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The Inverse Logics of Different Stages of Development under the Law of the Limit to Land Productivity

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土地生产率极限法则下不同发展阶段的反向逻辑

裴小林

Abstract

To remind China's policy makers that seemingly correct theories in the West can become harmful in China, this article builds a dynamic land-use model, where the limit to land productivity causes the physical, economic, and institutional systems of land use to change inversely in the stages before, in, and after the population trap. The article uses historical data to test the inverse changes, and finds that the English agricultural revolution was a result of a shift of land use first from intensive to extensive and then back to intensive cultivation. In the process of returning to intensive cultivation, the Norfolk rotation system combined planting with livestock husbandry and raised agricultural output and labor productivity by increasing the number of draft animals and the acreage devoted to forage crops. But the revolution was possible precisely because land productivity was much lower in England than in China.

Keywords

law of limit to land productivity, three worlds' dynamic land-use model, inverse logics of different stages of development, English agricultural revolution

摘要

为提醒中国的政策制定者在西方似乎正确的理论在中国可能变得有害，本文建立了一个动态土地使用模型，在其中土地生产率极限使土地使用的物质、经济和制度系统在人口陷阱之前、之中和之后的三个不同发展阶段反向地变化。本文用历史数据检验了这些反向变化，发现英格兰的农业革命是土地使用从集约向粗放倒退然后再返回集约化的结果。在返回集约化的过程中，诺福克轮作制使种植业和畜牧业结合，通过大幅增加饲料作物和耕畜数量提高了农业总产值和劳动生产率。但这一革命能出现正是因为英格兰的土地生产率比中国低得多。

关键词

土地生产率极限法则、三维世界的动态土地使用模型、不同发展阶段的反向逻辑、英格兰的农业革命

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In raising the question of whether China's rural development might follow a third road between capitalism and socialism, Philip Huang has stressed that the key to rural development is the improvement of labor productivity and per capita income, rather than rigidly following a "socialist" or "capitalist" road. In other words, the purpose of development is to improve per capita income and the general welfare. Furthermore, there can be more than one route to this goal. This view clearly contradicts the neoclassical theory of property rights. For example, North and Thomas (1973) claim that the rise of Western countries was the result of their efficient organization and that this efficiency sprang from the incentives created by private property rights and the market system. Thus, in their view, only private property rights and the market system can maximize per capita income. This deterministic line of thinking has been widely accepted in China and has dominated policy making. As a result, developing private property rights and the market system itself has become the purpose of development.

Because whether there is a third path to rural development in China is a theoretical question, I will not discuss the specifics of a third road before establishing a theoretical framework for such a discussion. Let me start from the general welfare theory of Richard T. Ely (1914: 545–46):

> Property exists because it promotes the general welfare and by the general welfare its development is directed. The statement seems simple enough, but it indicates a movement which carries all before it and is irresistible. It is a theory of social evolution, because as society is in a flux, property can accomplish its end only by a corresponding evolution. It is a legal theory, because property in itself implies law; and it is only through law that possession ripens into property. At the same time the words used to describe the theory show that law cannot be arbitrary. Free goods make way for property. Public property is transformed into private property, and private property again into public property, and extensive forms of property make way for intensive forms, because all this evolution promotes the general welfare.

Ely's theory is clearly different from that of Douglass North (see North, 1981). The former is dynamic; the latter is static. The former sees welfare as the purpose of development and the reason for changes in property rights; the latter sees property rights as the purpose and the reason for changes in welfare (e.g., growth, stagnation, or decline of per capita income). The former believes the state cannot make law at will; the latter contends that it can. The former argues that the private property system will not always maximize social welfare and thus there will be changes to the public property system. The latter argues that the private property system will always maximize social welfare and hence no other property rights system should emerge. Who meets and who fails the test of human evolution is very clear.

But Ely's theory is also flawed. It does not identify the factors that at times cause the private-property and sometimes the public-property regime to maximize the general welfare; the factors that prevent the state from arbitrarily imposing a property regime; and, finally, the factors that determine the level of general welfare and changes in that level. Ely's theory clearly misses a key factor: the law of the limit to land productivity. I will demonstrate that humans cannot change this law. It is this law that causes things to develop in the opposite direction when they become extreme. This is why sometimes it is the private-property regime and other times the public-property regime that maximizes the general welfare, and why the state can only select property regimes according to these changes in order to maximize the general welfare under the constraints of the limit to land productivity. I will also use this law to demonstrate that North's argument about the source of the rise of the Western world reverses history. The growth of per capita income in Western countries and the persistence of private property rights and market systems are results of the fact that those countries had few people and relatively abundant land. Few people and abundant land reduce the need for labor inputs per hectare and reduce land productivity so that it is far from its limit, and this limit does not restrict growth in labor productivity and per capita income, and the emergence of private property and market systems. But these logics all become the opposite in China where people are numerous but land is scarce.

To verify these inverse logics, the following section defines the law of the limit to land productivity. The section after that uses this law to examine the agricultural revolution in England. The next section compares land productivity in China and England. The final section establishes a dynamic land-use model, where the limit to land productivity gives rise to inverse changes in the physical, economic, and institutional systems of land use at different stages before, in, and after the population trap.[1] The conclusion recapitulates the arguments in this article. Finally, I must stress that this article analyzes the agrarian history of an organic economy as it existed before the emergence of a mineral-based-energy economy (Wrigley, 1988). The production of agricultural products in this history was mainly through the application of human and natural forces, whereas in a mineral-based-energy economy it is chemical energy that plays the main role. Thus, in the industrialized countries about three percent of the labor force is able to feed the entire population.

The Law of the Limit to Land Productivity

Soil fertility includes both natural fertility and artificial fertility. The combination of the two creates economic fertility in the form of land productivity. Natural fertility, which is not created by humans but by nature, provides the soil characteristics and surface environment needed for plants to grow: soil thickness, nutrients, moisture,

[1] The population trap is the situation where the rate of growth of the population exceeds the rate of growth of real income. This is equivalent to saying that real income per capita will decline to the subsistence level, and efforts to move away from this level are doomed to failure because population growth has more of an effect than income growth.

air, light, heat, and so on. All these are a combination of the biological, physical, and chemical properties of the soil and the surface environment. One end of natural fertility is zero, such as in the case of desert or permafrost. The other end is the highest limit of natural fertility. Hence natural fertility is a framework where one end is at zero and the other is at the highest limit. Artificial fertility is created by the productive activities of land consolidation, construction of irrigation and drainage systems, farming, fertilization, rotation, multiple cropping, and so on. Because the inputs of labor and capital and the corresponding technology of these activities are applied within the framework of natural fertility, the formation of artificial fertility and land productivity is confined within this framework. For example, artificial fertility and land productivity are difficult to achieve in the permafrost zone where natural fertility is almost zero. Even if we make an artificial greenhouse environment through inputs of labor, capital, and technology, the formation of the fertility is not economical. From the other end, the formation of artificial fertility and land productivity cannot exceed the maximum limit of natural fertility, such as the limits of annual sunlight and the accumulated temperature of a cultivated plot of land set by the nature.

In the short term, the formation of artificial fertility and land productivity depends on how labor and capital are invested and how natural fertility is manipulated. In the long run, the formation of artificial fertility and land productivity depends on the level of the technology that is used to exploit the potential of natural fertility. At a given stage, land productivity cannot be more than what is possible using the technology available at that stage. There is, in short, a limit. This limit can be seen as a relative limit to land productivity. In the next stage, technological progress raises the level by tapping the potential of natural fertility, but it cannot escape the framework of natural fertility. The highest limit of natural fertility, therefore, is the absolute limit to land productivity. For example, the amount of sunshine required for photosynthesis on a plot of land is in constant supply each year. Technological progress cannot override the maximum limit of natural fertility nor can it increase natural fertility. Thus, the limit to land productivity is like a ceiling. Technological progress can only push up but never can eliminate this ceiling, and thus the relative limit and the absolute limit to land productivity can be considered a unified ceiling under an available technology at a given stage of development. It is this limit to land productivity (LTLP hereafter) that leads to diminishing returns.

Table 1 illustrates how LTLP causes returns to diminish. The first column lists successive units of labor inputs. The second column shows land productivity or the output that a fixed area of land yields when successive units of input are expended on the area. The third column shows the marginal returns to a particular unit of input, which increase up to the fifth unit, then consistently decrease, and finally become negative. The last column shows the average returns per unit of input, which increase up to the seventh and eighth units and then decrease. If we consider a fixed area of land, the second column tells us that land productivity

Table 1. The Limit to Land Productivity (LTLP) and Diminishing Returns to Labor.

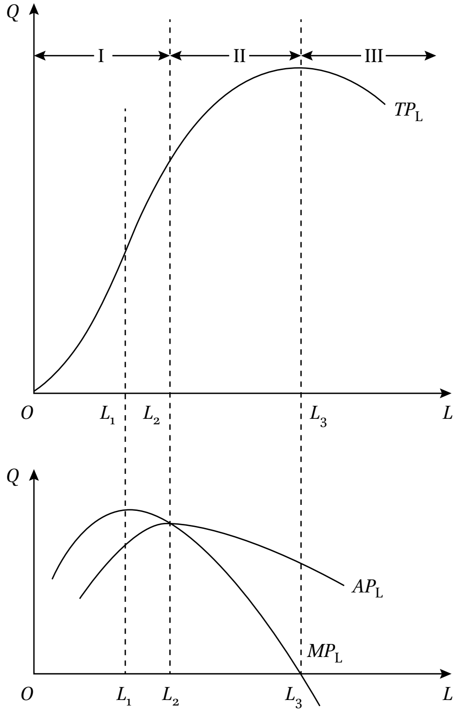
Units of labor input	Land productivity	Marginal returns to labor	Average returns to labor
1	5	5	5
2	20	15	10
3	45	25	15
4	80	35	20
5	125	45	25
6	162	37	27
7	196	34	28
8	224	28	28
9	243	19	27
10	260	17	26
11	275	15	25
12	288	13	24
13	299	11	23
14	308	9	22
15	315	7	21
16	320	5	20
17	323	3	19
18	**324**	1	18
19	323	–1	17
20	320	–3	16
21	315	–5	15
22	286	–29	13
23	253	–33	11
24	216	–37	9
25	175	–41	7

Source: Ely and Wehrwein, 1940: 53, table 7.

does not decrease until the nineteenth unit of input has been expended, and 324 is exactly the limit to land productivity and the benchmark, where the marginal returns change from positive to negative and land productivity changes from increasing to decreasing. It is the prior existence of LTLP that causes them to move in the opposite direction.

