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From Domestic Manufacture to Industrial Revolution: Long-Run Growth and Agricultural Development

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Abstract

This paper investigates the historical process of industrialisation. The allocation of labour between food and non-food activities and the pattern of consumption of domestic versus industrial manufacture are determined endogenously, depending on terms of trade between agricultural and industrial goods. It is demonstrated that growth in the industrial sector's productivity is crucial to the expansion and development of the agricultural sector and thus to the transfer of labour from agriculture to industry and to economic growth. This view contrasts with the traditional perception according to which the agricultural sector leads in the process of industrialisation.

Keywords: agriculture, industrialisation, time-allocation, transition.

JEL codes: O14, J21, J22

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1 Introduction

One of the most important elements in the historical process of industrialisation is the release of labour from food-generating activities. By 1500, the share of the English labour force engaged in agriculture was 74 percent (Allen, 2000). By 1800, that share consisted of 35 percent (*ibid.*). Even adjusting for food imports, which by the beginning of the nineteenth century was about one fifth of all English food consumption (Craft, 1985a), this change in the occupational structure reflects an astonishing performance of the agricultural sector over the period.

Surprisingly though, almost any standard textbook in history insists that growth in the *industrial* sector's productivity, such as the mechanization of the English textile industry, is synonymous with the Industrial Revolution. But why are technological breakthroughs in the industrial sector said to be responsible for the Industrial Revolution when it would seem that it is productivity improvements in the agricultural sector that enabled the transfer of labour from agriculture to industry?

This paper explores a possible link between improvements in the productivity of industrial workers and the performance of farmers. The work is inspired by the two salient observations about the pre-industrial economy made by Boserup (1965) and others, namely, that surplus labour existed in agriculture and could be allocated in a variety of ways, and that agricultural productivity was limited, not by the state of knowledge of how to increase output per unit of land, but by the fact that an increase in farmland productivity came at a cost to labour.

The allocation of labour between food and non-food activities and the pattern of consumption of domestic versus industrial manufacture are determined endogenously, depending on terms of trade between agricultural and industrial goods. It is demonstrated that growth in the industrial sector's productivity is crucial to the expansion and development of the agricultural sector and thus to the transfer of labour from agriculture to industry and to economic growth, a view that deviates from the traditional perspective, which suggests that it is the agricultural sector that leads in the process of industrialisation.

More specifically, the model shows that an increase in the industrial sector's productivity improves agricultural terms of trade, i.e., increases the price that a farmer receives for his food. This motivates the farmer to allocate more labour to agrarian activities, a change that comes about at a cost to his consumption of non-agrarian goods that are produced domestically. However, his lower consumption of domestic goods is compensated for by a larger consumption of industrial goods, obtained from selling his food surplus in the market.

The analysis also demonstrates that, given an inelastic demand for food, growth in the size of the farmer's food surplus releases labour from agrarian activities, thus increasing the share of workers employed in the industrial sector. Over all, this explains why technological breakthroughs in industrial manufacture would lead to intensification in the use of farmland, thereby stimulating the process of industrialisation and the consumption of industrial goods at the expense of the production and consumption of domestic goods. The process of industrialisation outlined in this paper is, therefore, essentially demand-driven.

In an extension of the model the effect that an increase in the size of the population has on the structural composition of the labour force is discussed. By assuming that the level of technology is an increasing function of the size of the population, we show that if the industrial sector uses the available technology more efficiently than does the domestic sector, then this, in a historical perspective, means that more densely populated regions will be more industrialised compared to sparsely populated ones, even though all regions use the same level of agricultural technology. The implicit reason is that farmers in densely populated areas spend more hours of work in their fields at a cost to domestic activities.

The paper proceeds as follows. After discussing the related literature, section 2 presents the historical evidence upon which the model is built. Section 3 presents the model, section 4 performs a comparative static analysis, while section 5 concludes.

1.1 Related Literature

The model presented below is inspired by the historical developments in the western world, particularly in England, as are a large series of theoretical studies that also examine the long transition from economic stagnation to sustained growth associated with the Industrial Revolution; these include Goodfriend and McDermott (1995), Galor and Weil (2000), Galor and Moav (2002), Galor *et al.* (2002), Hansen and Prescott (2002), Jones (2001), Lagerlöf (2003), Lucas (2002), Tamura (2002), and Weisdorf (2003).

Common to most of these papers is a Malthusian building block in which a fixed amount of land generates decreasing returns to labour when technology is held constant. Economic growth then reflects the interaction between new technology, diminishing returns to labour, and demographic growth. But whereas the Malthusian model implies that productive opportunities in agriculture are always fully exploited, the model in this paper suggests, inspired by Boserup's theory about agricultural development, that farmers are in fact able to increase their farmland productivity by moving labour-resources from other activities such as household production and leisure time.

The inclusion of Boserup's theory in long-run growth models is not entirely new. For example, Lee (1988) proposes a Boserupian construction by which greater population density encourages technical progress; Strulik (1997) employs a learning-by-doing mechanism that acts as a positive externality, which increases with the size of the population and helps it to overcome diminishing returns to labour; Klausen and Nestmann (2000) use Boserup's demand-driven technological change in an extension of the growth model presented in Kremer (1993); and Lagerlöf (2002) includes a Boserupian feature in which agricultural productivity progresses as a result of population pressure. All of these papers, however, lack significant aspects of Boserup's theory concerning the labour costs associated with an increase in farmland productivity.

An issue that is closely related to the work of Boserup, concerns the role of agriculture in the process of development. Whereas the new growth theory often neglects the importance of food production, development economists have long stressed that due to the income-inelastic demand for agricultural products, improvements in the agricultural sector's productivity are a significant source of economic growth since they enable the reallocation of labour from agrarian to non-agrarian activities.

