FROM FORAGING TO FARMING: EXPLAINING THE NEOLITHIC REVOLUTION

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Abstract. This article reviews the main theories about the prehistoric shift from hunting and gathering to agriculture. The transition, also known as the Neolithic Revolution, was ultimately necessary to the rise of modern civilization by creating the foundation for the later process of industrialization and sustained economic growth. The article provides a brief historical survey of the leading hypotheses concerning the rise of agriculture proposed in the archaeological and anthropological literature. It then turns to a more detailed review of the theories put forth in the economic literature.

Keywords. Agriculture; Hunting–gathering; Neolithic Revolution; Transition

'Why farm? Why give up the 20-hour work week and the fun of hunting in order to toil in the sun? Why work harder, for food less nutritious and a supply more capricious? Why invite famine, plague, pestilence and crowded living conditions?' Harlan (1992)

1. Introduction

The rise of Neolithic agriculture is unquestionably one of the most important events in human cultural history. Agriculture, or food production as archaeologists call it, appeared in and spread from many different regions of the world between 10,000 and 5000 years ago. From the appearance of the human race, some 7 million years ago until the introduction of agriculture, hunting and gathering was the only food procurement strategy practised. The transition to agriculture, which led to the rise of civilization and the procurement of material wealth beyond the wildest dreams of the Neolithic hunter and gatherer, has rightfully gained the title, the Neolithic Revolution.[1]

The evidence of where and when wild plants and animals were domesticated for the first time is relatively well-established, as are the theories of how hunters and gatherers actually transformed wild plants and animals into domesticates. But one important question is still subject to intense debate: What made human

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societies take the radical step from foraging to farming? This article will acquaint the reader with the main theories that deal with this issue.[2]

Traditional scholarship has regarded farming as highly desirable. Scholars of human history long assumed that once humans recognized the impressive gains from cultivation and domestication, they would immediately take up farming. However, more recent studies have indicated that early farming was indeed back breaking, time consuming, and labour-intensive. This motivates the question posed by Jack R. Harlan, one of the great pioneers of historical ecology, in the quotation above: Why farm?

This compelling issue has puzzled the scientific community for decades. Archaeologists, agronomists, anthropologists, demographers, biologists and historians have speculated intensely about the factors that eventually tipped the comparative advantage in favour of farming.[3] The only widely accepted idea, however, seems to be that no single explanation so far proposed is entirely satisfactory (e.g. Harlan, 1995; Smith, 1995; Fernandez-Armesto, 2001).

Economists, too, have contributed to the understanding of the emergence of agriculture. In the 1990s, economic growth theorists began to examine the historical transition from stagnant productivity to sustained economic growth that seems to have occurred with the Industrial Revolution (e.g. Goodfriend and McDermott, 1995; Galor and Weil, 1999, 2000; Jones, 2001; Kögel and Prskawetz, 2001; Hansen and Prescott, 2002; Kalemli-Ozcan, 2002; Lucas, 2002; Tamura, 2002; Lagerlöf, 2003; Weisdorf, 2004a). Inquiry into the pre-industrial economy has led some scholars to suggest that the rise of Neolithic agriculture had a crucial influence on later economic development. For instance, Galor and Moav (2002) suggest that the shift from the tribal structure of hunter–gatherer society to the household focus of agricultural societies amplified the potential evolutionary advantage of individuals with a quality-bias that favoured economic growth; Lagerlöf (2002), who investigates the institution of serfdom, argues that the birth of farming led to an era dominated by slavery; and Olsson and Hibbs (2004b) show that the timing and the location of the transition to agriculture is strongly correlated with the distribution of wealth among today's countries.