Figure 1 depicts the causality. The horizontal axis represents labor inputs and the vertical axis yield. TP_L is the total product curve of labor, MP_L is the marginal product curve of labor, and AP_L is the average product curve of labor. The causality of the marginal and total product of labor is: TP_L increases when $MP_L > 0$, decreases when $MP_L < 0$, and is highest when $MP_L = 0$. The marginal returns

Figure 1. The relationship of the marginal product, average product, and total product of labor, and their relationship to LTLP.



Source: MBAlib, http://wiki.mbalib.com/wiki/%E7%9F%AD%E6%9C%9F%E7%94%9F%E4%BA%A7%E5%87%BD%E6%95%B0.

to labor input pass through three stages: incremental, diminishing, and negative returns. When labor inputs increase from zero to L_1, labor inputs are less relative to natural fertility. It is the relatively more natural fertility that increases the returns to each new labor input and the total product of labor fastest. Labor inputs become more relative to natural fertility when they reach L_1 and available natural fertility used by each new labor input changes from increasing to decreasing. This in turn creates the peak of marginal returns to labor. When labor inputs increase from L_1 to L_2 and then to L_3, natural fertility gradually declines to zero, and thus the marginal return to labor falls to zero and the total output of labor reaches its peak.

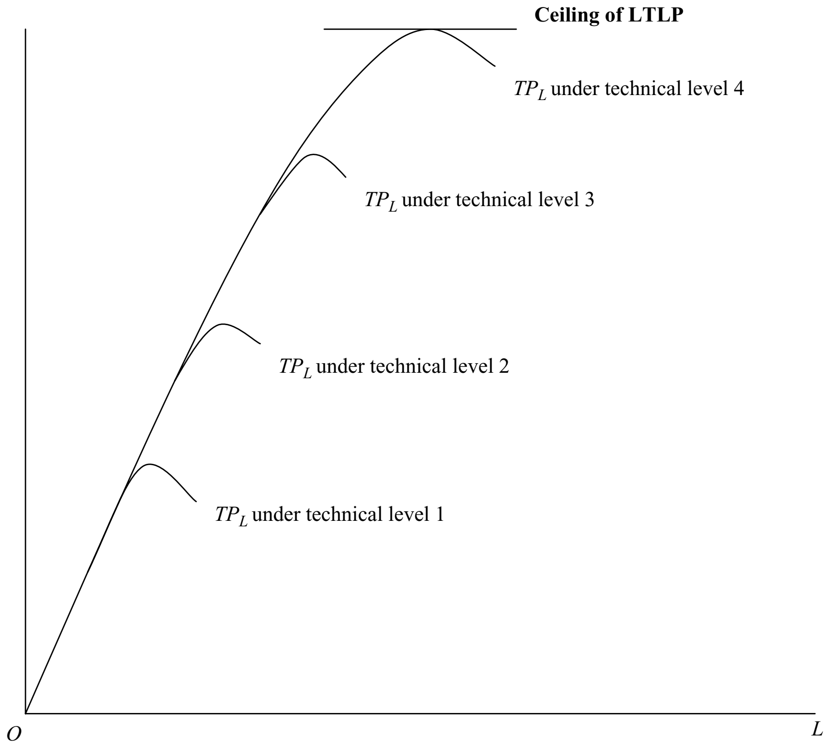
This peak is LTLP under a given level of technology (the relative LTLP as defined above). The farther labor input is from LTLP, the higher the marginal returns to labor. The closer labor input is to LTLP, the lower the marginal returns. When labor inputs go beyond LTLP, marginal returns change from positive to negative and land productivity switches from rising to falling. For example, when crops are watered so much that they are flooded or if too much fertilizer is applied so that the crops are burned, the yield drops because genes have set the water and nutrient absorption limit of the crop. This is the law of nature that once inputs exceed LTLP, their role changes from positive to negative. But if there were no LTLP, marginal returns would not diminish, land productivity would grow in proportion to any increase in labor input, and TP_L would not be a parabola but would slant upward. If this were so, farm outputs would, like industrial outputs, not correlate to the area of land but to labor inputs, and the same amount of labor inputs in 1 ha and 100 ha would result in the same amount of outputs. In this case, there would be no need to struggle for land and to establish land rights.

Figure 1 also shows the causality of the marginal product and average product of labor. AP_L increases when $MP_L > AP_L$ and decreases when $MP_L < AP_L$, and is highest when $MP_L = AP_L$. The three relations tell us that changes in the average product of labor are the result of changes in the marginal product of labor. Changes in the latter in turn are the result of changes in the distance between the amount of labor input per hectare and LTLP, and so changes in the average product of labor are also the result of changes in this distance. When labor inputs increase from zero to L_1 and the marginal product of labor increases, the average product of labor grows fastest and the AP_L curve is steepest. When labor inputs increase from L_1 to L_2 and the marginal product of labor diminishes, the AP_L curve becomes gentle but the average product of labor still grows because $MP_L > AP_L$. When labor input reaches L_2, the average product of labor reaches its apex. Since the average product of labor is labor productivity, labor productivity is highest when $MP_L = AP_L$.

In a country with relatively ample land and few people, labor inputs do not exceed L_2 because more land and fewer people means more food per capita, a lower opportunity cost of land and a higher opportunity cost of labor, and the highest labor productivity. But in a country with little land and a large population, labor inputs tend to reach L_3 because less land and more people means less food per capita, a higher opportunity cost of land and a lower opportunity cost of labor, making the highest possible land productivity the only option. Hence pursuing the highest labor productivity is bound to sacrifice the highest land productivity, and pursuing the highest land productivity is bound to sacrifice the highest labor productivity. The two are contradictory and both sides cannot be satisfied at the same time. In fact, pursuing the highest land productivity in order to ensure people will have enough to eat is a process of approaching LTLP, and thus it is also a process whereby LTLP prevents labor productivity from growing. We can see from the declining AP_L curve that when labor inputs increase from L_2 to L_3, LTLP prevents labor productivity from growing by reducing the average product of labor.

It is difficult for technological progress to solve this problem of overpopulated poor countries, because technology can only tap the potential of natural fertility but cannot cancel LTLP. As shown in Figure 2, new technology can only push up the TP_L curve, but it cannot change its parabolic shape. In other words, it cannot stop the MP_L curve from declining and change its relation to the TP_L curve and

Figure 2. Technological progress cannot break the natural fertility framework and cancel LTLP.



the AP_L curve. Under each new level of technology, it remains the case that TP_L increases when $MP_L > 0$, decreases when $MP_L < 0$, and is highest when $MP_L = 0$; similarly, AP_L increases when $MP_L > AP_L$, and decreases when $MP_L < AP_L$, and thus is highest when $MP_L = AP_L$. Moreover, technological progress in exploiting natural fertility reduces its potential step by step, and the result is less potential for over-populated poor countries to improve labor productivity.

Ester Boserup (1965) argued that population growth and a reduction in land per capita caused agriculture to go through five stages of development: forest fallow, bush fallow, short-term fallow, one cropping, and multiple cropping. In addition, they led to farming techniques and tools to develop from slash and burn cultivation to the use of the hoe, and then to the use of the plow. In short, the more densely a country is populated, the higher it will be on the five stages. Therefore Boserup argued that population growth is not a dependent variable but an independent variable. By reversing Malthusian causality (Malthus, 1989), she made population growth the source of technological progress. Her argument is valid to a certain extent since humans are both the producer in her model and the consumer in the Malthusian model. But her argument cannot overturn the core of the Malthusian model: population grows geometrically but food production grows arithmetically. Her five stages of technological advancement have not changed this difference and allowed overpopulated poor countries to escape from the population trap. For example, China's population pressure made it one of the first countries to develop multiple cropping, but the result was that China's natural fertility potential was exhausted and the country then fell deeper into the population trap. Obviously, there are loopholes in Boserup's theory. North (1981: 60) points out that she provides no theoretical bridge to account for the overcoming of diminishing returns to a fixed factor.

This fixed factor is LTLP. First, population growth is certainly not the ultimate cause of technological progress. Otherwise, technology would advance whenever population grows, and there would be no population trap, and the most populous countries (such as China and India) would have the highest technology and per capita income. Second, technological advances occur only in a specific period, such as the transition from forest fallow to bush fallow. This must be because population growth encounters a formidable obstacle. That obstacle is the LTLP of forest fallow: the relative LTLP defined above. Technological progress, however, can overcome this obstacle. Third, as shown in Figure 2, the five tillage systems cannot break out of the framework of natural fertility and increase the supply of sunlight energy. The only way they can evolve is to use land more intensively and capture a fraction of that fixed supply. This in turn further reduces marginal returns to labor and increases labor costs per kilogram of output. Thus a new farming system can only push up the TP_L curve of the old system, but cannot change its parabolic shape and the causality underlying the marginal product, the average product, and the total product of labor. Under each farming system, the causality is repeated. What makes the cycle is that each system has its own LTLP. Otherwise there would be no next system. In sum, LTLP is both the origin of the difficulty of obtaining food in the Malthusian model, and the origin of technological innovation in Boserup's model. Thus LTLP remedies the defects of the two models, resolves their conflicts, and makes it possible to unify them into a theoretical framework.

LTLP can be considered a law of nature, which is objective and refers to the inherent, natural, and repeated stable relations of the motion of matter. For example, each day the sun rises in the east and sets in the west. Humans cannot create, alter, or destroy the laws of nature, but they can make use of the material and energy flows. The framework of natural fertility is an inherent objective thing of nature. Technological progress in agriculture involves a process of utilizing and developing natural fertility. This process can form relative limits to land productivity under various levels of technology, causing them to approach but not go beyond the absolute LTLP, because technology can only advance within the framework of natural fertility and the framework's maximum limit is the absolute LTLP. LTLP gives rise to four causal relations which are repeated under each level of technology. First, Malthus (1989) did not answer the question of what causes the population to grow geometrically but food production to grow arithmetically. Hence his observation does not constitute a causal explanation but instead is a description of a phenomenon. In fact, by acting as a ceiling, LTLP checks population growth by causing food production to grow arithmetically. Second, Malthus also did not answer the question of what causes diminishing returns; thus his point about diminishing returns is a description of a phenomenon as well. Table 1, Figure 1, and Figure 2 all illustrate that LTLP makes returns diminish and that this phenomenon is repeated under each level of technology; thus diminishing returns are not a law but are the result of the law of LTLP. Because diminishing returns mean rising labor costs per kilogram of output, this rise is also a result of the law of LTLP. Third, Figure 1 shows that it is LTLP that prevents labor productivity from growing by reducing the average product of labor, when labor inputs increase from L_2 to L_3 and the AP_L curve falls. This is why it is difficult for labor productivity and per capita income of overpopulated poor countries to grow. Fourth, LTLP is the critical point where MP_L changes from positive to negative and TP_L from increasing to decreasing—or the benchmark where things develop in the opposite direction when they become extreme. The four casual relations are component parts of the law of LTLP. They exist independently of property rights and markets and cannot be changed by the latter. On the contrary, as we will see, they can change the role of the latter.