This issue is taken into consideration in a body of papers, mainly following in the footsteps of Jorgenson (1961, 1967), that examine the structural transformation of a dual economy (e.g., Chanda and Dalgaard, 2003; Duranton, 1998; Echevarria, 1997; Galor and Mountford, 2003; Gollin *et al.*, 2002; Kongasmut *et al.*, 2001; Kögel and Prskawetz, 2001; Laitner, 2000;

Matsuyama, 1992). The main insight gained from these papers, most of which address the cause of the disparity in income per capita in contemporary countries, is that non-homotetic preferences, with an income-elasticity of demand for agricultural goods below unity, create a positive link between improvements in agricultural productivity and economic growth.

The work presented in this paper is most closely related to the studies by Duranton (1998), Galor and Mountford (2003), and Kögel and Prskawetz (2001). Kögel and Prskawetz, who allow for increasing returns to labour in manufacturing, demonstrate, holding constant the share of workers employed in agriculture, that there exists a balanced growth path upon which growth in the agricultural sector's total factor productivity will lead to economic as well as demographic growth. However, their model does not explain the declining share of workers employed in the agricultural sector, which plays an important role in the process of industrialisation. Nor do changes in the level of the industrial sector's productivity influence the farmers' behaviour, as is the case in our model.

Both Duranton's and Galor and Mountford's studies consider the role of international trade in the process of development. Duranton engages in the puzzling question of why some—often newly industrialised—countries are able to combine a low total factor productivity in agriculture with a high degree of industrialisation, a fact that Duranton shows can be attributed to the mere circumstance that countries are open to trade. The model in the current paper is capable of replicating the evidence presented in Duranton, even though we consider a closed economy, because a high degree of industrialisation in our model can be achieved with relatively inferior agricultural technology when farmers put a relatively large amount of work into their fields.

Galor and Mountford's paper illustrates how the current distribution of world population can be assigned to the different effects that international trade played in the timing of the demographic transition in agricultural and industrialised countries. An important feature of their work, which is in parallel to ours, is that the level of agricultural productivity is determined endogenously. In their model, the agricultural sector's total factor productivity increases with the economy's overall level of technology, which in turn is positively correlated with the population's level of human capital. Unlike our model, however, the food output per unit of farmland is not the result of the farmer's optimisation behaviour.

In general, our work differs from the existing literature in three important ways. First, we question the idea that pre-industrial farmers fully utilised their productive potential in agriculture. Inspired by the thinking of Boserup and others, we show that when the intensification of farmland comes at a cost to labour and when utility is derived from spare-time activities such as home production, farmers may not use the highest level of farmland productivity possible, which is why the productive opportunities in the agricultural sector need not be fully exploited.

Second, we propose a new way in which to endogenise agricultural productivity. With the exception of Galor and Mountford's model discussed above, improvements in the level of agricultural productivity in the literature on dual economies always occur exogenously. In the current paper, the number of hours that a farmer chooses to spend in his fields, which implicitly determines the productivity of his farmland, is based upon optimization behaviour.

Third, we include domestic activities. Models that deal with long-run growth from a historical perspective tend to neglect the fact that, in societies whose occupational structure is dominated by agriculture, a significant part of the non-agrarian goods that farmers consume are produced by themselves. This subject is examined in a number of papers, most of which are rooted in Becker's (1965) theory of time-allocation, that explores the labour-allocation of an agrarian household (e.g., Devereux and Locay, 1992; Gronau, 1977; Hymer and Resnick, 1969; Locay, 1990).

Here, we mainly build upon the work by Hymer and Resnick (1969), who, in a partial equilibrium analysis, investigate the role of non-agrarian activities in an agrarian economy. Comparable to their study, we take the analysis further by implanting the agrarian sector's activities in a general equilibrium framework. We then use this framework to show that the process of industrialisation, not only in a historical perspective but also in contemporary developing countries, actually consists of a shift in the consumption of non-agrarian goods from goods produced domestically to similar goods produced by an industrial sector.

2 The Evidence

Contrary to the common belief, the process of industrialisation is not confined to the past two centuries. In the words of Hicks (1969, p. 141), "[t]he Industrial Revolution is the rise of modern industry, not the rise of industry as such." In today's terms, Hicks is referring to the concept of 'proto-industrialisation'. Mendels, the initiator of this modern version of this concept, writes that "[w]ell before the beginning of machine industry, many regions of Europe became increasingly industrialized in the sense that a growing proportion of their labor potential was allocated to industry" (Mendels, 1972, p. 241). Mendels' statement encapsulates well the way in which this paper attempts to define an economy's degree of industrialisation, namely, as its share of workers devoted to industrial production.

Due to Engel's law, which captures the fact that the demand for agricultural goods is income-inelastic (e.g., Craft, 1985b), the transfer of labour from agrarian to non-agrarian activities is inseparably linked to improvements in the agricultural sector's performance. Intuitively, one would therefore expect that the historical movement of workers into industrial manufacture awaited advances in the knowledge of how to intensify the use of farmland.

Unlike the classical economists, such as Malthus and Ricardo, who took it for granted that the productive opportunities in agriculture are always fully exploited, one of the most striking aspects of Boserup's (1965) theory about agricultural development is that the intensity with which farmland is cultivated is not limited by the state of knowledge about how to increase output per unit of land. Instead, she convincingly argues that pre-industrial peasants were virtually always capable of increasing farmland productivity by increasing the number of hours that they spent in their fields.

More contemporary studies support Boserup's theory. Grantham (1999, p. 212), for example, asserts that intensive cultivation during the Middle Ages, "demanded more labour and capital per acre of land than traditional farming, and therefore cost more per hectare, but they did not require advances in knowledge."[1] In order to increase the output per acre of land, Grantham argues that fields were seeded more thickly and that farmers weeded, ploughed, harrowed and hoed their fields more frequently and more intensively (*ibid.*). Sim-

[1] In fact, Grantham claims that the techniques that were used to increase output per acre of land during the Middle Ages had been around since the Iron Age.

ilarly, Hatcher and Bailey (2001, p. 154) postulate that the high levels of Medieval farmland productivity recorded in eastern Norfolk, England, "were achieved largely by the use of labour-intensive methods of farming such as weeding, marling, and manuring, rather than through any revolutionary innovations in agricultural technology." Clark (1987), providing evidence that output per farm worker in the northern United States and Britain in the early nineteenth century was many times that in Eastern Europe, claims that "[t]echnical progress explains little of the high American and British productivity [...], nor, in the American case, does abundant land per worker. Instead, most of the differences derived from more intense labor" (*ibid.,* p. 419). But did surplus labour really exist among pre-industrial farmers, and if so, then what made the farmers agree to the inherent decline in other activities that would accompany an increase in farmland productivity?