A small but growing number of articles deal specifically with the emergence of farming. Smith (1975) examines the hypothesis that the extinction of large herding animals by Paleolithic hunters led to the rise of agriculture. North and Thomas (1977) argue that population pressure, together with the shift from common to communal property rights, spurred on the development and application of cultivation and domestication techniques. Locay (1989) studies the implications of nomadic versus sedentary lifestyles vis-à-vis the rise of agriculture. More recently, Morand (2002) has presented a model that discusses the family's resource-allocation behaviour in relation to the shift to farming. Olsson (2001), in a framework that manages to compare a number of archaeological explanations, finds support for the theory that environmental factors, along with genetic changes in the species suitable for domestication, paved the way for agriculture, while Weisdorf (2004b) argues that the emergence of non-food specialists played a crucial role in the transition to farming. All of these economic theories about the origins of agriculture are addressed in detail in Section 3.

The adoption of agriculture in the Stone Age certainly did more, in the long run, to alter the world than any previous human innovation. Today, agriculture is the primary source of food worldwide. However, in terms of labour and capital endowments, agriculture represents only a small part of the world's economic activities. The United States, a net exporter of food, dedicates only three per cent of the labour force to food production (World Bank, 1999). By contrast, the most advanced Bronze Age societies allocated all but a fraction of their labour to agrarian activities (Redman, 1978). The transfer of labour from food to non-food activities, a central element to the process of industrialization, has been of crucial importance to the wealth of nations.

Probably the main reason the Neolithic Revolution was decisive to economic growth and development is that the food surplus that early farmers were able to generate made possible for the first time in human history the establishment of a non-food-producing sector (e.g. Diamond, 1997). The presence of non-food specialists – craftsmen, chiefs, bureaucrats, scientists and priests – enabled and even demanded innovations such as writing, metallurgy, city planning and scientific principles, all necessary to the Industrial Revolution and the accumulation of material wealth.

Yet the question still remains: why did our ancestors decide to take up farming after millions of years of successful foraging? Section 2 provides a brief historical survey of the hypotheses that have dominated the archaeological and anthropological literature. Section 3 offers a more detailed review of the related contributions in the economic literature. Finally, Section 4 provides a conclusion.

2. The Archaeological Literature

Over the years, a variety of theories have been forwarded to pinpoint human motivations and identify the underlying causes of the emergence of agriculture. This section briefly reviews the major hypotheses proposed primarily in the archaeological and anthropological literature. Table 1 summarizes a chronological summary of the theories.

In the eyes of the ancient Greeks, agriculture was the last of three stages: '[F]irst came a hunting and gathering stage; this slowly led to the domestication of animals and a pastoral nomadic stage; finally came the invention of agriculture' (Isaac, 1970; p. 3). This 'stage' hypothesis persisted in Europe throughout the Middle Age. But whereas the Greeks envisioned a cyclical development, in which humans would eventually return to the beginning and start all over again, the medieval version, and even more so the view of the 18 century Enlightenment, postulated an evolutionary sequence from less-advanced to more-advanced societies in a linear fashion. Conjectural history, wherein Enlightenment philosophers compared contemporary living peoples whose cultures ostensibly differed in sophistication, and arranged these cultures to form a logical sequence from simple to complex, was widely accepted (e.g. Trigger, 1989).

Table 1. The Hypotheses.

Time	The Hypothesis	Its Main Idea	The Reason for Leaving It
?–1930	'Stage'	Agriculture was the final stage in a uni-linear development path	External pressure was believed to have generated the shift
1930–1950s	'Oasis'	The shift was motivated by changes in the environment	Climatic changes too slow; earlier interglacial periods did not result in the adoption of agriculture
1960s	'Natural Habitat'/ 'Nuclear Zone'	Abundance of leisure led to plant experimentation	Evidence suggested that farming arose out of necessity rather than opportunity
1960–1980s	'Marginal Zone'	The shift was generated by population pressure in infertile zones	The first domestications took place in resource-abundant societies
	'Population Pressure'	The shift was generated by population pressure on a global scale	Skeletal evidence did not indicate a food crisis
	'Overkill'	Animal extinction indicated the presence of a food crisis	Animal extinction and agriculture did not occur together, neither geographically nor chronologically
1980–1990s	'People–Plant Interaction'	The shift resulted from unintentional human behaviour/manipulations	(Still under consideration)
	'Human–Plant Symbiosis'	Land exploitation and energy input are strongly correlated	(Still under consideration)
1990–2000s	'Competitive Feasting' were delicacies	The first domestications were important foods	The first domestications
	'Younger Dryas'	The shift was motivated by changes in the environment	(Still under consideration)