Since things develop in the opposite direction when they become extreme, the only way to release the constraints of LTLP on the growth of labor productivity is to reduce labor inputs from L_3 to point O, or for labor inputs per hectare to deviate from LTLP (see Figure 1). This is like a change from the situation today where land is scare and people are numerous to the past when land was plentiful and people were scarce. If land per laborer changes from a decrease to an increase and labor inputs per hectare change in the opposite direction, MP_L and AP_L will shift from falling to rising. The change in land per laborer from falling to rising will also shift the opportunity cost of labor relative to capital from cheap to expensive, the demand for agricultural machinery from a lack to rising, and agriculture from labor intensive to capital intensive. This is achieved by using fertilizer, pesticides, herbicides, and agricultural machinery and energy to drive that machinery. Since industry consumes a great deal of energy to produce these inputs, modern agriculture is an energy agriculture. This is the distinction between an organic economy and a mineral-based energy economy (Wrigley, 1988). It also means that the above reversal cannot occur before industrialization, because land per laborer changes from falling to rising only when many laborers have shifted from the farm to the industrial sector. Moreover, TP_L (total product of labor) will fall when we reduce labor inputs from L_3 to O. This can reduce the food supply and cause famine, thus stopping labor from shifting to industry. Hence William Nicholls (1970: 296) states that until a country succeeds in achieving and sustaining (either through domestic production or imports) a reliable food surplus, it has not fulfilled the fundamental precondition for an industrial revolution. However, a large number of deaths caused by disease before industrialization can also induce the reversal shown in Figure 1. Let me use the Black Death in England in 1348–1349 to illustrate how this catastrophe triggered a reversal and its relation to the English agricultural revolution.

The Law of Limit to Land Productivity and the Agricultural Revolution in England

The agricultural revolution in England has long been debated. For example, Mark Overton (1996a, 1996b) contends that the agricultural revolution—caused by the enclosure movement—occurred in England from 1750 to 1850. Robert C. Allen (1992, 1999) argues that England had two agricultural revolutions: the yeoman's revolution from 1600 to 1700 and the landlord's revolution, which was the same as the revolution discussed by Overton. Gregory Clark (2002, 2007) does not accept that England had an agricultural revolution during its industrial revolution. Alexander Apostolides et al. (2008: 2–3, 28) have pointed out that the source of the debate is the lack of long-term reliable data on agricultural output and productivity in England. Thus some people (such as Allen) use techniques of economics to derive indices of output and productivity from prices, inflate agricultural output after the Black Death, and conclude that there was a yeoman's revolution. Others insist on using incomplete data, but only to estimate individual areas and time points. The different methods of arriving at estimates therefore lead to different views and conclusions. To solve the problem, Apostolides et al. use manorial records from medieval period (1250–1450), probate inventories from the early modern period (1550–1750), and farm accounts from the modern period (1700–1850) to establish a database, and then reconstruct the data using economics techniques. This allows them to provide *the first annual estimates* of English agricultural output and labor productivity during the period 1250–1850.

Apostolides et al. conclude that English agricultural labor productivity increased sharply after the Black Death (1348–1349) and remained at this higher level for the rest of the medieval period. There was a further increase between the mid-fifteenth and mid-sixteenth centuries, with labor productivity remaining at this higher level until the early eighteenth century. These premodern increases in labor productivity were achieved without a substantial increase in output per unit of land. The early eighteenth century saw the start of a continuous upward trend in both agricultural labor productivity and land productivity. In my view this conclusion, despite the valuable data on which it is based, is not a causal explanation but merely a description of a phenomenon. It does not tell us why agricultural labor productivity could grow rapidly when land productivity fell sharply, and why from the early eighteenth century land productivity and labor productivity could rapidly grow together. Without answers to these questions, there can be no answer to how the English agricultural revolution came into being. This in turn is because Apostolides et al. have no theory of LTLP to get to the root of the matter. I have used Figure 1 to show that a sudden fall in population caused by disease can also change land per labor from decreasing to increasing, labor inputs per hectare from increasing to decreasing, and MP_L and AP_L from falling to rising. Thus the reason agricultural labor productivity could grow rapidly when land productivity fell sharply was that when labor inputs per hectare deviated from LTLP, the check of LTLP on growth in labor productivity became progressively weaker and marginal returns on labor shifted from falling to rising. Moreover, the decrease in population also meant that the potential of natural fertility was saved or reserved, so that in the early eighteenth century natural fertility provided sufficient potential for land productivity and labor productivity to rapidly grow together. Let me use the valuable data of Apostolides et al. to verify my deduction from the theory of LTLP.

As shown in Table 2, the Black Death reduced England's population by 46.5 percent, from 4.25 million in 1300 to 2.28 million in 1420. By 1600 the population (4.11 million) was still smaller than in the fourteenth century. The agricultural population fell by 48.5 percent, from 3.34 million in 1300 to 1.72 million in 1420, and thereafter did not exceed the level in the fourteenth century. Thus arable land per agricultural head suddenly increased, and this was realized even when the total amount of arable land decreased (see Table 2). The population decline reduced both the labor force and demand for food to such an extent that much land was left uncultivated—even in 1750 there was less arable land (9.9 million acres) than in the fourteenth century. The fall in the size of the labor force and in the demand

Table 2. Changes in Arable Land, Population, and Arable Land Per Agricultural Head in England, 1250–1871.

Years	Arable land use (millions of acres)				Population			Arable land per A. head* (acres)
	Total arable	Fallow arable	Sown arable	Fallow rate (%)	Total (millions)	Agriculture (millions)	Share (A/T) (%)	
1250	10.30	3.68	6.62	35.70	3.80	3.05	80.26	3.38
1300	10.53	3.77	6.76	35.80	4.25	3.34	78.59	3.15
1380	7.98	3.22	4.76	40.40	2.34	1.77	75.64	4.51
1420	7.09	2.97	4.13	41.90	2.28	1.72	75.44	4.12
1600	8.23	2.00	6.23	24.30	4.11	2.87	69.83	2.87
1700	9.00	1.80	7.20	20.00	5.20	2.78	53.46	3.24
1750	9.90	1.50	8.40	15.20	5.89	2.60	44.14	3.81
1800	10.69	1.20	9.49	11.20	8.62	3.14	36.43	3.40
1830	14.19	1.33	12.86	9.40				
1871	13.83	0.48	13.35	3.50	16.51	3.30	19.99	4.19

Source: Apostolides et al., 2008: tables 2A and 17.
* A. head = agricultural head.

for food not only reduced the area of arable land, but also drove up the fallow rate. All these changes show that as the Black Death reduced the population, the labor force, and the demand for food, the acreage per laborer increased, the opportunity cost of labor relative to land rose, labor inputs per acre decreased, and the potential of natural fertility changed from being fully exploited and hence reduced to being preserved and increased. In short, this is a history of turning back from intensive land use to extensive, contrary to the evolution of farming Boserup posited.

The far-reaching impact of the Black Death was that the share of the agricultural population formed a long-term downward trend, from 79 percent in 1300 to 44 percent in 1750 when the English agricultural and industrial revolutions began. Consequently, after the Black Death arable land per rural head also followed a long-term upward trend, except for the 1600 level, which was below the level in 1300. This not only reversed the pre–Black Death trend that growth in the agricultural population reduced arable land per rural head (see Table 2), but also ensured that the trend in English history would be contrary to that in Chinese history. The share of China's rural population in the total population was still as high as 89.4 percent in 1949 (China Statistical Yearbook, 1990: 89). In particular, the historical transition in which the absolute number of China's rural population began a downward trend and arable land per rural head began an upward trend has appeared only in recent years. Moreover, the share of the agricultural population generally fell concomitant with a sharp increase in grain yields and more surplus grain for the urban population. But in England the fall in the agricultural population began with a sharp drop in the grain yield. This must have been because the decline in the population suddenly expanded the arable land per capita.

As Table 3 shows, halving the English population caused grain yields to fall sharply in the period from 1250–1299 to 1450–1499. Yields did not begin to exceed their pre–Black Death levels until around 1600, then grew steadily, with the highest growth rate in the period 1800–1899.

For one thing, this high growth resulted from increased population pressure. Table 2 shows that in 1600 the English population began to approach its 1300 level and exceeded that level by 1700 (5.20 million) and then tripled by 1871 (16.51 million). For another, the growth stemmed from using the potential of natural fertility that had been saved. For example, the fallow rate fell from 42 percent in 1420 to 24.3 percent in 1600, and then continued to drop and reached 3.5 percent in 1871. Moreover, the total area of arable land did not exceed the level in 1300 until the year 1800 (10.69 million acres), and by 1830 it increased to 14.19 million acres (an addition of 3.5 million acres in thirty years). This means that from 1380 to 1800 not only was much arable land uncultivated, but also there was a large reserve of land that could be made arable quickly. Land in both categories had an adequate store of natural fertility. In short, it was a combination of growing demand for food (itself the result of population growth) with an increasing supply of fertile land

Table 3. Yield Per Acre Net of Seed (Bushels) in England, 1250–1899.

Years	Wheat	Rye	Barley	Oats	Pulses
1250–1299	8.71	10.71	10.25	7.24	6.03
1300–1349	8.24	10.36	9.46	6.60	6.14
1350–1399	7.46	9.21	9.74	7.49	5.86
1400–1449	5.89	10.46	8.44	6.55	5.42
1450–1499	6.48	13.96	8.56	5.95	4.49
1550–1599	7.88	9.21	8.40	7.87	7.62
1600–1649	10.45	16.28	11.16	10.97	8.62
1650–1699	11.36	14.19	12.48	10.82	8.39
1700–1749	13.79	14.82	15.08	12.27	10.23
1750–1799	17.26	17.87	21.88	20.9	14.19
1800–1849	23.16	19.52	25.90	28.37	17.85
1850–1899	26.69	26.18	23.82	31.36	16.30

Source: Apostolides et al., 2008: table 4C.

that led to the English agricultural revolution. In this revolution, grain yields were raised by changing from a pattern of extensive to intensive land use.

