the economy with $E_m$ at one-quarter the leader’s level, relative per capita GDP does not change much over the industrialization process. And for the economy with $E_m$ at half the leader’s level, relative per capita GDP increases. We note that asymptotically the per capita GDP of these three economies relative to the benchmark are 1.6 percent, 6.25 percent, and 25 percent respectively.

Consequently, the model offers a plausible explanation for why a number of countries have maintained a constant relative income with the leader over the last century; why other countries have gained ground relative to the leader over the last fifty years; and why still other countries (e.g., many in sub-Saharan Africa) continue to lose ground relative to the leader. According to the model, a country that begins the structural transformation in 1950 will lose ground relative to the leader for the next 100 years provided that its non-agricultural efficiency is less than 25 percent that of the leader. Differences of this magnitude in non-agricultural efficiency do not seem implausible, given estimates of TFP at the firm level. (See, for example, Bailey and Solow (2001).)

Not surprisingly, the rates at which the structural transformation proceeds in each country differ dramatically. As Figure 6 shows, differences in non-agricultural efficiency can have large effects on the rate of decline in agriculture’s share of employment. For the economy with $E_m = 0.5$ of the leader’s level, agriculture’s share of employment falls to 50 percent in 1989. By comparison, in the economy with $E_m = 0.25$ of the leader’s level, agriculture’s share of employment does not decline to 50 percent until 2006; and for the economy with $E_m = 0.125$ of the leader’s level, agriculture’s share of employment reaches
this level only in 2014. The date at which agriculture is mechanized in each economy also
differs. Agriculture is fully mechanized in 1969, 2006 and 2093 in the three economies.

We make two additional points.\textsuperscript{16} The first point to be taken from this experiment
concerns the speed of convergence once industrialization begins. Like the one-sector
neoclassical growth model, our model predicts that asymptotically a country will
converge to a steady-state relative per capita income level determined by its efficiency in
non-agricultural production ($E_m$, in our model). But our model generates a strongly
different prediction about the speed of this convergence. Compared with a one-sector
neoclassical growth model with the same capital share and a given (low) level of initial
capital, our model includes an extended period in which a fraction of the workforce is
tied down in agricultural production. By contrast, in the standard one-sector neoclassical
growth model the entire labor endowment is always in that sector. As a result,
convergence is slowed in our model because of the food problem.

The second point is that in general there need not be any systematic relation between
income levels and prices in the cross-section. In this experiment this is the case with
respect to the real interest rate in the 1990 cross-section. In 1950, the date at which the
structural transformation begins, the real interest rate is systematically related to the level
of non-agricultural efficiency being the greatest in the economy with $E_m$ equal to the level

\textsuperscript{16} There is actually an additional point worth mentioning. Namely, in poor countries, sectoral productivity
differences tend to be larger with labor being less productive in agriculture than in non-agriculture. Our
model is qualitatively consistent with this observation, even though labor employed in the two sectors earn
the same wage. In domestic prices, the ratio of output per worker between the two sectors equals the ratio
of the labor share parameters in agriculture and non-agriculture. Because there are three different
agricultural technologies and because different economies will use different technologies (or mixes of
technologies) at any given point in time, the model allows for a range of sectoral productivity differences
across countries. In general, because the calibrated labor share in Agriculture Technologies 0 and 1 is
greater than that in Agriculture Technology 2, the model predicts that sectoral labor productivity
differences are greater in poorer countries. The use of PPP prices exacerbates these differences.
of the leader. For each economy, the real interest rate declines monotonically as the structural transformation proceeds, converging asymptotically to the same rate. A country with a higher $E_m$ will converge to the asymptotic rate faster, because its higher efficiency in non-agriculture allows it to move resources out of agriculture faster. For this reason, the interest rate in a country with a higher $E_m$ will begin higher than the interest rate in the country with a lower $E_m$, but will fall below the second country’s rate of return, before they converge to the same level asymptotically. Thus, the model does not predict any clear relation between a country’s income level and its real interest rate. For a similar reason, the model does not predict any systematic relation between a country’s income level and the relative price of the non-agricultural good in a given year. We conclude from these results that it is problematic to use cross-section data for multi-sector development accounting (as in Restuccia, Yang, and Zhu 2004 and Ripoll and Cordoba 2004). Without accurate measures of sectoral productivity levels, we cannot tell from the cross-section data where a country stands on its own transition path.17

5.3 Growth Miracles

The model is consistent with the observation that growth miracles are a relatively recent phenomenon limited to countries that were poor at the time the miracle started. This result has little to do with the food problem, however, and so we do not emphasize this virtue of the model in this section. Instead, we examine what, if any, role the food problem plays in making a miracle.