The view of 19th century scholars deviated very little from their 18th century counterparts. To Darwin (1868), who represented the prevalent view at the time, agriculture was simply a practice waiting to be discovered. He notes (p. 326–327) that . . . '[t]he savage inhabitants of each land, having found out by many and hard trials what plants where useful, [. . .] would after a time take the first step in cultivation by planting them near their usual abodes. [. . .] The next step in cultivation, and this would require but little forethought, would be to sow the seeds of useful plants'. Underlying this view is the assumption that foragers were ever on the verge of starvation and that the quest for food absorbed their time and energy to an extent that prevented them from building more-advanced cultures.

During the first half of the 20th century, farming was believed to have appeared first on the dry plains of Mesopotamia where the early civilization of the Sumerians arose. For at least 20 years from the mid-1930s, the most popular theory relied entirely on the 'oasis' hypothesis (also known as the 'propinquity' or the 'desiccation' theory). In the 1930s, the end of the last ice age was thought to be a period of dryer conditions. In the Near East, a dry region to begin with, higher temperatures and less precipitation would invite not only humans but also domesticable plants and animals to take refuge in zones that were spared the desiccation, namely oases and river valleys. The only solution to competition for food in these circumstances, the reasoning went, would be for humans to domesticate plants and animals (e.g. Childe, 1935).

However, evidence that emerged during the 1940s and 1950s showed that the climate changed too gradually to trigger this kind of behaviour. Furthermore, no evidence of any crisis with sufficient impact to have predetermined the shift to food production was produced (i.e. Braidwood and Howe, 1960). In addition, agriculture also appeared in regions where no major climatic changes had occurred and under a wide variety of climatic ecological conditions (e.g. Perrot, 1962). Finally, it was argued that earlier interglacial warm periods had not led to the adoption of agriculture (e.g. Braidwood, 1963).

As the oasis hypothesis fell into disfavour, new ideas took its place. In contrast to the oasis hypothesis, the new theories suggested that farming was a response to opportunity rather than necessity. Sauer (1952), for example, hypothesized that farming was invented by fishermen residing in regions where the abundance of resources afforded them the leisure to undertake plant experimentation. In a similar category, Braidwood and Howe (1960) suggested that agriculture was the by-product of leisurely hill-dwellers, whose habitat was particularly rich in domesticable plants and animals. These theories, stemming from studies of regions with high potential for domestication, went under the 'natural habitat' or 'nuclear zone' hypothesis.

Farming, at this point, was still assumed to have been clearly preferable to foraging. But, in the 1960s, this perception was to be turned up-side down. Evidence started to appear which suggested that early agriculture had cost farmers more trouble than it saved. Studies of present-day primitive societies indicated that farming was in fact back breaking, time consuming, and labour intensive (e.g. Lee and DeVore, 1968), a view that would later gather strong support (e.g. Sahlins, 1974). In so-called 'affluent societies', farming was not desirable; hunters and gatherers would not embark upon time-costly methods of agriculture unless there was good reason to do so. Farming was in fact a last resort.

A picture began to emerge that showed that foraging communities were able to remain in equilibrium at carrying capacity when undisturbed and that new cultural forms would only result from nonequilibrium conditions. In the light of the fact that climatic changes did not seem to have led to significant crises and that foragers, reluctant to take up farming, decided to adopt it nevertheless the idea that agriculture resulted from necessity again began to take hold:

Binford (1968), looking for conditions that would upset the established equilibrium in favour of increasing productivity, reasoned that the shift to farming could have been caused by population pressure. This inspired Flannery (1969) to suggest that agriculture would initially appear in regions where the need for food was most acute, not in affluent societies but in marginal areas. This became known as the 'marginal zone' hypothesis.