But how could the share of agricultural population and labor continue to fall when there was a shift from extensive to intensive land use? The answer is that the number of draft animals greatly increased and hence reduced the need for manpower. Table 4 shows that draft animals increased from 0.7 million in the period 1250–1299 to 1.12 million in the period 1800–1849, with horses in particular increasing very rapidly and eventually entirely replacing oxen. In terms of the number of draft animals and livestock units per 100 sown acres, English agriculture went through three phases: before the Black Death draft animals and livestock were relatively numerous, after the Black Death the number fell, but during the agricultural revolution the number reached its high point. Obviously, the fall in number of draft animals after the Black Death is consistent with a decline in the area of arable land and grain yields and a rise in the fallow rate. I have stressed that a decrease in population can lead to an increase of land per laborer, a decrease in labor inputs per acre, and a shift from intensive to extensive land use. This also applies to draft animals, so that the fall in number of livestock units per 100 sown acres after the Black Death confirms that the plowed area per animal increased and animal power inputs per acre decreased. Note, however, that marginal returns to each unit of horsepower inputs (a horse plowing one day) and annual grain yields produced by each horse (see MP_L and AP_L in Figure 1) actually increased. This was because when horsepower inputs per acre changed from being close to being distant from LTLP, the check of LTLP on growth in annual grain yield per horse (its "labor productivity") decreased, so marginal returns to per unit of horsepower inputs rose. These logics were all reversed when population growth

Table 4. Sown Structure, Fallow Rate, and Number of Draft Animals in England, 1250–1871.

Years	Sown structure (%)				Fallow rate (%)	Years	Working animals (millions)		Livestock units per 100 acres*
	Wheat/ barley, rye/ potatoes	Oats	Pulses	Other crops			Horses	Oxen	
						1250–1299	0.24	0.46	10.63
1250	56.3	40.3	3.3	0.0	35.7	1300–1349	0.24	0.37	10.38
1300	55.7	38.8	5.5	0.0	35.8	1350–1399	0.19	0.26	9.68
1380	59.4	32.6	8.2	0.0	40.4	1400–1449	0.23	0.14	8.50
1420	59.4	31.7	8.7	0.0	41.9	1450–1499	0.23	0.14	8.01
1600	60.5	19.6	9.1	10.9	24.3	1550–1599	0.25	0.17	7.73
1700	55.4	15.0	12.8	16.8	20.0	1600–1649	0.30	0.17	8.10
1750	40.4	20.4	11.0	29.3	15.2	1650–1699	0.40	0.11	8.47
1800	42.5	20.3	8.2	30.6	11.2	1700–1749	0.63	0.13	12.11
1830	44.8	12.4	4.7	40.4	9.4	1750–1799	0.87	0.04	13.20
1871	42.9	10.9	6.7	42.4	3.5	1800–1849	1.12	0.00	13.50

Source: Apostolides et al., 2008: tables 2A, 2B and 6A.
* Livestock units are derived from comparing different animals on the basis of their relative feed requirements.

picked up steam and turned the pattern from extensive to intensive land use, and hence the use of livestock units per 100 sown acres reached its peak during the agricultural revolution. Although marginal returns to per unit horsepower inputs fell, farmers' labor productivity and marginal returns to a work day rose, because horsepower replaced manpower, expanding the area of land per farmer and reducing manpower inputs per acre.

What made it possible to add draft animals was an increased output of feed crops. In the sown structure (see Table 4), wheat, rye, barley, and potatoes were consumed by humans, and oats and pulses were consumed by both humans and working animals. Before the Black Death, 70 percent of oats were consumed by humans and 30 by animals. But the ratio became 50:50 in 1600 and 30:70 in 1800. More than half of pulses were also consumed by draft animals. Thus a long trend sparked by the Black Death involved a change whereby oats and pulses, which once had been mainly eaten by humans, mostly became animal feed (see Apostolides et al., 2008: 16–19). Before the Black Death, the sown share of oats was 40.3 percent in 1250, much higher than that of wheat, rye, barley, and others. But the share fell to 10.9 percent in 1871, because oats were rarely consumed by humans, and because other crops, mainly turnips and clover, were introduced and planted around 1600, and finally replaced the oat dominance in feed. The sown share of other crops became largest in 1871 (42.4 percent). This changed the sown acreage devoted to fodder for draft animals from less than 14 percent in 1250 (30 percent of the oats sown share plus 50 percent of the pulse sown share) to about 54 percent (70 percent of the oats sown share plus 50 percent of the pulse sown share and the sown share of other crops). However, the expansion of the sown share of other crops from zero in 1420 to 42.4 percent in 1871 was not at the expense of the area sown in grain crops, but rather was the result of a combination of a reduction in the fallow rate, which fell from 41.9 percent to 3.5 percent, and the spread of the Norfolk four-crop rotation system. What this system did was to change the way soil fertility was restored: land was no longer left fallow for a year, but instead was planted in turnips and nitrogen-fixing clover, and was fertilized with livestock manure. Moreover, crops were rotated: on any particular field, the first year wheat was sown, followed by turnips in the second year, barley or oats in the third year, and nitrogen-fixing clover in the fourth. The Norfolk rotation system did not involved a reduction in the sown area of wheat, rye, barley, and so on. Instead, it involved a more intensive use of land. Hence the ultimate source of the increase in forage crops and draft animals during the English agricultural revolution was the low efficiency of land use before the revolution; in other words, land use that was far from LTLP.

Table 5 reveals more about the impact of LTLP on the labor costs of grain and the average annual growth rate of agricultural labor productivity (AAGRALP) in England. From 1250 to 1300, when the population increased, the number of agricultural families rose from 680,000 to 740,000 and arable land per family decreased from 15.21 to 14.18 acres. This increased the days worked per family, from 315 to 381, and it also increased wheat yields. However, AAGRALP was negative, −0.27 percent in the years 1265–1300 and −0.32 percent in years 1300–1348. Wheat yield per working day (WYPWD) also dropped from 0.42 to 0.31 bushels, indicating diminishing returns to labor and a rise in labor costs per bushel. When the Black Death reduced the population and the number of agricultural families from 740,000 in 1300 to 380,000 in 1420, arable land per family increased from 14.18 to 18.54 acres. This reduced the days worked per family per year from 381 to 266, and also substantially reduced the yield of wheat. But AAGRALP became positive, respectively 0.61 percent in the years 1348–1400, 0.08 percent in 1400–1450, and 0.48 percent in 1450–1475. WYPWD in particular rose rapidly, from 0.31 bushels in 1300 to 0.46 bushels in 1380, revealing increasing returns to labor and a significant fall in labor costs per bushel. Clearly, the reason for the decline in the labor costs of grain and growth in labor productivity and per capita income was that the area of arable land determined the amount of natural fertility, such as sunlight, rainfall, and so on. So it was that the expansion of land per laborer increased natural fertility per laborer and caused labor productivity and per capita income to grow. That expansion and more natural fertility absorbed by each bushel of wheat also

Table 5. Impact of LTLP on Labor Costs of Grain and the Average Annual Growth Rate of Agricultural Labor Productivity (%) in England, 1250–1871.

Years	Agricultural families (millions)	Arable land per family (acres)	Wheat yield (bushels per acre)	Wheat yield (bushels per family)	Days worked per family	Wheat yield per day worked (bushels)	Years	Labor productivity
							1265–1300	−0.27
							1300–1348	−0.32
1250	0.68	15.21	8.71	132.48	315	0.42	1348–1400	0.61
1300	0.74	14.18	8.24	116.80	381	0.31	1400–1450	0.08
1380	0.40	20.30	7.46	151.40	331	0.46	1450–1475	0.48
1420	0.38	18.54	5.89	109.20	266	0.41	1475–1555	−0.05
1600	0.64	12.92	10.45	134.96	404	0.33	1555–1600	−0.16
1700	0.62	14.58	11.36	165.63	405	0.41	1600–1650	−0.11
1750		17.15	13.79	236.43			1650–1700	0.64
1800	0.69	15.30	17.26	264.08	473	0.56	1700–1750	0.70
1830	0.73		23.16		539		1750–1800	0.37
1871		18.86	26.69	503.24			1800–1850	0.63

Source: Apostolides et al., 2008: tables 2A, 4C, 18, and 19A. Apostolides et al. assume that the average family consisted of 2 adults and 2.5 children. To simplify the analysis, I assume that all arable land was used to grow wheat.

reduced labor inputs per acre and labor costs per bushel of wheat. In short, it was not that the English farmer became more efficient than his pre–Black Death era predecessors, but instead it was the expanded arable land per farmer that caused labor inputs per acre to deviate from LTLP, and thus labor costs of grain to fall and labor productivity and per capita income to grow.

LTLP did not stop changes in the labor costs of grain and AAGRALP. When arable land per family declined from 18.54 acres in 1420 to 12.92 acres in 1600, AAGRALP became negative again, respectively −0.05 percent, −0.16 percent, and −0.11 percent in the years 1475–1555, 1555–1600, and 1600–1650. WYPWD also fell, while labor costs per bushel of wheat began to rise. In contrast, when arable land per family increased from 12.92 acres in 1600 to 14.58 acres in 1700, 17.15 acres in 1750, 15.3 acres in 1800, and 18.86 acres in 1871, AAGRALP became positive: 0.64 percent, 0.70 percent, 0.37 percent, and 0.63 percent in the years 1650–1700, 1700–1750, 1750–1800, and 1800–1850 respectively. In this period the positive growth in labor productivity and increasing returns to labor were highly correlated with the Norfolk rotation system in terms of the ensuing reduction of labor inputs per acre achieved through increasing the number of draft animals. Thus it was this increase that caused labor inputs per acre to deviate from LTLP, marginal returns to labor to rise, and labor costs of grain to fall.

Table 6 summarizes the English agricultural output structure. The high share of the pastoral sector reflects the fact that the area of England's meadows, pastures, and commons was at least twice the area of its arable land (see Allen, 2005: table 1). Hence agricultural land per family was at least three times the area of arable land per family (see Table 5). The plentiful grassland thus was the source of the rising share of the pastoral sector after the Black Death: the Black Death had less effect on pastoral products (which were land intensive) but largely reduced arable products (which were labor intensive) by reducing the labor force. The long-term change in the arable sector was that the shares of wheat, barley, and pulses rose, and the shares of rye and oats fell. But the shares of all arable products declined sharply after the Black Death. Thus in 1420 the share of the arable sector in total agricultural output dropped to its lowest point (25.9 percent).[2] Long-term changes within the pastoral sector included increases in the share of dairy (milk, butter, and cheese) and beef and hay, and decreases in the share of pork, mutton, wool, and hides. But in the short term, the share of mutton increased rapidly after the Black Death, and in 1420 its share (29.1 percent) exceeded that of all other livestock and crop products. This not only led to the share of pastoral products in agricultural output reaching a record peak in 1420 (74.1 percent), but also allowed the English to eat more meat, improving their standard of living. But this change was a result of historical retrogression, because the growth in the number

[2] Potatoes were not involved in this history because they were not introduced until after the discovery of America.

Table 6. English Agricultural Output Weights in Current Prices, 20-year Averages (%), 1300–1850.