It has been argued that the systems of land use and cultivation can be understood only if considered as a part of the pattern of social organisation as a whole. The pre-industrial economy is commonly thought of as being dominated by agriculture, when in fact, as pointed out by, for example, Reynolds (2000), it is actually dominated by household production. Reynolds postulates that up to 1700, 80-90 percent of the European population lived in rural areas, on isolated farms or in small villages close to the farmland. In these rural households, Reynolds notes (*ibid.,* p. 80), "[e]ach family produces not only most of its own food, but most of its housing and clothing, plus a wide range of services."

Industrial manufacture gains a foothold to the extent that farmers decide to abandon their self-sufficient life-style by allocating labour-resources to the production of marketable agrarian goods that can then be exchanged for goods produced by specialised manufacturers. But from where did peasants get the labour needed to improve their agricultural performance? Based mostly on studies of developing countries, Boserup (1981) reckons that before the Industrial Revolution, agriculture was, primarily due to its seasonal character, a part-time occupation. She claims (*ibid.*, p. 120) that farmers used their spare time in the production of non-agricultural goods for own-use consumption or, as also proposed by de Vries (1972), in leisurely activities. Similarly, Reynolds (2000, p. 80) asserts that out of the time available to the pre-industrial rural household "agricultural activities take perhaps 50 to 60 percent of the total, the remainder going to 'industrial' and service activities" (Reynolds' quotation marks).

Due to a lack of data, only a few studies have dealt seriously with the existence of surplus labour in pre-industrial agriculture (see, e.g., Allen, 1988; Campbell and Overton, 1991; Clark, 1991). Recently, a study by Karakacili (2004) has provided overwhelming support that surplus labour was indeed present during the middle ages, even at the time which is thought to have had the lowest agrarian labour productivity rates in the pre-industrial era, namely, in the period shortly prior to the Black Death.

Presuming that surplus labour did exist in pre-industrial agriculture, then to what extent did farmers allocate this labour to the production of marketed goods? According to de Vries (1994), the Industrial Revolution was preceded by an 'industrious revolution' during which "a broad range of households made decisions that increased both the supply of marketed commodities and labour and the demand for goods offered in the marketplace" (*ibid.*, p. 255).

If the pre-industrial farm household increased the amount of marketed foodstuffs by increasing its farmland productivity, then this should be mirrored in the share of workers needed in agriculture and thus in the occupation structure of the economy. Allen (2000), reporting such data for pre-industrial Europe, estimates that the proportion of England's labour force engaged in agriculture declined from 74 percent in 1500 to 45 percent in 1750 (see Table 1). This seems to indicate that in the English case, a significant increase in farmland productivity occurred in the centuries leading up to the time of the Industrial Revolution.

[Table 1 about here: Estimated English Population Distribution]

What inspired the farm household to improve the performance of its farmland? In the early modern era there appears to have been an upward movement in agricultural terms of trade, i.e., in the number of non-agrarian goods that a farmer would receive for a unit of food. This shift in terms of trade between the two types of goods is believed to have encouraged the farmer to improve the productivity of his farmland with the aim of increasing the number of agrarian goods that could then be traded in the market for non-agrarian goods.

For example, Craig and Fisher (2000, p. 46) note that "[t]he effort to expand acreage and production during the fifteen and sixteenth centuries was prompted by favorable trends in the demand for agricultural products, which was reflected in the upward movement in farm prices relative to all other prices." A contribution by O'Brien (1985) that estimates prices of agricultural as well as industrial goods for England between 1660 and 1820 reaches a similar conclusion. Using O'Brien's data, Figure 1 illustrates the development in agricultural terms of trade over the period. Although the terms of trade decline slightly over the first half of the observed period, the second half of the period, particularly at the onset of the Industrial Revolution between ca. 1750 and 1800, indicate a significant upward trend in the price that farmers received for their products.

[Figure 1 about here: English Agriculture Terms of Trade]

In support of the view that improvements in agricultural terms of trade encouraged the farmer to improve his output per unit of land, Reynolds (2000, p. 89) mentions that "[a]s agricultural production becomes more labour-absorbing and more profitable, and as manufacturers can be purchased from outside on more favorable terms, the rural family sheds some of its goods-producing functions and passes them over to the specialized producers." Along similar lines, Boserup (1990, p. 35) notes that around the time of the Industrial Revolution, "[s]ome family members had produced textiles and other non-agrarian products for home consumption, but when prices of such products declined steeply, home production was replaced by the purchase of industrial products. Home workers either gave more help in agriculture, or they began to work in or for the new factories."

Although there is very little direct information about patterns of the farmer's home work versus his agrarian work in the early modern era, Voth (2000), who investigates the working hours in England during the Industrial Revolution, estimates that a 19 percent decline in the total number of workers in agriculture between 1760 and 1800 was accompanied by a 45 percent increase in the annual number of hours spent per person in agriculture (*ibid.*, table 3.34). Note that this enormous increase in agrarian working hours coincides with the strong improvements in the price that a farmer received for his products over the same period (see

Figure 1).

Since the transfer of household activities into commercial manufacture is reflected in the occupational structure, and since commercial activities are more readily detected and measured than are those performed by the household,[2] one would expect to see a negative relationship between the share of the total labour force engaged in agrarian activities and the output per capita. Figure 2, which plots the share of workers in agriculture against the (log) GNP per capita in 134 contemporary countries,[3] clearly indicates that countries that employ a relatively small proportion of their labour force in the agrarian sector, also enjoy relatively higher standards of living. This seems to be consistent with the idea that economic growth is strongly linked to the transfer of workers from agriculture to industrial activities.