The idea that population pressure was the impetus behind the shift to farming gained momentum. In 1977, Cohen presented his hypothesis of global population pressure. Inspired by Boserup's argument that agricultural intensification would not have occurred without the stimulus of an increasing population (e.g. Boserup, 1965), Cohen posited that population growth spikes had occurred frequently throughout human history (Cohen, 1977). This, he reasoned, had led to global over-population by some 15,000 years ago, a conclusion that seemed to accord with the fact that the human species, departing from Africa, had by then colonized all the inhabitable areas of Europe, Asia and the New World.

The stress brought about by increasing populations and depleted resources meant that foragers had to expand their subsistence to include less-favoured foods of greater abundance. Archaeological findings had shown a widening variety of wild plants and animals in the diet of hunters and gatherers, a process which Flannery (1973) referred to as the 'broad spectrum revolution'. Moreover, megafauna extinction shortly prior to the rise of agriculture, i.e. the disappearance of large herding animals such as the mammoth and the woolly rhino, was also interpreted as evidence of population pressure and went under the 'overkill' hypothesis (e.g. Martin, 1967; Roberts, 1989). The 'population pressure' hypothesis accordingly concluded that the only way a rapidly increasing population could deal with declining resources was to embark upon agriculture.

In all parts of the world where adequate evidence is available, archaeologists have found that increasing population densities appeared in relation to the emergence of agriculture (e.g. Diamond, 1997).[4] Population growth certainly explains why agricultural intensification could not have been reversed. Once the population has increased, the 'ratchet effect' makes a return to less intensive ways of food procurement impossible. However, the core 'chicken-and-egg issue' remains unresolved; did human societies domesticate plants and animals as an adaptive response to population pressure or did domestication give rise to a larger population?

Population pressure and depleted resources are bound eventually to cause a decrease in people's dietary intake. As dietary stress leaves its mark on the bones and teeth, the population pressure hypothesis is testable using methods of physical anthropology. Because early hunter–gatherers were relatively well-nourished and free of disease, the dietary stress brought about by the pressure of an increasing population among later hunter–gatherers would then have marked their skeletons. However, studies of skeletal remains have failed to show nutritional stress immediately prior to plant domestication. In fact, in some instances, the health of the last hunter–gatherers in a region where agriculture was adopted appears to have been significantly better than that of the first farmers (Cohen and Armelagos, 1984). Moreover, as animal extinction has not been shown to have happened in any of the places or at any of the times prescribed by the population pressure hypothesis, this school of thought has been all but discredited (Fernandez-Armesto, 2001).[5] In general, the idea of a global food crisis no longer seems convincing (e.g. Mithen, 1996).

Because of insufficient evidence in favour of the hypothesis of demographic pressure, other explanations were forwarded. Unable to find evidence of dietary stress among foragers, researchers returned to the view that farming arose from opportunity. In the 1980s, contributions increasingly stressed the continuities rather than the contrasts between foraging and farming. Concepts such as 'human–plant symbiosis' and 'people–plant interaction' were introduced. These imply an unintentional process by which human intervention, selection and replanting (i.e. environmental manipulation) eventually gave rise to strains of plants and animals that depended upon human assistance for their survival and upon which humans in turn depended sustenance. These theories did not address the question of *what* motivated human societies to shift primary dependence from wild foods to cultivated ones but merely emphasized the Darwinist view that the path to agriculture could have been an evolutionary process (e.g. Rindos, 1984) and that there seemed to be a positive relationship between the energy input into food procurement and the output per unit of area of exploited land (e.g. Harris, 1989).