A. Arable products

Year	Wheat	Rye	Barley	Oats	Pulses	Potatoes	Total products
1300	20.1	2.5	6.7	6.1	1.1	0.0	36.4
1380	17.7	2.0	13.2	5.8	1.5	0.0	40.2
1420	11.8	1.8	8.3	2.9	1.1	0.0	25.9
1600	12.9	4.6	6.4	2.1	2.2	0.0	28.2
1700	22.5	3.4	11.2	1.0	3.6	0.0	41.8
1800	24.9	0.4	9.0	4.8	3.0	2.8	44.8
1850	28.6	0.3	9.6	2.9	2.5	6.7	50.6

B. Pastoral products

Year	Dairy	Beef	Pork	Mutton	Hay	Wool	Hides	Total products
1300	8.1	2.2	21.4	13.9	0.7	15.8	1.3	63.6
1380	6.4	2.0	11.9	19.4	0.9	18.6	0.7	59.8
1420	4.6	1.3	14.9	29.1	1.6	20.7	1.9	74.1
1600	12.5	3.4	31.9	10.6	1.2	10.3	1.9	71.8
1700	13.9	3.8	19	10.6	3.1	6.5	1.4	58.2
1800	18.5	5.8	10.4	8.0	8.3	3.4	0.8	55.2
1850	19.4	4.2	9.8	5.4	7.4	2.7	0.5	49.4

Source: Apostolides et al., 2008: tables 16A and 16B. Arable products excludes other crops (turnips, clover, etc.) because they were converted into pastoral products. Oats and pulses for animal feed are also not included.

of sheep was made possible by allowing arable land to return to grassland. According to Boserup's view that population growth causes agriculture to develop by stages, England was still at a backward stage when its share of pastoral products in agricultural output was as high as 63.6 percent in 1300, and England became even more "backward" when the Black Death raised this share to 74.1 percent in 1420 by halving the English population.

But according to the law of LTLP, a retreat from farming to animal husbandry reduces labor inputs per acre and the check of LTLP on the growth of labor productivity, so marginal returns on labor, labor productivity, per capita income, and the standard of living all change from falling to rising. In England, these inverse changes, with abundant grassland, kept the share of the pastoral sector in agricultural output high from 1300 to 1850. The current price share is affected by both the trend in the relative price of pastoral to arable products, and the real growth rates of the two sectors. (Note that the share is in current prices.) Since before

1550 there was no long-run shift in the relative price ratio, the rising share of the pastoral sector indicated its real higher growth rate than that of the arable sector. From 1550 on, arable and pastoral output grew at similar rates in real terms. This resulted in a declining share of the pastoral sector in current price output because of a fall in the relative price of pastoral products (Apostolides et al., 2008: 25). This decline in prices meant that there was a greater supply of pastoral products relative to arable products, so that in real terms the share of pastoral output in agricultural output was still close to 70 percent during the agricultural revolution. This is confirmed by the expanding dairy share from 1600 to 1850, which in turn was a result of the expanding hay share because hay was the principal feed during winter. The share of hay grew ten-fold from 1300 to 1850; this growth was especially rapid during the agricultural revolution. Hay was no doubt grown on England's abundant grasslands. Its rapid increase during the agricultural revolution was evidence that the enclosure movement entailed a change from extensive to intensive use of grasslands.

Using the law of LTLP to explore the causes and effects of the agricultural revolution in England, we have seen that the revolution was a result of a regression from intensive to extensive land use and then a return to intensive use. This is confirmed by the fact that the area of arable land, livestock units per 100 sown acres, number of days worked per family per year, and grain yield per acre all rapidly fell after the Black Death, and then all rapidly rose during the agricultural revolution, as well as the fact that there was an inverse movement in the fallow rate. Table 7 shows that from 1250 to 1700 the pastoral sector grew 0.24 percent annually and the arable sector grew 0.03 percent annually. It was the growth of the former that led to the growth in agricultural output and labor productivity by 0.13 percent and 0.15 percent respectively. But this was the result of the regression in land use: the Black Death halved the English population and labor force, leading to arable land being transformed into grassland, farming to degrade into animal husbandry, and the share of the latter in agricultural output to rise and remain at more than 60 percent. The expansion of grassland and the nature of the pastoral sector where labor inputs per acre were much less than required for planting in turn reduced the check of LTLP on the growth in labor productivity, and thus the sector's output could grow by 0.24 percent annually from 1250 to 1700.

In the years 1700–1850 there was a return to intensive land use. If we look at the average annual growth rate (AAGR) in 1700–1850 and compare it with the rate in 1250–1700 (see Table 7), we see that there was growth across the board: the arable sector grew by 0.86 percent, 28.67 times greater than the preceding stage; the pastoral sector by 0.58 percent, 2.42 times the preceding stage; agricultural output by 0.70 percent, 5.38 times the preceding stage; agricultural labor productivity by 0.58 percent, 3.87 times the preceding stage. At first glance it may seem that the explosive growth of the arable sector led to the high growth of agricultural output and labor productivity. But in fact this remarkable increase was a result of the Norfolk rotation system, which combined farming with animal husbandry. This

Table 7. Growth in English Agricultural Output and Labor Productivity in Constant Prices (% per annum), 1250–1850.

Years	Arable sector	Pastoral sector	Total agriculture	Agricultural labor productivity
1250–1700	0.03	0.24	0.13	0.15
1700–1850	0.86	0.58	0.70	0.58
1250–1850	0.23	0.32	0.27	0.26

Source: Apostolides et al., 2008: tables 15 and 18.

combination, with its increase in the number of draft animals and a growth in fodder crops, involved replacing manpower with animal power, and this in turn led to growth of arable output and labor productivity. The Norfolk rotation system was a way of dealing with the past high fallow rate. Grain yields could grow rapidly because the past sharp decline of labor inputs and yield per acre caused the natural fertility of arable land to be preserved. Moreover, the pastoral sector grew faster than in the past because the enclosure movement privatized commons, improved the quality of grasslands, and transformed the use of such lands from extensive to intensive. In the final analysis, then, the agricultural revolution occurred in England because its past land use was inefficient and far from LTLP. Table 7 shows that from 1250 to 1850, because of the nature of the pastoral sector wherein labor inputs per acre are low, the AAGR of that sector was the highest (0.32 percent) and its contribution to the AAGR of agricultural output (0.27 percent) and labor productivity (0.26 percent) was the largest. From 1250 to 1850 the AAGR of arable output could reach 0.23 percent because its high growth from 1700 to 1850 was averaged over six hundred years. This raises two questions: If the population of England had not been halved by the Black Death from 1348 to 1349 but continued to grow, would there have been a reversion from intensive to extensive land use and would land productivity have been far from LTLP? Would England have had an agricultural revolution in the years 1700–1850?

Comparing Land Productivity in China and England

In comparing land productivity in China and England, one can begin by comparing the amount of arable land per capita of the rural population. But since we lack long-term data on China's rural population, we can only compare China's arable land per capita of the total population with arable land per capita of the English agricultural population. Such a comparison is valid since the rural share of China's total population was as high as 89.4 percent as late as 1949 (China Statistical Yearbook, 1990: 89). Unlike England, in China total population has grown continuously, and its high rural share has never followed a downward trend until recent decades. Table 8 shows that the continued population growth halved China's arable land per

Table 8. A Comparison of Arable Land Per Agricultural Head in China and England, 1400–1957.

China				England		China: England	
Years	Population (millions)	Arable land (millions of mu)	Land per capita (mu)	Years	Arable land per A. head*	Years	
1400	72.5	370	5.1	1250	20.5	1400–1420	1:4.91
1600	160	500	3.13	1300	19.14	1600	1:5.56
1770	270	950	3.52	1380	27.37	1750–1770	1:6.57
1850	410			1420	25.02	1871–1873	1:7.35
1873	350	1,210	3.46	1600	17.41		
1893	385	1,240	3.22	1700	19.65		
1913	430	1,360	3.16	1750	23.11		
1933	500	1,470	2.94	1800	20.67		
1957	647	1,678	2.59	1871	25.44		

Source: China's population and arable land are from Dwight H. Perkins, 1984: table 2-1; England's arable land per agricultural head from Table 2 of this article and acres are converted into Chinese mu (1 acre = 6.07 mu).
*A. head = agricultural head.

capita, from 5.1 mu in 1400 to 2.59 mu in 1957.[3] This reduced the area of land used per farmer to grow grain for the urban population, thereby preventing the share of the urban population from rising. In contrast, arable land per capita of the English agricultural population followed a long-term upward trend after the Black Death, meaning that the area of land used per farmer to grow grain for the urban population expanded, which in turn made possible the expansion of the share of the urban population. That China was trapped in a vicious cycle while England enjoyed a virtuous cycle is confirmed by the growing gap of arable land per rural head between China and England: about 1:4.91, 1:5.56, 1:6.57, and 1:7.35 in years 1400–1420, 1600, 1750–1770 and 1871–1873 respectively (see Table 8). But this contrast was still very one-sided because England's grasslands were at least twice its arable land and were also an important source of food. Thus, in the above four periods the gap of agricultural land per rural head between China and England should be expanded to around 1:14.7, 1:16.7, 1:19.7, and 1:22.1 respectively. This in turn further aggravated China's vicious cycle and promoted England's virtuous cycle.

As Philip Huang (2002) stresses in his comparison of development in China and England in the eighteenth century, China's agriculture was a crop-only system while in England arable was rotated with pasture and, within the arable,

3 One mu is about a sixth of an acre.

animal-feed crops were rotated with grains for human consumption. Liang Fangzhong (1980) further confirms that China's agriculture was actually a single farming system under multiple cropping. In the years 1077–1080, the 19.21 percent of the grain tax was levied in the summer and 80.89 percent in the autumn. From the perspective of area, the Northern Song dynasty levied the summer and autumn grain tax on all of its 19 administrative provinces (see Liang, 1980: B-table 9–10). Hence at least from the year 1000 onward, a multiple cropping system was already common in south China. The system had developed much earlier in north China, but the climate dictated that in some areas in the north two crops a year could be grown while in others three crops in two years was possible. Ho Ping-ti's study (Ho, 2000 [1959]) also makes it clear that double cropping of rice had spread throughout south China around the year 1000. In Matteo Ricci's lifetime (1553–1610), peasants in the Pearl River Delta even managed to raise three crops of rice a year. In short, when English agriculture was still based on grazing and supplemented by farming, Chinese agriculture had evolved to a single farming system under multiple cropping. Because of China's population growth, grassland and fallow land had long been eliminated, and it was only by relying on a single farming system under multiple cropping that the food needs of the population could be met. A look at the disparity between the rice yield of southern China and the wheat yield of Norfolk, England, will further illuminate this issue.