[Figure 2 about here: Log GNP per Capita vs. the Share of Workers in Agriculture]

The discussion in this section suggests that the historical process of industrialisation actually consisted of a shift in the farm household's consumption of manufactured goods, from goods produced domestically to similar goods produced by the industrial sector. Moreover, it appears that the shift was accompanied by an increase in farmland productivity that might have arisen from growth in the number of hours that the farmer spent in the fields.

In the following, a simple framework that is capable of replicating this evidence is presented. The framework is then used to trace the underlying factors that prompted the process of industrialisation.

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[2] See Devereux and Locay (1992) for a discussion.

[3] The data stems from World Bank (1999, Tables 1.1 and 1.15). There were originally 148 countries in the data set but 14 have been left out due to missing observations.

3 The Model

Consider a two-sector, one-period, non-overlapping generations model with agrarian as well as non-agrarian production and consumption. The economy consists of N identical individuals, out of which the share $s \in (0,1]$, which is determined endogenously below, is engaged in the agricultural sector. Non-agrarian goods are produced domestically as well as by an industrial sector. Residually, the share $1-s$ of the labour force is engaged in the industrial sector.

Each individual is endowed with $\bar{l}$ units of time. As will become apparent below, this time-endowment is divided between domestic production on the one hand, and agricultural or industrial production—depending on the individual's sectorial choice—on the other.

3.1 Agricultural Production

We assume that agricultural production has constant returns to land and labour. Throughout the paper, we suppress the use of capital; this is not an uncommon simplification in models that investigate pre-industrial development.[4]

The output per farmer (superscript A for *agrarian* goods) is

$$y^A = \Omega_A l^{\alpha} x^{1-\alpha}, \quad \alpha \in (0,1), \tag{1}$$

where l is the number of hours that a farmer spends producing food, x is the units of farmland that he has at his disposal, and Ω_A is the total factor productivity in agriculture. We assume a fixed amount of farmland of X units. As is customary in this field of study,

[4] The inclusion of capital goods will hardly affect the qualitative results of the model.

we also assume that there are no property rights over the land, i.e., land is divided equally among the farmers and therefore y^A is the farmer's income, expressed in terms of food. With N being the size of the total labour force and s being the share hereof engaged in agriculture, each farmer thus receives $x = X/sN$ units of farmland.

With a fixed amount of land at the farmers' disposal, the assumption that $\alpha \in (0, 1)$ implies that there are diminishing returns to labour in agrarian production. Note, though, that a farmer is capable of increasing his output per unit of farmland by increasing the number of hours that he spend in the fields, that is, by increasing l. However, since the farmer derives utility from spare time activities (see below), he need not necessarily want to set l equal to his time-endowment $\bar{l}$.

Note also that the economy's total agrarian output is

$$Y^A = y^A \cdot sN = \Omega_A \left(lsN\right)^{\alpha} X^{1-\alpha} \equiv \Omega_A \left(lsN\right)^{\alpha}, \quad X \equiv 1. \tag{2}$$

Both the share of the labour force that is employed in agriculture, s, and the number of hours that a farmer spends producing food, l, will be determined in the following.

3.1.1 Food Market Clearing

In accordance with Craft (1985b), we assume that the demand for food, unlike other goods that we consider, is income-inelastic. More specifically, we assume that a units of agrarian goods are required per individual in order to ensure the individual's survival.

With N individuals who each demand a units of food, equilibrium in the market for food implies that the total demand, aN, equals the total supply, Y^A. The share of workers in agriculture that is required to satisfy the economy's food needs is thus determined endogenously from the food market equilibrium. Using equation (2), it follows that the share of the total labour force engaged in agrarian activities, in equilibrium, is

$$s = \left(\frac{aN^{1-\alpha}}{\Omega_A}\right)^{1/\alpha} \frac{1}{l}. \tag{3}$$

Accordingly, the share of workers employed in agriculture, s, increases with the size or, in effect, the density of the economy's population, N, and decreases with the level of the total factor productivity in agriculture, Ω_A.

The latter result is a well-known conclusion from the existing literature. However, for the story that we are going to tell here, the key is that the share of workers engaged in agriculture also decreases to the extent that the farmers decide to increase their work hours spent producing food, measured by the variable l.

3.2 Preferences

Suppose that having consumed the a units of food that are required for survival, the individual then derives utility from the consumption of non-agrarian goods. As indicated above, non-agrarian goods can be of an industrial type denoted m (for *manufactured* goods) and of a home-made type denoted d (for *domestic* goods). Home-made or domestic goods are produced by the individual in his or her spare-time. Manufactured goods are produced by the share of the labour force, $1 - s$, that is engaged in the industrial sector, henceforth denoted as, manufacturers.

Domestic and manufactured goods are considered to be perfect substitutes. The representative utility function is thus

$$u(m, d) = m + \gamma d \equiv m + d, \quad \gamma \equiv 1, \tag{4}$$

with γ being the subjective value of domestic goods relative to manufactured goods. For convenience, γ is assumed to be the same for all individuals, and in the following is set to one. Note that the consumption of the a units of food that the individual needs in order to subsist does not provide any utility but is necessary for survival.[5]

3.3 Non-Agrarian Production

There are two types of technologies available for producing non-agrarian goods: domestic technology (denoted D) and industrial technology (denoted M). Both are assumed to exhibit constant returns to labour, which implicitly means that land for the purpose of non-agrarian production is not constrained. The total non-agrarian output is thus

$$Y^i = \Omega_i \cdot L, \quad i = \{D, M\}, \tag{5}$$

where L is labour and Ω_i is the level of productivity in sector $i = \{D, M\}$.