In the 1990s, cultural or social theories were proposed to explain why communities with stable populations and abundant resources also eventually introduced domestication. Hayden (1990), for example, envisions the rise of agriculture as resulting from what he calls 'competitive feasting'. His idea is that food was regarded as a source of social prestige and that early domestication took place in order to create delicacies for families or individuals who wanted to improve their social status. Hayden's hypothesis, however, has not received much support. It appears that early domestication unambiguously consisted of important foods rather than delicacies (e.g. Smith, 1995).

Mithen (1996), a physiologist who focuses on the capacity of the human brain, argues that early humans, despite possessing knowledge about how plants and animals reproduce, simply lacked the imagination to domesticate plants and animals. Hence, in Mithen's view, the origins of agriculture 10,000 years ago are best explained by a fundamental change in the way the human mind conceived of nature.

In the latter part of the 20th century, more detailed environmental studies have reawakened scholars' interest in the idea of climatic changes as the impetus to take up farming. It has been proposed that, as European ice sheets ceded to warmer and moister conditions, hunters and gatherers were able to exploit an increasing number of productive food plants, which increased their population (Legge and Rowley-Conwy, 1987). But between 10,800 and 10,300 years ago,[6] a global climatic downturn, known as the 'Younger Dryas', brought colder and drier environmental conditions (and even drought). This climatic episode decreased the yield of wild cereals and thus could have motivated the so-called Natufians communities of hunters and gatherers in the Levant to cultivate wild cereals (Bar-Yosef and Belfer-Cohen, 1991). It has also been argued that because evidence indicates that sedentary communities emerged in the Near East up to 3000 years before the birth of agriculture, it was inevitable that the level of food procurement should increase, once the constraint on population growth imposed by nomadic life had been relaxed (Bar-Yosef and Belfer-Cohen, 2000).[7]

Though many of the theories presented in the archaeological and anthropological literature correspond well with regional data, no single explanation appears to be universally applicable (e.g. Harlan, 1995; Smith, 1995; Fernandez-Armesto, 2001). The section below examines how the economist interprets the shift from foraging to farming.

3. The Economic Literature

Despite its tremendous impact on economic growth and the wealth of nations, very few economists have attempted to explain the Neolithic Revolution. Those that do generally divide into two camps. One consists of three contributions: two that came in the 1970s, one examining the 'overkill' hypothesis (Smith, 1975), and one dealing with the differences in the nature of property rights between foraging and farming (North and Thomas, 1977); and one that came in the late 1980s, dealing more broadly with the archaeological and anthropological theories from an economic perspective (Locay, 1989).

The other camp consists of four recent contributions (Olsson, 2001; Morand, 2002; Olsson and Hibbs, 2005; Weisdorf, 2004b). As mentioned in the introduction, these belong to a branch of the growth literature dealing with very long-run economic development and the emergence of 'modern' economic growth.[8] This section reviews both categories of articles. For a summary of the economic literature, see Table 2.

Before we start the excursion, it is useful to look at some expositional similarities of the models. Two aspects are common to nearly all the contributions. First, *how* agriculture was invented is generally not an issue. Regardless of whether this is explicitly stated, all articles seem to agree with the view in Olsson and Hibbs (2005), who note (p. 8) that the first domesticates 'probably appeared near latrines, garbage heaps, forest paths and cooking-places where humans unintentionally had disseminated seeds from their favourite wild grasses, growing nearby'. Second, all contributions can be examined within the context of a simple, static comparative economic model. Figure 1 provides a graphic representation of

Table 2. The Economic Literature.