17 Once we allow for changes in agricultural efficiency and non-agricultural efficiency as in the next subsection, the possible patterns become even more complicated. For instance, there is no longer a positive correlation between a country’s income level and its savings rate once we allow for these changes.
As the food problem affects the speed of convergence to the steady state, it obviously has important implications for growth miracles. (Following other researchers, we define a growth miracle as a doubling of real per capita income in a decade or less.) In light of the previous experiment, it is clear that a growth miracle can occur through convergence, as in the standard one-sector framework. But our model also offers a second mechanism by which growth miracles may occur. Namely, a country can experience a growth miracle if it realizes a large increase in agricultural efficiency over a short period of time. A real-world parallel is the Green Revolution that occurred in some developing countries in the 1960-2000 period, in which new crop varieties increased productivity dramatically. (See, for example, Evenson and Gollin 2002.)

In this section, we compare the transition paths associated with these two types of growth miracles. In this comparison, we take two economies that are initially identical in agricultural productivity, such that they will both begin their structural transformation in 1950. From this point, we subject the two economies to different experiments. One of the economies we will treat as receiving a positive shock to its non-agricultural productivity, such that its non-agricultural productivity rises to the same level as the world leader.\textsuperscript{18} The second economy will receive a Green Revolution (\textit{i.e.}, an agriculture-led growth miracle). Beginning in 1951, this economy’s level of agricultural productivity unexpectedly rises to the level of the leader. Obviously, how fast this economy grows once it begins its structural transformation depends on the value of its non-agricultural

\textsuperscript{18} Think of this as a major policy reform that accompanies the onset of industrialization. Equivalently, we can think of this economy as having had a high level of non-agricultural efficiency all along, but it was not relevant until 1950, when the country solved its food problem. Either interpretation is valid for the purposes of our analysis.
efficiency. To make the comparison between the two “growth miracles” informative, we will make the magnitudes of their growth miracles the same. Specifically, we choose $E_m$ for the Green Revolution economy to achieve this goal. At this level, the two model economies, which started at the same level of income in 1950, will have both experienced growth miracles by 1962, and in fact their income levels will once again be the same. For the Green Revolution economy, we achieve this target by setting $E_m$ to a value roughly one-third of the leader’s level.

Figure 7 shows the path of real per capita GDP for the leader, the non-agriculture miracle economy, and the agriculture miracle economy, from 1950 to 2050. For comparison purposes we also include the path of per capita GDP for a 1950 late starter that neither undergoes a Green Revolution nor an Industrial Revolution; in other words, it has $E_m$ as the agriculture miracle country and the same value of $E_a$ as the industrial miracle. For lack of better term, we use the label, “neither” to refer to this economy’s plot in Figure 7. Real per capita GDP for each country in the figure is again measured as before.

By construction, per capita output in the two miracle economies is the same in 1962, which is roughly two times the 1950 level. The paths are extremely different both before and after this date. Before 1962, the economy that undergoes the increase in agricultural efficiency is richer, but after that point the Industrial Revolution economy outperforms it. This is not surprising, given the properties of the model: agricultural efficiency does not affect a country’s asymptotic level of relative per capita income whereas non-agricultural efficiency does.
The miracle generated by an increase in agricultural efficiency is thus short-lived compared to the miracle generated by a high level of non-agricultural efficiency. The effects of the Green Revolution are not trivial, however. This is seen by comparing the transition path of the country that undergoes a Green Revolution with that of the country that experience neither an Industrial or Green Revolution. One hundred years later, the economy that undergoes a Green Revolution in 1951 is still richer than the comparison economy.

The late starter with the non-agricultural efficiency of the leader grows rapidly over the 1950 to 1985 period, experiencing a 13 fold increase in real per capita GDP. The annual growth rate for the economy is not monotonic. Indeed, it is hump-shaped, a pattern that has been documented for some growth miracle countries, such as Japan.\(^{19}\) The annual growth rate increases over the 1950-1960 period, and thereafter decreases until it converges to the steady state growth rate of the leader. This hump-shaped pattern for the economy’s growth rate is a consequence of the subsistence constraint, which prevents an economy from releasing it’s a large number of workers in agriculture at the initial stages of its structural transformation.\(^{20}\) With few workers employed in non-agriculture, capital is less productive than if all labor were allocated to non-agriculture, which implies small increases in industrial output. As more workers are shifted into non-agriculture, capital’s product increases resulting in an increasing growth rate of output.