We then define the relationship between the levels of productivity in the two sectors as

$$\Omega_M = (1 + \Phi)\, \Omega_D, \tag{6}$$

where the size of Φ, which we assume is larger than zero, measures the degree to which the industrial sector's productivity exceeds that of the domestic sector.

3.4 Occupation, Income, and Consumption

The individual can choose between being a farmer and a manufacturer. It is assumed that once the occupational decision is made, then manufacturers do not have access to farmland

[5] A similar construction is found in Kögel and Prskawetz (2001). It is possible, but severely complicates matters, to have food consumption entering the utility function such that, once a given amount of food has been consumed, individuals care about food as well as non-agrarian goods.

and farmers do not have access to industrial technology.[6]

3.4.1 The Manufacturer's Income and Consumption

The manufacturer's income consists of the wage that he earns in the industrial sector, which is Ω_M times the number of hours that he decides to work. Since the manufacturer is more productive at work than at home (i.e., $\Omega_M > \Omega_D$), he chooses not to produce domestic goods at all and instead spends his entire time-endowment, $\bar{l}$, at work.[7]

A share of the income that the manufacturer generates at work is spent on the a units of food that he needs in order to subsist. Since utility is derived from the consumption of non-agrarian goods, once his food needs are fulfilled, the remaining income is spent on manufactured goods. The number of manufactured goods that the manufacturer consumes is thus

$$m^M = \Omega_M \bar{l} - pa, \tag{7}$$

where p is the price of food in terms of manufactured goods, i.e., agricultural terms of trade. Since the manufacturer is not engaged in domestic production, his consumption of domestic goods is zero, i.e.,

$$d^M = 0. \tag{8}$$

[6] The reason could be that the production of industrial goods takes place in urban areas that farmers are unable to reach in their spare time. The same would be true for manufacturers, *mutatis mutandis*. It could also be that the industrial technology requires certain, non-explicated educational skills that farmers do not have time to obtain. Or it could be that the industrial technology requires use on a daily basis that farmers, due to their agrarian obligations, are prevented from obtaining.

[7] We could allow for diminishing returns to labour in the non-agrarian production, which would mean that there are circumstances under which manufacturers would enjoy domestic goods as well. Such a modification will, besides complicating the model, not affect its qualitative results.

3.4.2 The Farmer's Income and Consumption

The farmer's income consists of the value of his food surplus. The food surplus is the difference between his food output, y^A, and the number of food units required for survival, a. The price that the farmer receives, measured in terms of manufactured goods, is p per unit of food. It thus follows that the number of manufactured goods that the farmer consumes is

$$m^A = p\left(y^A - a\right). \tag{9}$$

Since the farmer does not have access to industrial technology, he spends his spare time, i.e., the time left after agrarian activities, $\bar{l} - l$, producing domestic goods. His consumption of domestic goods is therefore

$$d^A = \Omega_D\left(\bar{l} - l\right). \tag{10}$$

Note that as long as $l < \bar{l}$, the farmer is potentially able to increase his output per unit of farmland and thus his food surplus. However, as this increase in farmland productivity means that he needs to reduce his consumption of domestic goods, the farmer is reluctant to use the highest farmland productivity possible, which, given the level of Ω_A, is obtained by setting $l = \bar{l}$. In other words, an increase in the farmer's output per unit of farmland, and thus an increase in his consumption of manufactured goods, is obtained at the expense of his production and consumption of domestic goods.

4 Analysis

Using the set-up presented above, we are now ready to find the number of hours, l, that a farmer chooses to spend in his fields. Then, we find agricultural terms of trade, p, and the economy's degree of industrialisation, $1-s$, in order to see how these variables, particularly the latter, respond to changes in productivity and demography.

4.1 Optimization

A farmer chooses the number of agrarian working hours, l, that maximises his utility. Inserting the farmer's consumption of manufactured as well as domestic goods, equations (9) and (10), and the farmer's production function, equation (1), into the utility function, equation (4), the optimization problem thus becomes

$$\max_{l} u^{A} = m + d = p\left(\Omega_{A} l^{\alpha} (sN)^{\alpha-1} - a\right) + \Omega_{D}\left(\bar{l} - l\right), \tag{11}$$

subject to the time-budget constraint that requires that $l \leqslant \bar{l}$. An interior solution to the maximisation problem implies that

$$p\alpha\Omega_{A} (lsN)^{\alpha-1} = \Omega_{D}, \tag{12}$$

meaning that the marginal utility that a farmer gains from increasing his agrarian work hours (the left-hand term), which stems from an increase in his income made from selling a larger food surplus and thus an increase in his consumption of manufactured goods, in optimum equals the marginal utility forgone from increasing his agrarian work hours (the right-hand term), which is due to a decline in his consumption of domestic goods.

Note, in particular, that an increase in the price that a farmer receives for one unit of food increases the marginal utility obtained from increasing his agrarian working hours.

4.2 Equilibrium

Suppose that there is free labour mobility. Occupational indifference then implies that the individual receives the same level of welfare regardless of whether he is a farmer or a manufacturer. The economy is therefore in equilibrium when all workers receive an identical level of utility, i.e., when

$$u^A = u^M. \tag{13}$$

Inserting equations (7), (9), (8), (10), and (12) into (13), it follows that the price of food in terms of manufactured goods is

$$p = \frac{1}{\alpha}\left(\frac{\alpha}{1-\alpha}\Phi\bar{l}sN\right)^{1-\alpha}\frac{\Omega_D}{\Omega_A}. \tag{14}$$

Note that p increases with both the degree to which the industrial sector's productivity exceeds that of the domestic sector, measured by the variable Φ, and with the size of the population, N. However, p decreases to the extent that the agricultural sector's total factor productivity, Ω_A, increases.[8]

By inserting equation (14) into the solution to the farmer's optimization problem, equation (12), it follows that the optimal number of hours that a farmer spends producing food, in equilibrium, is

$$l = \frac{\alpha}{1-\alpha}\Phi\bar{l}. \tag{15}$$

Accordingly, the number of hours that a farmer spends producing food increases with the degree to which the industrial sector's productivity exceeds that of the domestic sector,

[8] Note also that, despite the fact that a farmer and a manufacturer receive the same level of utility, the model indicates that if the value of domestic production is not taken into consideration, then an income-study will show that the wage of a manufacturer exceeds that of a farmer. In other words, urban wages tend to be larger then rural wages.