The Contribution	The Key Determinant	The Main Argument
Smith (1975)	Animal extinction	Excessive hunting favoured agriculture
North and Thomas (1977)	Property rights	Common property rights among foragers cause incentive failure, whereas exclusive communal property rights roperty rights among farmers do not
Locay (1989)	Nomadism	Population pressure made foragers more settled, which favoured farming
Olsson (2001)	Population growth	Higher population growth among farmers relative to foragers pushed people into agriculture
Morand (2002)	Inter-family exchange	Changes in external forces determined the modes of production and the nature of transfers between household members
Weisdorf (2004b)	Non-food specialists	The emergence of non-food specialists were crucial to the adoption of time-costly agricultural methods
Olsson and Hibbs (2005)	Biogeography	Biogeograpic endowments were crucial to the timing of the transition to agriculture

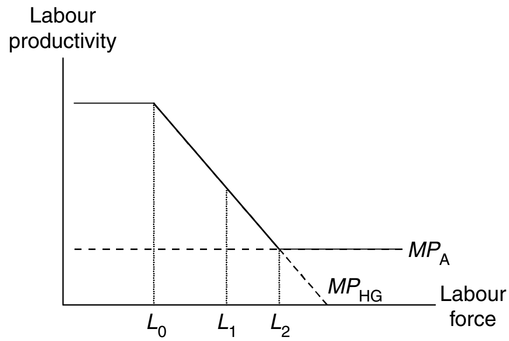

Figure 1. The Standardized Model.

this model. It illustrates the relationship between the size of the labour force and the marginal product of labour in food provision.

The figure can be divided along the labour force axis into three areas. First, when the size of the labour force is below L_2, human effort is devoted exclusively to foraging, because, here, the marginal product of labour in foraging exceeds that of farming. Second, for sufficiently low levels of labour, i.e. when the size of the labour force is below L_0, marginal labour productivity in foraging is constant and equals the average labour productivity. The latter property is valid only as long as there is empty land that surplus labour can migrate to.[9] Third, when the size of the labour force is between L_0 and L_2, additional labour, running up against the land constraint, is subject to diminishing returns. Finally, note that once the size of the labour force surpasses L_2, any additional labour will enter agriculture. Any growth in the labour force will therefore increase the share of labour engaged in farming. Note also that farming exhibits constant returns to labour, a fair assumption given the abundance of suitable land at that time.[10]

Consider any point along the labour force axis where the size of the labour force falls between 0 and L_2. Here, the entire labour force is devoted to foraging activities. Assume for the sake of argument that we start with a situation where the labour force has a size of L_1 (L_0, L_2). From here, three changes can account for the transition to agriculture: (i) declining marginal product of labour from foraging, corresponding to downward shift of the MP_{HG}-curve (Figure 2); (ii) an advance in the marginal product of labour in farming, expressed as the MP_A-curve shifting upwards (Figure 3) and (iii) growth in the labour force (Figure 4). In each of the three cases, the economy enters a regime of mixed activities.[11]

With this representation in mind, recall Childe (1935) oasis hypothesis, where desiccation decreases the stock of wild foods. This shifts the MP_{HG}-curve downward as illustrated in Figure 2. The theories of Darwin (1868), Sauer (1952), Braidwood and Howe (1960), Harris (1989) and Rindos (1984), suggest that as humans became better acquainted with their later domesticates (Childe actually also proposed this), translate here to an upward shift in the MP_A-curve as

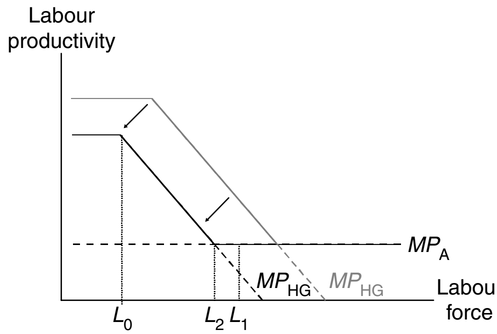

Figure 2. Lower Productivity in Hunting–Gathering.

illustrated in Figure 3. Finally, the population pressure theories of Binford (1968), Flannery (1969) and Cohen (1977) can be interpreted as movement along the labour force axis illustrated in Figure 4.

Because all the three bodies of research can be interpreted in terms of the standardized framework illustrated in Figure 1, the general outcome, though derived from very different models, is essentially the same. That is, the three changes outlined above, whether occurring individually or in concert, will eventually induce the rise of agriculture. The purpose of the following is therefore to disentangle each theorist's contribution to the story of what underlying causes eventually tipped the comparative advantage in favour of farming.