\(^{19}\) A factor increase of 13 in a 35-year period may seem too large relative to the actual growth miracle experiences of Japan and South Korea. However, neither country was as poor relative to the United Kingdom in 1950 as the model economies in these experiments are. Japan’s per capita GDP in 1950 was about 30 percent of the UK level. In the next 35 years, Japan’s per capita GDP increased by factor 8. This is roughly the predicted increase for the non-agricultural miracle economy for the 35-year period that follows the date it attains a relative income equal to 30 percent the leader.

\(^{20}\) King and Rebelo (1993) and Christiano (1989) have similarly found in the one-sector growth model that a subsistence constraint has important implications for growth miracles.
per capita. Eventually, the number of workers in non-agricultural production reaches a critical level whereby the law of diminishing returns to capital dominates, at which time the economy’s growth rate declines monotonically.

6. Conclusion

We have demonstrated that the “food problem” has the potential to explain three distinct features of the observed evolution of income levels across countries. First, the food problem offers an explanation for the long delays that some countries have experienced in the onset of sustained growth in per capita income. Consequently, the model offers an explanation for the huge current differences in income. Second, the food problem offers a reason for the relatively slow speed of convergence observed in some countries subsequent to the beginning of their industrialization. Even a country with the same industrial efficiency as the leader, but with its onset of industrialization delayed until 1950 by the food problem, will take approximately 75 years to attain half the level of income of the leader. This slow convergence, compared with a standard one-sector model, is driven entirely by the food problem. Third, the “food problem” has important implications for the growth miracles. Although the “food problem” is unimportant for asymptotic relative income levels, the model shows us that an agricultural “transformation” (to use T.W. Schultz’s term) can generate a growth miracle with long-lasting effects – although this miracle will not be sustained unless it is accompanied by non-agricultural reforms or innovations.
In light of the theory’s success, further examinations and tests seem warranted. In particular, one could undertake a growth accounting exercise based on the model to determine the extent that the growth miracles of Southeast Asia were driven by increases in agricultural efficiency or non-agricultural efficiency. Additionally, one could undertake an accounting exercise in the spirit of Restuccia, Yang, and Zhu (2004) to determine whether low agricultural efficiency or non-agricultural efficiency ails a country. The implied accounting exercise would proceed country by country, making use of time-series data. This follows from our finding that there is no systematic relation in the cross section between a country’s income level and the relative price of the non-agricultural good, or the real rate of interest, or the investment rate on account that countries with the same level of income can differ significantly in where they are on their transition paths.
References


Table 1: Regression results: Changes in agricultural productivity and their relationship to changes in agriculture’s share of employment, 1960-2000, for 92 developing countries.

Dependent Variable: Change in Log of Agriculture's Share of Workforce, 1960-2000

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<td>Normalization</td>
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<td>Log utility approximation</td>
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<tr>
<td>$\varepsilon$ labor productivity</td>
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<td>Enables economy to accumulate capital but does not impact the subsequent equilibrium path</td>
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<td>.6</td>
<td>Modern estimate for labor share by Hayami and Ruttan (1985)</td>
<td></td>
</tr>
<tr>
<td>$\gamma_a$ TFP growth rate</td>
<td>.0074</td>
<td>UK employment shares in 1800 and 1950 reported by Kuznets (1966) of 35 and 5%</td>
<td></td>
</tr>
<tr>
<td>$E_a$ efficiency</td>
<td>.993</td>
<td>UK employment shares in 1800 and 1950 reported by Kuznets (1966) of 35 and 5%</td>
<td></td>
</tr>
</tbody>
</table>
Table 3: Agricultural TFP and Industrialization

<table>
<thead>
<tr>
<th>Date</th>
<th>$E_a$</th>
<th>Relative Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>1708</td>
<td>.93</td>
<td>1.00</td>
</tr>
<tr>
<td>1800</td>
<td>.51</td>
<td>0.42</td>
</tr>
<tr>
<td>1850</td>
<td>.35</td>
<td>0.21</td>
</tr>
<tr>
<td>1900</td>
<td>.24</td>
<td>0.11</td>
</tr>
<tr>
<td>1950</td>
<td>.17</td>
<td>0.06</td>
</tr>
<tr>
<td>2000</td>
<td>.12</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Figure 1
Agriculture's Share of Employment
Figure 2
Per Capita GDP Relative to 1820
Figure 3
Agriculture's Share of GDP
Figure 4: Relative Price of Non-Agricultural Goods to Agricultural Goods

Relative price of Clothing to Food

Model Economy

UK

Year

1725 1740 1755 1770 1785 1800 1815 1830 1845 1860
Figure 5
Relative Per Capita GDP For Late Starters

- $E_m = \frac{1}{2}$ Leader
- $E_m = \frac{1}{4}$ Leader
- $E_m = \frac{1}{8}$ Leader
Figure 6
Agriculture Employment Shares for Late Starters
Figure 7
Growth Miracles