There are several reasons why I have chosen to use the data of Dwight Perkins (1984) and Mark Overton (1996) to compare rice yields of several provinces in south China with Norfolk's wheat yields. First, the two sets of data are from the same historical period. Second, Norfolk's planting system was the most developed in England. Although south China developed agriculture much later than north China, it became China's most developed farming region. Third, Perkins' data are reliable because his estimate of rice yields in south China was based on a large number of samples. He also estimated the grain yields in the northern provinces of China, but had less success there because the northern historical record was incomplete and because more kinds of grains were grown in the north than in the south, which made the number of samples of each kind of grain far smaller

Table 9. Changes in Wheat Yields in Norfolk (in both Chinese and English units of measurement).

Years	1250–1349	1350–1449	1584–1640	1660–1739	1801	1836	1854
Bushels/ acre	15	12	15	15	20	23	30
Jin/mu	134.51	107.61	134.51	134.51	179.35	206.25	269.02

Source: Overton, 1986: table 1; Overton, 1966b: table 3.
Note: The jin/mu figures have been calculated from the data in Overton's tables, using the following values: 1 acre = 6.07 mu; 1 kg = 2 jin; 1 bushel of wheat = 27.216 kg = 54.432 jin. Thus the formula for the wheat yield in 1854, for example, is 30 × 27.216 × 2/6.07 = 269.02 jin/mu.

Table 10. Changes in Rice Yields in Several of China's Southern Provinces (jin/mu), 960–1899.

Years	Zhejiang	Jiangsu	Jiangxi	Hunan	Hubei	Guangdong	Guangxi	Yunnan
960–1279	402	326			255			
1280–1367	473	347						
1368–1499							300	
1500–1599		450	400	288	250	416		
1600–1699	600	450	400	288	249	512		380
1700–1799		550	423	321	267	447	438	380
1800–1899		501	423	467	555	1,037		

Source: Perkins, 1984 [1969]: table 2-4.

than the sample for southern rice. Thus we face the question of whether southern China's rice yield and Norfolk's wheat yield are comparable. Despite this problem, Perkins' and Overton's data can still be used to compare the different trends in grain yields between China and England. As shown in Table 9, Norfolk's wheat yields in most years indeed far exceeded England's average wheat yields (see Table 3), but the trend was consistent with both. The former also fell from the level of the pre–Black Death period 1250–1349 (down from 15 to 12 bushels), and did not grow in the five hundred years from 1250 to 1739 (no more than 15 bushels, thus the potential soil fertility accumulated), but doubled in the subsequent hundred years of agricultural revolution.

In contrast, rice yields in China's southern provinces (see Table 10), unlike grain yields in post–Black Death England, neither declined dramatically nor stagnated for five hundred years, but continued to grow under population pressure. This was also the trend in northern China that Perkins (1984 [1969]: 24–25) saw from his incomplete data. Of course, there were exceptions. Between 1700–1799 and 1800–1899, for instance, the rice yield in Jiangsu decreased by 49 jin when the Taiping uprising (1851–1864) reduced Jiangsu's population and rice yield.[4] But between 1700–1799 and 1800–1899, rice yields in Hunan and Hubei increased by 45 percent and 108 percent respectively. Could the growth of Hubei have been boosted by an agricultural revolution like that in England? The answer lies in the law of LTLP. From 1700 to 1799, Hunan's rice yield was 321 jin, much lower than the 550 jin in Jiangsu. This put it far from LTLP, indicating that it had the potential to increase. But after growing 45 percent, it was still lower than Jiangsu's level in the years 1800–1899. Hubei's rice yield was even lower than Hunan's from 1700 to 1799, and it was even further from LTLP and had a greater potential than Hunan—in fact the yield in Hubei rose by 108 percent. Between 1700–1799 and 1800–1899 Guangdong's rice

[4] One jin is about half a kilogram.

yield even increased by 132 percent, suggesting it might have been the center for an agricultural revolution. But, according to Perkins, the apparent increase in the yield in Guangdong was due to the fact that most of the data in Guangdong during this period came from counties with above the provincial average yield. Of all the provinces of China, the grain yield in Zhejiang was number one not only as early as the Song dynasty (960–1279), but was still the leader in the Mao era (see Zhongguo nongcun tongji nianjian). Time has proven the accuracy of Perkins' data, although they are not complete.

Table 11 shows the gaps (in terms of multiples) between rice yields in southern China and wheat yields in Norfolk. The gap began to narrow from 1700 to 1899, because Norfolk's wheat yields began to rise rapidly only in the period 1750–1850. The data in Table 11 show that China's grain yields were growing under population pressure, while England's grain yield grew only during its agricultural revolution, and thus the gap between the two was widening from 1280 to 1699. This period was a time when China's population was increasing but England's was decreasing. The convergent period 1700–1899 was also a time when population pressures increased in both countries. This convergence suggests that, under normal conditions, rice yields should be about twice the yield of wheat.

However, the above comparison is not a comparison of land productivity, because the grain yield per sown acre is related only to the sown area, regardless of the area of arable land, and thus is not a measure of land productivity (Overton 1996: 7). For example, when the fallow period is long, the yield of the sown area is high but the annual yield of all arable land (land productivity) is low. As mentioned, although the Norfolk four-crop rotation pattern intensified the use of land, it was still an inter-year rotation system and not a multiple cropping system. It began to be popular only around 1700 (England's fallow rate was still as high as 9.4 percent in 1830; see Table 2), whereas China had extensive multiple cropping by at least around 1000 AD. Taking into consideration China's multiple cropping and assuming that the summer grain crop of Jiangsu, Jiangxi, Hunan, Hubei, and Guangdong was wheat and its yield was half that of autumn rice, land productivity would have been 2.79 times, 2.36 times, 2.61 times, 3.09 times, and 5.78 times respectively Norfolk's land productivity in the English agricultural revolution period 1800–1899. If, on the other hand, one assumes that both the summer and autumn grain crops were rice and their yields were equal, then the multiplier differences would have been 3.72 times, 3.14 times, 3.48 times, 4.12 times, and 7.7 times. In short, the agricultural revolution in England can be called a revolution when viewed in terms of past land productivity, but it was not a revolution when compared to China's land productivity in the same period.

But China's higher land productivity came at the price of much lower returns to labor. Data provided by Philip Huang (2002: 509) show that in the Norfolk four-crop rotation system, wheat was the most labor intensive, with labor inputs of 25.6 days per acre, or 4.22 days per Chinese mu. The ratio of the four crops of wheat, turnips, barley, and clover was 4:3:3:1—or 4.22 days, 3.17 days, 3.17 days, and 1.05

Table 11. Multiples of Rice Yields in Provinces in Southern China to Norfolk's Wheat Yields, 1280–1899.

Years	Zhejiang to Norfolk	Jiangsu to Norfolk	Jiangxi to Norfolk	Hunan to Norfolk	Hubei to Norfolk	Guangdong to Norfolk	Guangxi to Norfolk	Yunnan to Norfolk
1280–1367	3.52	2.58						
1368–1499							2.79	
1500–1599		3.35	2.97	2.14	1.86	3.09		
1600–1699	4.46	3.35	2.97	2.14	1.85	3.81		2.83
1700–1799		3.07	2.36	1.79	1.49	2.49	2.44	2.12
1800–1899		1.86	1.57	1.74	2.06	3.85		

Source: Tables 9 and 10 of this article. To correspond to the period, the data from Norfolk in 1836 have been removed.

days per mu. Adding up the days and then dividing by four results in an average of 2.9 days per mu per year. In China's Yangzi River Delta, winter wheat was the least labor-intensive crop, requiring 7 days per mu of one male laborer's work. The labor input per mu of rice was 10 days. Thus if the first crop was winter wheat and the second late rice, the average investment was 17 days per mu per year, equal to 5.9 times the input of labor in the Norfolk rotation system. If the first crop was early rice followed by late rice, which was more common, the average investment was 20 days per mu per year, 6.9 times the input of labor in the Norfolk rotation system. Hence, the favorable ratio of China's land productivity to England's was at the price of a higher ratio of labor inputs, indicating that the labor costs per kilogram of grain were much higher in China than in England.

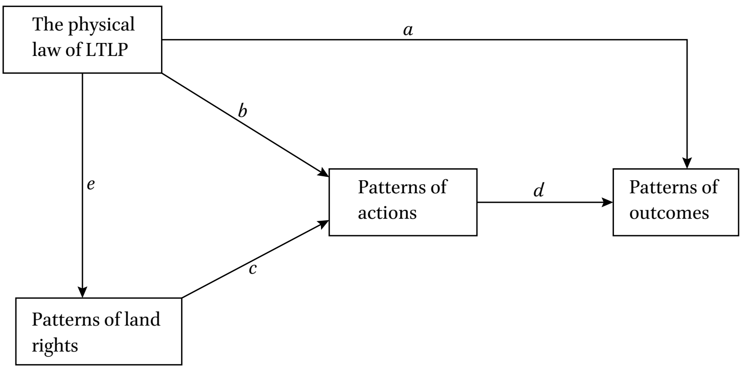
But in turn, the labor costs of grain were higher in England than in the New World countries. As noted above, England's grain yields doubled during its agricultural and industrial revolutions. When the grain yield was rapidly growing and approaching LTLP, this limit was bound to cause returns to labor to diminish, the cost and price of food and wages to rise, and industrial profits and capital accumulation to fall correspondingly. To reverse this trend, which hindered industrialization, England in 1846, in line with Ricardo's comparative cost theory, abolished the law that restricted the import of grain, and allowed the low-cost grain of the United States, Canada, Australia, Argentina, and others, to be imported. The result was that England changed from being a food exporter to an importer during its agricultural revolution. The free trade policy and competition from cheap foreign grain caused food prices in England to drop for twenty years, but also drove small and medium-sized farms into bankruptcy and propelled the farming industry into a long recession after 1870. England thus enjoyed high growth in its agricultural revolution for about a century. Nonetheless, this growth has still been regarded as the classic agricultural revolution, because many people believe that it was this revolution that caused the industrial revolution to occur first in England. Clark (2002, 2007), however, does not subscribe to this view, precisely because the accelerated expansion of the urban population and demand for food, the rise in wages, the fall in industrial profits and accumulation, and so on, were all solved by foreign low-cost grain. Allen (2005: 4) also notes that "increased food imports were critical in feeding the urban population during the industrial revolution: in an important sense, labour release 'fed on itself' as the released labour produced manufactures that were exported to pay for the food it ate. . . . For these reasons, the share of the English population in agriculture fell much more rapidly than agricultural labour productivity increased." Obviously, the low-cost surplus grain of the United States, Canada, Australia, and Argentina not only greatly helped promote England's shift to the industrialized stage, but also meant that these New World countries had never experienced the population trap stage, and therefore could directly transform from the pre-population trap stage to the industrialized stage because the two stages were not in logical conflict. Let me use the law of LTLP to establish a dynamic three (physical, economic, and institutional) worlds' land-use model to illustrate the logical relationships in detail.