Φ, but is unaffected by changes in the size of the economy's population, N, or by changes in the agricultural sector's total factor productivity, Ω_A.

Finally, the share of workers that is employed in the agricultural sector in equilibrium is found by inserting equation (15) into equation (3). It thus follows that the share of the labour force engaged in agricultural activities, in equilibrium, is

$$s = \frac{1-\alpha}{\alpha}\left(\frac{aN^{1-\alpha}}{\Omega_A}\right)^{1/\alpha}\frac{1}{\Phi\bar{l}}, \tag{16}$$

which increases with the size of the population, N, but decreases with the degree, Φ, to which the industrial sector's productivity exceeds that in domestic production, and with the total factor productivity in agriculture, Ω_A.

4.3 Productivity Changes

We want to examine the way in which changes in the level of productivity in each of the three sectors influence the economy's degree of industrialisation. The following proposition summarises the results.

Proposition 1 *The model predicts that*

(i) an increase in the industrial sector's productivity, Ω_M, relative to that in the domestic sector, Ω_D—that is, an increase in Φ—increases the farmer's agrarian work hours, l, which reduces the share of workers in agriculture, s, and thus transfers labour from agriculture to industry.

(ii) an increase in the agricultural sector's total factor productivity, Ω_A, reduces the share of workers in agriculture, s, and thus transfers labour from agriculture to industry, without affecting the farmer's agrarian work hours, l.

Proposition 1 follows trivially from the solution to the optimization problem, and thus from the derivatives of equations (15) and (16) with respect to Φ and Ω_A. The model accordingly suggests that an increase in the farmer's agrarian work hours, which increases the size of his food surplus and thus transfers workers from agriculture to industry, will result from inventions that improve the industrial sector's productivity. Similarly, the model shows that the introduction of inventions that improve the agricultural sector's productivity, even though they do not affect the farmer's agrarian work hours, also transfer workers from agriculture to industry.

The latter is the trivial result, well known from the existing literature. The news here is, therefore, the former result, according to which the historical release of workers from food-generating activities could have arisen from the introduction of new technology in the *industrial* sector, even in the absence of new technology being introduced into agriculture. This thus affirms the history textbooks' conviction that events such as the mechanization of the English textile industry actually prompted the process of industrialisation.

4.4 Demographic Changes

One of the most salient features of the early modern era, one that most likely affected the process of industrialisation, is the increase in the size of the population. According to Allen (2000), the English population more than trebled over the three centuries from 1500 to 1800 (see Table 1 on page 11).

One of the key determinants in the process of agricultural development, according to Boserup (1965), is the pressure of an increasing population. She predicts (*ibid.,* p. 71) that "output per man-hour in agriculture tends to decline with increasing population density, but [...] this decline is likely to be offset, more or less, by longer hours."[9]

[9] Boserup also mentions that a relatively large agricultural population within a given territory under pre-industrial systems of cultivation can support an absolute larger non-agrarian population than a relatively

How does the model presented above accord with the predictions of Boserup? It follows from the solution to the optimization problem, and thus from the derivative of equations (15) and (16) with respect to N, that,

Proposition 2 *An increase in the size of the population, N, increases the share of labour employed in agriculture, s, without affecting the farmer's agrarian work hours, l.*

The Proposition thus indicates that an increase in the size of the population reduces the degree of industrialisation. All other things being equal, the decline in output per man-hour that stems from an increasing population is due to the fact that a larger population reduces the amount of farmland available to each farmer. However, the farmer does not, as proposed by Boserup, respond by putting more hours of work into his fields. Instead, there is an increase in the share of workers that are engaged in the agricultural sector. That is, more labour does enter agriculture in order to fulfil the increase in the demand for food that arises from a larger population, but the individual farmer's work hours are not affected.

However, if we consider an economy in which the *entire* labour force is devoted to agricultural activities, then the model actually does replicate the prediction of Boserup. From setting s equal to one in equation (3), isolating l and then differentiating with respect to N, it follows that,

Corollary 1 *In a subsistence economy—defined as an economy in which the entire labour force is engaged in agriculture—an increase in the size of the population, N, increases the farmer's agrarian work hours, l.*

smaller one. However, this is not the same as saying that a larger population will cause an increase in the degree of industrialisation. In fact, Boserup imagines (*ibid.*) that a higher degree of urbanisation, which is a proxy for the share of workers in industrial activities, is attained from improvements in agricultural productivity through the industrial sector's delivery of better tools to agriculture, and the provision of better administration, and education, and so forth.

Corollary 1 implicitly states that an increase in the size of the population, leaving each farmer with less farmland to cultivate, forces the farmer to increase his agrarian work hours in order to be able to produce the amount of food that is needed for his survival.

In any case it is clear that a larger population appears to make it increasingly difficult for an economy to become industrialised, a result that seems to contradict the pre-industrial evidence. Because, according to Allen (2000), the share of the English labour force devoted to agricultural activities declined from 76 percent in 1500, to 69 percent in 1600, and 55 percent in 1700, until it reached 36 percent in 1800. These structural changes occurred despite the significant increase in the size of the English population (see Table 1). Although it is possible that higher total factor productivity in the agricultural and/or the industrial sector counterbalanced the adverse effect that an increase in the size of the population had on the share of workers employed in the industrial sector, it appears to be more likely that the size of the population in itself somehow had a positive effect on the total factor productivity in the various sectors.