Inverse Logics Created by the Law of Limit to Land Productivity

Because farmland can be simultaneously a part of nature, the property of landowners, and a means of production used by tillers, its use takes place in a tri-world system: 1) the relation of population numbers to land resources and the physical laws of nature that govern crops' growth belong to the physical world; 2) the property relations among people belong to the institutional world; and 3) tillers' actions in using land according to cost/return ratios and the outcomes, to the realm of the economic world. The institutional world's land rights pattern is the result of the physical world because human-to-human property relations arise from the physical relation of population to land resources. The economic world's pattern of action and its outcomes are the joint results of the physical and institutional worlds because the physical laws of nature and land-rights patterns jointly govern how land is used. Physical law here specifically refers to the law of LTLP, especially in the sense that things develop in the opposite direction when they become extreme.

Figure 3 illustrates the inner links of the land use tri-world system. LTLP and patterns of land rights jointly affect patterns of action, which combine with LTLP to produce outcomes. The hard restraints of LTLP affect outcomes in two ways: one path leads via patterns of action (lines *b* and *d*); the other path, line *a*, affects outcomes directly and independently of human choice. Patterns of land rights, however, only indirectly affect outcomes via lines *c* and *d* because they are soft restraints and work only via human choices and actions. Therefore, the three-worlds land-use model has four relations: 1) LTLP directly affects outcomes (line *a*) with diminishing returns as its result and evidence; 2) LTLP restricts actions (lines *b* and *d*) by fixing cost/return ratios; 3) private land rights can create both positive incentives to act if returns exceed costs and negative incentives if costs exceed returns (lines *b*, *c*, and *d*); 4) private land rights harm others and the general welfare if they mismatch LTLP (line *e*). For example, the exclusive right to land threatens the survival of new additions to a village's population (Pei, 2004, 2008) and

Figure 3. The system of three worlds of land use.



Source: Pei, 2014: 49.

reduces the food supply by maintaining the inverse relation of farm size to yield per hectare: that is, low in big farms, which seek more marginal returns to labor, and high in small farms, because survival forces them to exploit their own labor (Chayanov, 1925).

From the perspective of time, I use the Malthusian population model (1989) to depict the different stages of development before, in, and after the population trap. The model can be written as $AY > NS \rightarrow AY = NS$, or $AY/N > S \rightarrow AY/N = S$. The area of arable land (in hectares) is A and Y the yield of grain per hectare (kg/ha); AY is the grain supply; N is number of heads; and S the subsistence level in terms of grain (kg/head). NS is the demand for grain. Malthus held that growth in N can lead any country from the stage of $AY/N > S$ (everyone has a farm surplus) to the stage of $AY/N = S$ (no one has a farm surplus), because A and S are constants, and N and Y are variables to growth over time, and what turns $AY/N > S$ to $AY/N = S$ is geometric growth in N (1, 2, 4, 8, 16 . . . every twenty-five years) vs. arithmetic growth in Y (1, 2, 3, 4, 5 . . . every twenty-five years). Put another way, the denominator increases more rapidly than the numerator. But Malthus could not account for this divergence and diminishing returns. We know that, acting as a ceiling, LTLP checks N from growing quickly by causing returns to diminish and Y to grow arithmetically. If we use Figure 3 and its four relations to sum up, what Malthus studied are only the *results* of the first relation: the end of line *a*. What he missed is LTLP: the outset of line *a*.

The North/Thomas (1973: 8) model also misses LTLP, and uses the neoclassical assumption of self-interested man to claim that "given the described assumption about the way people behave, economic growth will occur if property rights make it worthwhile to undertake socially productive activity." This claim only has lines *c* and *d* of Figure 3: private property rights via line *c* create incentives to act; the incentives to act via line *d* cause growth. This one-way model is unbalanced, like a car without brakes. It only takes into consideration the third relation shown in Figure 3, but at the same time denies that LTLP can affect outcomes via line *a* and check actions via line *b*. It implies that humans can control both their actions and the outcomes of their actions. However, in reality although humans can control their actions, they cannot control the outcomes of their actions. For example, diminishing returns to labor are the result of actions that humans cannot control but can only accept. Another of North's (1981: 17) one-sided claims is also unsupportable but has misled many reformers: "A theory of the state is essential because it is the state that specifies the property rights structure. Ultimately it is the state that is responsible for the efficiency of the property rights structure, which causes growth or stagnation or economic decline." The reason this theory is unsupportable is because, although the state can specify the property rights structure, it cannot control the effects that will flow from the structure it specifies. Table 12 shows that the same land rights specified by the state have inverse effects at different stages of development, which are not caused by the state but by the law that things develop in the opposite direction when they become extreme. Therefore, in the final analysis the effects of the land rights structure are not determined by the state but by LTLP.

Table 12 explicates the tri-world dynamic land-use model. It further specifies Figure 3's tri-world land-use system and renders the system dynamic from the perspective of time. Columns 2, 3, and 4 represent three different stages of development: before, in, and after the population trap (or after industrialization).

Table 12. Inverse Logics of Different Stages of Development under the Law of LTLP.

	$AY/N > S$	$AY/N = S$	$AY/N > S$
The Physical World:			
A: area of arable land	Constant	Constant	Constant
N: population under the law of LTLP	Less	Most	Least
Land per rural head	Large	Smallest	Largest
The Economic World:			
Land size per family farm	Large	Smallest	Largest
Labor inputs per ha	Less	Most	Least
Labor inputs to LTLP	Far	Closest	Farthest
Marginal returns to labor	High	Lowest	Highest
The average labor cost per kg grain	Low	Highest	Lowest
Labor productivity	High	Lowest	Highest
Y: land productivity	Low	Highest	High
Returns to fixed capital investment	High	Lowest	Highest
To invest in farm machines?	Yes	No	Yes
Above ***S***: surplus grain	Have	No	Most
Aim of farming	Survival & profits	Survival	Mainly for profits
The Institutional World:			
Transfer of land use right	Work	Not work	Work
Land rental markets	Work	Fail	Work
Mortgaging land titles for bank loans?	Yes	No	Yes
Credit markets	Work	Fail	Work
Exclusive land rights	Not harm SNAP*	Harm SNAP	Not harm others
Patterns of land rights	More private	More communal	More private

* SNAP = survival of newly added population.
Source: Pei, 2014: 53.

The horizontal items show the inverse logics of the three stages and extend the span of the Malthusian population model—which has a time factor and hence an analogue of columns 2–3 but not column 4 and an institutional world that is not its focus—to history after the Industrial Revolution. From the space perspective, the vertical items show that both the institutional and economic worlds are the results of the physical world's relation of population to land resources. The North/Thomas model has no physical world in a space perspective, and so it sees the economic world as the result of the institutional world by defying the physical checks of LTLP on the institutional and the economic worlds. This static model lacks the time factor and thus breaks off in a time perspective and has an analogue of columns 2 and 4 but not column 3. If it had an analogue of column 3, it would contradict its own causality. In sum, the Malthusian model takes into consideration the information in columns 2–3 but ignores column 4 and the institutional world, while the North/Thomas model is fragmented and not a valid theory since it considers the information in columns 2 and 4 but not column 3 and not the physical world. Table 12 uses a greater time-space framework to remedy the defects of the above two and provides a basis for *a dynamic land rights theory*: 1) from the perspective of space, its vertical items show that cost/return ratios determine the effects of land rights; 2) from the perspective of time, its horizontal items show that changes in cost/return ratios alter the effects of land rights; 3) its three-worlds' horizontal-dynamic contrast tells us that changes in the land/labor ratio first alter the cost/return ratio and then the pattern of land rights. In an earlier work (Pei, 2014) I have used data to confirm this theory and its related inverse logics.

Conclusion

The agricultural revolution in England was the result of a shift from intensive to extensive land use and then back to intensive. In the process of returning to intensive land use, the Norfolk rotation system combined farming with animal husbandry, increased fodder crops and the number of horses, and thus horsepower inputs replaced manpower inputs and raised labor productivity. The Norfolk rotation system in turn originated in the past high fallow rate. Grain yields could grow rapidly because the past sharp decline of yields and labor inputs per acre preserved the natural fertility of arable land. In short, England's agricultural revolution occurred because its past land use was not very efficient and its land productivity was much lower than China's. England's path to industrialization began by retreating from the $AY/N = S$ population trap stage back to the $AY/N > S$ stage before the trap (see column 2 of Table 12), and then to the $AY/N > S$ industrialized stage (column 4), because there is no conflict in the logic of the two stages. The consistency of the two processes confirms the reasoning of Figure 1: the only way to free growth of labor productivity from the constraints of LTLP is to reduce labor inputs from L_3 to point O (or from right to left), forcing labor inputs per hectare to deviate from LTLP. For this reason, when England's grain yield was growing rapidly and approaching LTLP, this limit once again caused returns to labor to diminish, the cost and price of food and wages to rise, and industrial profits and capital accumulation to fall. But England solved these problems and shifted to the industrialized stage by international trade, market integration with the United States, Canada, Australia, Argentina, and others, and importing their cheap surplus grain. These New World countries also benefited from the market integration and international trade and shifted directly from the $AY/N > S$ stage before the population trap to the $AY/N > S$ industrialized stage, because they had never experienced the $AY/N = S$ population trap stage. In contrast, when China entered the $AY/N = S$ population trap stage from the $AY/N > S$ stage before the trap, it fell deeper and deeper into this trap. Figure 1 shows that China's labor inputs per unit of land always moved from left to right and approached LTLP.

This article has focused on the history of organic agriculture and used the formula of the movement from $AY/N > S$ to $AY/N = S$ and then to another $AY/N > S$ to summarize the history of the relation between human survival and nature. The essence of this history is a biological energy conversion between plants and animals when humans, like their hominoid ancestors who ate wild fruits, consume grain. Grain provides humans with energy, strength, and life itself. Humans use physical strength to produce more grain. The energy of food is obtained by the application of human energy and strength. At the $AY/N > S$ pre–population trap stage, each kilogram of grain is obtained more through natural forces and less through manpower, because humans can use less physical strength in exchange for more food when nature can provide more food relative to population. But at the $AY/N = S$ population trap stage, the share of natural forces bestowed per kilogram of grain falls to the bottom and the share of manpower reaches a peak. When the total energy of grain reaches its natural limit, workers must use increasing amount of physical strength in exchange for the energy of the same single kilogram of grain. This means that the biological chain of nature has been stretched to the limit. At this point it is controlling the population and does not allow humankind to break its ecological balance, that is, when Y reaches LTLP and can grow no further, growth in N must also stop. From this point of view, a history of interchange, interdependence, and mutual restraint of plant life and animal life is involved. The mineral-based energy economy has changed this history, because agricultural machinery has replaced human energy, and fuel to run machinery, make fertilizers, and other inputs in the final analysis is from petroleum buried in the earth and other mineral resources. These inputs are inanimate iron and other metals (producing them also consumes a great deal of energy) and the energy from chemicals and other substances. Increasing these inputs does not require an increase in the output of food to "feed" them. Their growth is also not limited by LTLP. Industrial development can also reduce their costs and prices, thereby further reducing the cost of grain. Thus the original biological energy conversion between plants and animals changed to the conversion between chemical energy and plant energy. We can even say that this has changed from the conversion between life and life into a conversion between inanimate and living matter. This has made food production and growth no longer dependent on human strength. Humans have finally been liberated from the biological chain of nature. This is why in industrialized countries 3–5 percent of the population can support the entire population, but non-industrialized countries must rely on the vast majority of the population and labor force to support the national population.

In short, the sources of grain at the above three different stages of development have the following inverse structures. At the $AY/N > S$ pre–population trap stage, the large land area per farmer made the share of natural forces that created each kilogram of grain high and the share of manpower low. At the $AY/N = S$ population trap stage, the smallest land area per farmer made the share of natural forces fall to the bottom and the share of manpower rise to the peak. At the $AY/N > S$ industrialized stage, the area of land per farmer is even much more extensive than at the stage before the population trap, because the vast majority of the population and labor have shifted to nonagricultural sectors. This raises the share of natural forces bestowed per kilogram of grain to its highest point in the history of human cultivation. But this is only a vertical comparison. In terms of a horizontal comparison, chemical energy contributes the largest share, natural forces the second largest, and manpower the least, because agricultural machinery and chemical energy not only replace manpower, but also raise the capacity of each farmer in terms of the area cultivated to an unprecedented height. This is illustrated in Figure 1. Here, labor inputs per hectare move from right to left and deviate from LTLP more and farther, progressively decreasing the check of LTLP on growth in labor productivity and per capita income. The epoch-making change is that population growth no longer causes labor inputs per hectare to move from left to right and constantly approach LTLP. Therefore, both the English model of movement from the $AY/N = S$ population trap stage back to the $AY/N > S$ stage before the trap and then to the $AY/N > S$ industrialized stage, and the model of the New World countries of movement from the $AY/N > S$ stage before the population trap directly to the $AY/N > S$ industrialized stage, are a development model of "sailing with the wind." Market exchange of industrial and agricultural products can accumulate capital for industrialization precisely because agricultural products absorb less of a contribution from humans and more of a contribution from nature, which is free of charge. Hence it is not the market and private property rights system, but the contribution of natural forces from "sailing with the wind" that made these countries develop and industrialize.

But "sailing with the wind" becomes "sailing against the wind" in China. The starting point of China's history of movement from the $AY/N > S$ pre–population trap stage to the $AY/N = S$ population trap stage is the growth in N, and the end point is LTLP. Hence growth in N in China historically led to the following results: (1) it constantly reduced land per labor; (2) it made labor input per mu constantly approach LTLP, because the constant A (area of arable) had to feed more people; (3) it made the contribution of natural forces per kilogram of grain fall to the bottom, and the share of manpower rise to a historical peak; (4) it made labor productivity stagnate when labor inputs per mu reach LTLP; (5) as late as 1949, it squeezed 90 percent of China's population and labor force under the ceiling of LTLP. The only way for China to rid itself of this ceiling was to industrialize, because industrialization can transfer agricultural labor and population to industry, thus moving rural China from $AY/N = S$ to $AY/N > S$. Therefore, reducing N and the labor force in agriculture led to the following interrelated results: (1) it allowed more and more labor and population to escape from the LTLP ceiling; (2) it expanded land per farmer; (3) it reduced labor inputs per mu; (4) it caused the contribution of natural forces per kilogram of grain to increase and the share of humans' contribution to diminish; (5) it started to raise agricultural labor productivity and narrow the gap between industrial and agricultural labor productivity. This is why I (Pei, 2008: 245–51) define the essence of industrialization as freeing the growth of labor productivity from the law of LTLP. But China has not been able to industrialize by the market exchange of industrial and agricultural products, because its share of natural forces bestowed per kilogram of grain had fallen to the lowest point in China's history and the human share had risen to its peak. So it was that from 1953 to 1978 China depended on the planned economy to directly transform the agricultural surplus value into industrial investment. After establishing a complete industrial system, China began to return to the market economy in 1979. In short, China experienced a process of negation of negation by using nonmarket methods to overcome the negative role of the market in hampering industrialization at the $AY/N = S$ population-trap stage, and then returned to the market system. But the negation of negation does not negate China's pre-reform development. China unavoidably followed a spiral road to free its labor and population from the ceiling of LTLP, or to move itself from the $AY/N > S$ stage to the $AY/N = S$ stage and then to another kind of $AY/N > S$ stage with logical conflicts. Hence it would be a mistake for China's policy makers to treat China's post-reform high growth as something that disproves the value of its pre-reform system. In fact, it was the planned system that gave birth to the industrialization that old China's market system failed to establish, opened up a route to free its rural population and labor from the ceiling of LTLP, and reversed China's long history wherein LTLP checked labor productivity growth by ushering in a new history where the country freed itself of this check (Pei, 2015).

This is why Table 12 uses the tri-world's dynamic land-use model to reveal that it is the change in the land/labor ratio in the physical world that first alters the economic world's cost/return ratio and then the institutional world's pattern of land rights. The reason why the transition from the $AY/N > S$ stage to the $AY/N = S$ stage and then to another kind of $AY/N > S$ stage is bound to produce different property rights systems is that these formulas represent the dynamic relation between the human demand for food and the limited supply of nature, while the property rights regime involves human-to-human relations. Since the former is the main system and the latter is a subordinate system, changes in the main system determine changes in the subordinate system, and the opposite is absolutely not the case. Moreover, the above change in the shares of natural forces, manpower, and chemical energy bestowed per kilogram of grain is the result of changes in the land/labor ratio and in the distance between labor inputs per hectare and LTLP at the three different stages of development, so they are independent of property rights, markets, and social systems and cannot be changed by the latter. On the contrary, the law of LTLP that things develop in the opposite direction when they become extreme can change the latter's role, thus affecting the state's choices. This shows that Richard T. Ely's welfare theory, introduced earlier in the article, is both in keeping with history and valid in the sense that the parties in each historical stage rationally choose a property rights system to fit changes in that stage and thus promote the general welfare of society, no matter whether property rights are private or public. On the other hand, North's theory about "the rise of the Western world" is completely static. It violates history by contending that rich countries are rich because they rationally choose private property rights, and poor countries are poor because they irrationally choose a public property system. Marx once described scientific exploration as climbing high mountains. The panorama is different at different heights. The height Ely climbed is far above what North achieved. Thus, when Ely sees welfare as the purpose and cause of changes in the property system, North sees the property regime as the purpose and cause of welfare changes.

It is precisely because China's policy makers accept North's theory that they think that the more the pre-reform system is negated, the higher the growth will be. This has caused China's reform to go to the extreme, and China to change rapidly from a country with the smallest gap between the rich and the poor before its reform, to one with the greatest gulf between the rich and the poor. In order to correct this extreme tendency, Philip Huang has organized this special issue of *Rural China* to explore the possibility of a third road—between capitalism and socialism—for rural development in China. Table 12 provides a theoretical framework for this discussion. Figure 3 is a reverse diagnostic tool, tracing the roots of the problem by starting from the pattern of its outcome. For example, Huang (2014: 113) points out the outcomes: grain yields per mu of enterprise-style farms, "big" family farms, and small family farms are respectively 550 kg, 800 kg, and 900 kg; the net incomes per mu of the three are respectively 315 yuan, 520 yuan, and 1,270 yuan. The first-order causes of the different outcomes can be found in the patterns of action: enterprise-type farms have to pay rent and hiring fees and so on; "big" family farms must hire auxiliary labor; small family farms use their own labor and have no wage expenditures. The different actions show that the more market-oriented and the bigger the farm, the less the labor inputs per mu; contrarily, the smaller the farm, the more labor per mu the family puts in. This again confirms the reasoning reflected in Figure 1: few laborers with more land are bound to pursue the highest labor productivity; more laborers with less land are bound to pursue the highest land productivity. The two contradict each other and cannot be combined into the best of both worlds. What then is creating the action incentives that clash with China's situation of abundant people and little land? We can find the second-order and the final causes from the *e*-line relationship in Figure 3 of whether the land property system conflicts with LTLP: the land policy of the Chinese state as of 2013 encouraged developing American-style family farms by market transfers of land. This policy is derived from neoclassical theory, which contends that the market will cause land to flow from farms with low marginal returns to farms with high marginal returns. When the marginal returns of all farms are equal, the best resource allocation is achieved. But I (Pei, 2004) have demonstrated in theory that under the constraints of LTLP, only an equal distribution of land can cause labor inputs per mu and marginal returns to labor to be equal, and maximize grain yields and total output, total factor productivity, and the general social welfare. Therefore, in the process of labor and population escaping from the ceiling of LTLP, a system in which the area of all farms is expanded equally is a system of optimal allocation of resources. This is the third way, which is neither capitalist nor socialist, but can overall achieve a balance and dynamically maximize the general welfare.

We know that the neoclassical theory of resource allocation ignores the constraints of LTLP. But why does the theory work in the United States? It is because LTLP almost does not restrict farming in the United States. The United States is an example par excellence of an $AY/N > S$ country with few people and ample land. Its supply of grain can meet both the domestic demand and the demand of foreign markets. Its large, medium-sized, and small farms are all $AY/N > S$-type commodity production enterprises. The Y level (land productivity) may be lower in large farms than in medium-sized and small farms, but labor productivity is higher. Hence when the market allows land to flow from the latter to the former, it can improve (but not optimize) the efficiency of resource allocation, such as increasing labor productivity and reducing the labor costs and market prices of grain. For China today, the law of LTLP that things develop in the opposite direction raises the following question: to improve the efficiency of labor use and reduce the efficiency of land use is logical in the United States, where there are few people relative to land, but is it also logical in China, where people are numerous relative to land? The reduction of the level of Y in large farms in the United States, a country that enjoys a large amount of surplus grain that can be exported, is acceptable, but is it acceptable in food-short China? To raise labor productivity, reduce the share of manpower bestowed per kilogram of grain, and increase the contribution shares of chemical energy and natural force is logical in the United States, where a labor shortage and high wages cause its farms to hire Mexican workers, but is it also logical in rural China, where surplus labor takes the form of peasants with nothing to do who spend their days bored at home playing mahjong? In short, I think that of all the man-made factors that harm human development, the false theory of misleading policy is number one.

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