4.4.1 Population and Technology

Over the years, a larger number of studies that deal with long-run growth and development have argued that diminishing returns to labour are neutralised, or even reversed, due to the fact that an increase in the size of the population has a positive effect on the emergence of new technology. This idea originates with Kuznets (1960), who argued that a larger population contains more potential inventors; with Smith (1776), who attributed the adoption of more productive technologies to the impetus of increasing specialisation and division of labour;

and, not least, with Boserup (1965), who hypothesized that the increasingly intensive land-use that follows from the pressure of an increasing population would supposedly lead to a drop in labour productivity, following which, methods that raise productivity, such as ploughing and fertilization, would be developed. A contribution by Kremer (1993) provides a number of empirical tests that support the prediction that pre-industrial societies with relatively large populations also enjoyed relatively fast technological growth. More recently, Alcalà and Ciccone (2001) found that the size of the labour force in contemporary countries positively influences labour efficiency.

In the following, we show that our framework can easily be extended so as to capture this idea. In line with the construction in Galor and Mountford's (2003) paper discussed on page 5 above, we propose an extension by which we allow the size of the population to positively influence not only the agricultural sector's total factor productivity, as proposed by Boserup, but the level of productivity in all of the sectors. We then demonstrate that even if the effect that an increasing population has on agricultural productivity is absent, then the model is still able to explain the transfer of workers from agriculture to industry, due to the effect that a larger population has on the non-agrarian sectors' productivity.

One of the papers that has recently argued for a model in which the growth rate and therefore the level of technology can be linked to the size of the population is Jones (1998).[10]

Here, we propose a slightly modified version of Jones' approach by assuming that the

[10] Jones proposes a construction where the economy's stock of knowledge, measured by the variable A, grows according to the rule $\dot{A}_t = \delta L_t$, where δ is the number of new ideas that each person discovers per unit of time. This, in discrete time, means that $A_{t+1} = \delta L_t + A_t$, and is why the level of technology is positively correlated with the size of the population.

economy has an *overall* level of technology, denoted Ω, which increases with the size of the population, N, such that

$$\Omega = \kappa N^{\varepsilon}, \quad \varepsilon \in (0,1), \kappa > N^{-\varepsilon}. \tag{17}$$

Note that $\varepsilon \in (0,1)$ implies that there are diminishing returns to labour in the creation of new technology. As will become apparent below, the requirement that $\kappa > N^{-\varepsilon}$ is equivalent to the assumption that $\Phi > 0$ made on page 17.[11]

Next, inspired by the construction in Galor and Mountford (2003), we assume that the overall level of technology, Ω, affects the level of productivity in all of the three sectors.[12] However, the intensity with which each of the three sectors uses the overall level of technology is not necessarily the same. More specifically, suppose that

$$\Omega_i = \Omega^{\beta_i}, \quad \beta_i \in [0,1), \quad i = \{A, D, M\}, \tag{18}$$

where β_i is the intensity with which the overall technology is used in sector $i = \{A, D, M\}$.

We then propose the following result that emerges from inserting equations (6), (17) and (18) into (16) and then differentiating with respect to N.

[11] In Jones' (1998) model, new technology occurs even in the absence of population growth. In the current model, the level of technology that is available, measured by the variable Ω, increases only to the extent that there is an increase in the *size* of the population. What's more, our construction, unlike that of Jones, implies that a decline in the size of the population will actually result in a reduction in the level of technology that is available to the economy. The relationship between population and technology promoted here is, therefore, somewhat similar to the one that Smith (1776) had in mind, in which more people utilises more productivity technologies due to the economies of scale that arise from specialisation and division of labour. Thus, our framework, in contrast to the set-ups in the existing literature, is able to explain why major demographic setbacks, such as the Black Death that eliminated one-third of Europe's population during the fourteenth century, led to a contraction of economic activity and to a lower degree of industrialisation. The idea that the level of technology in a historical perspective regresses as a result of a reduction in population density is well documented in a recent paper by Aiyar and Dalgaard (2002).

[12] In Galor and Mountford's model, the level of technology is positively influenced by labour's skill intensity (i.e., individual human capital) and by the level of technology in the previous period.

Proposition 3 *If (i)* $\beta_A > (1-\alpha)/\varepsilon$ *and* $\Omega_M > \Omega_D$ *with* Ω_i *being independent of* N *for* $i \in \{D, M\}$, *or if (ii)* $\beta_A = 0$ *and* $\beta_M > (1-\alpha)/\alpha\varepsilon + \beta_D \geqslant (1-\alpha)/\alpha\varepsilon$, *then an increase in the size of the population,* N, *increases the degree of industrialisation,* $1-s$.

Proposition 3 states that if the overall level of technology influences the total factor productivity in the agricultural sector only, and if the effect hereupon of an increase in the size of the population is sufficiently strong, then an increase in the size of the population will stimulate the process of industrialisation.[13]

Although improvements in the agricultural sector's total factor productivity are known to have occurred throughout the pre-industrial era, this need not be the only force by which workers were transferred from agriculture to industry. For reasons that were expounded above, improvements in the industrial sector's productivity, via an increase the number of hours that a farmer chooses to spend in his fields, may also have added to the process of industrialisation.

Suppose, therefore, that the effect that the overall level of technology has on the agricultural sector's total factor productivity is turned off, and that it only affects the level of productivity in the non-agrarian sectors. Then, provided that the industrial sector uses the overall technology more efficiently than does the domestic sector (i.e., that $\beta_M > \beta_D$), this means that an increase in the size of the population will stimulate the process of industrialisation, despite the lack of new agricultural technology being introduced.[14]

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[13] For a stylised representation that also captures this result, see Craft (1985a, pp. 117-118). Craft's model, however, is a one-sector framework, which only includes agricultural production.

[14] Other combinations than those proposed in Proposion 3, for example, when the overall level of technology influences the level of technology in all of the three sectors, may also give rise to an increasing degree of industrialisation.

Implicitly, the second part of Proposition 3 thus indicates that variations in occupation structures across countries or regions, for example, at the time of the Industrial Revolution, could result of differences in industrial technology rather than differences in agricultural technology, which means that the farm households in the more densely populated regions spend more hours of work in the fields.

5 Conclusion

This paper investigates the process of industrialisation with specific focus on the macro impact of the farm household's decisions concerning its allocation of labour between agrarian and non-agrarian activities. The work is inspired by the two important observations about the pre-industrial economy made by Boserup (1965) and others, namely, that surplus labour existed in agriculture and could be allocated in a variety of ways, and that agricultural productivity was limited, not by the state of knowledge about how to increase output per unit of land, but by the fact that an increase in farmland productivity came at a cost to labour.

The main contribution in this paper is that productivity improvements in the industrial sector, through changes in terms of trade between agricultural and industrial goods, make farmers increase their output per unit of farmland by mobilising labour-resources from domestic activities. The growth in the farmer's food output expands the amount of food that is traded in the market, which then increases the share of workers engaged in industrial activities.

In effect, the process of industrialisation in this paper is demand-driven. That is, improvements in the industrial sector's productivity make farmers substitute non-agrarian goods produced at home for similar goods that are produced by the industrial sector. The model therefore explains why technological breakthroughs in industrial manufacture, such as the mechanization of the English textile industry, would have intensified the use of farmland and transferred workers from agriculture to industry, even in the absence of technological breakthroughs in agriculture.

By assuming a positive link between the level of technology and the size of the population, it is also shown that more densely populated regions will be more industrialised compared to sparsely populated ones, even though they use the same agricultural technology, and that the higher degrees of industrialisation in the more densely populated regions are achieved at the expense of farmers' spare-time activities.

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Table 1

Estimated English Population Distribution

Year	Total (mio.)	Agri. (mio.)	Agri. (pct.)
1500	2.5	1.85	74.0
1600	4.4	3.03	68.8
1700	5.2	2.86	55.0
1750	6.0	2.70	45.0
1800	9.1	3.23	35.5

Source: Allen (2000)

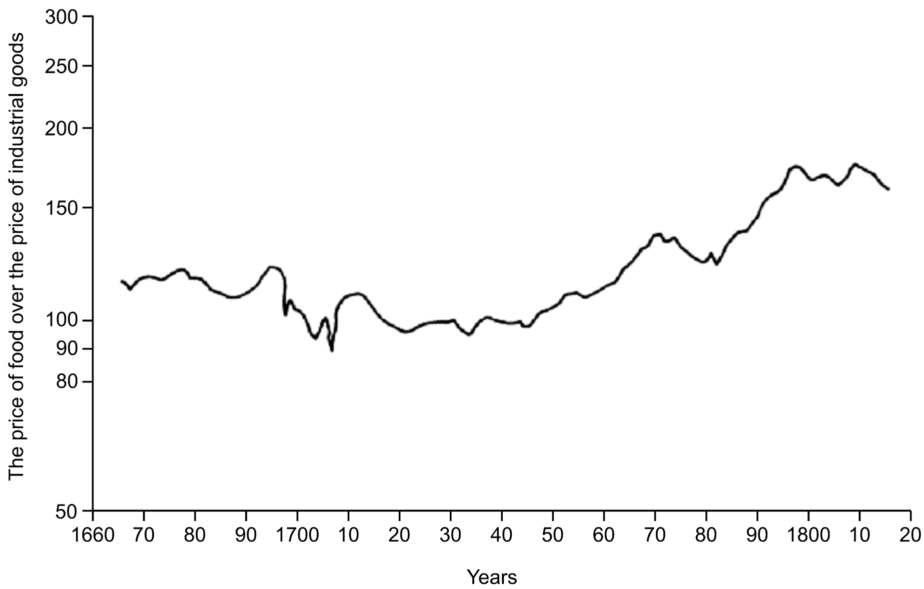

Figure 1: Terms of Trade between Agriculture and Industry in England 1660-1820 (Source: O'Brien, 1983)

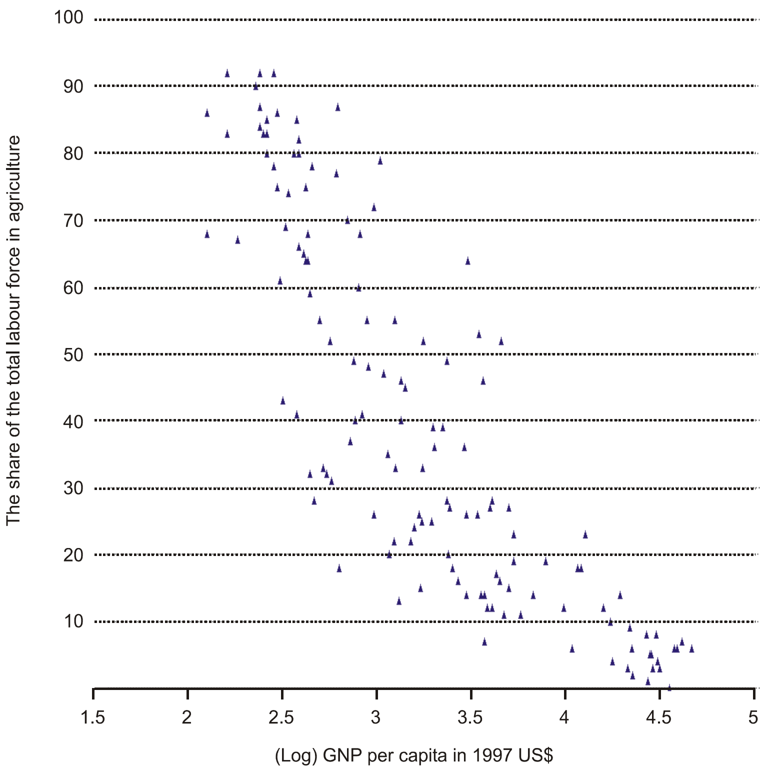

Figure 2: Log GNP/Capita vs. the Share of Workers in Agriculture 1997 (Source: World Bank, 1999)