3.1 *Excessive Hunting*

In the 1970s, when the archaeological community favoured the idea that agriculture emerged as a result of necessity, Smith (1975) examined the so-called

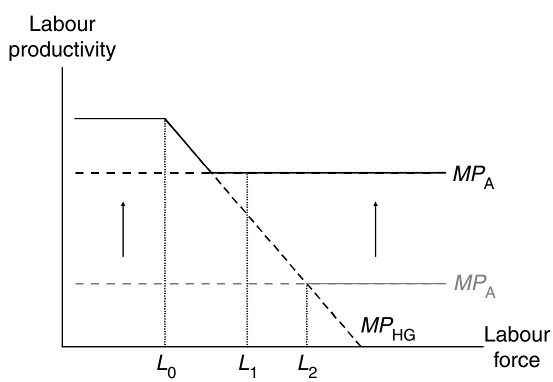

Figure 3. Higher Productivity in Agriculture.

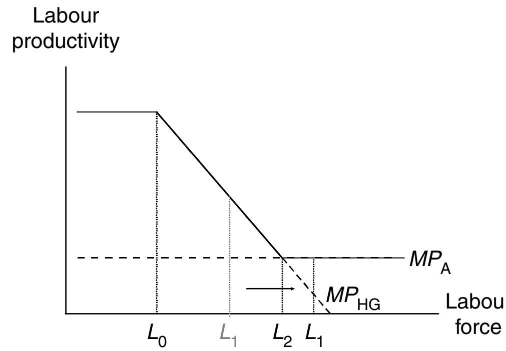

Figure 4. Larger Labour Force.

'overkill' hypothesis, i.e. the theory that the extinction of large herding animals some 10,000 years ago was because of excessive hunting.[12,13]

An important aspect of Smith (1975) model is that he identifies a list of parameters that reflect the growth rate and nutritional value of the biomass consumed by hunters. although his setup is more sophisticated than the models reviewed later on, Smith's model, in its simplest form, is nevertheless interpretable in terms of the standardized framework just presented.

Smith reaches the expected conclusion that an increase in the size of the labour force increases the share of labour in agriculture. This result matches the outcome predicted by Figure 4. Furthermore, in Smith's model, as climatic deterioration adversely affects the reproduction rate and availability of foraged biomass, declining productivity from hunting and gathering creates an incentive to increase the share of labour in agriculture as in Figure 2. Smith does not discuss the effect of changes in agricultural productivity and therefore has no conclusions related to the illustration in Figure 3.

By focusing on a number of parameters that reflect the growth rate and value of the biomass upon which hunters subsist, Smith reaches conclusions that appear to run counter to the results in most of the remaining economic models. His setup illustrates how improvements in hunting efficiency adversely affect the growth rate of the hunted biomass. Because lower biotic growth favours agricultural effort at the expense of hunting, more efficient hunters may actually *increase* the share of labour in farming. To understand this conclusion, which would seem to conflict with the outcome predicted by Figure 2, it is necessary to consider how the model changes over time. The short-run effect of an increase in hunting efficiency is always an increase in per-hunter output. But increased efficiency lowers the stock of animals, gradually lowering the marginal productivity of labour in hunting. Improvements in hunting efficiency therefore eventually translate to the illustration in Figure 2.

Smith's model does not provide any new insights with regard to the causes of Pleistocene extinction (p. 750). In any case, the main task of his paper – to compare free-access hunting to socially optimal resource regulation – relates to work by two economic historians, North and Thomas (1977), on the question of prehistoric property rights.

3.2 *Property Rights*

In their article, North and Thomas claim to provide a new explanation for the emergence of agriculture.[14] The work of two economic historians, their model is not expressed in terms of mathematics but relies entirely on an illustration similar to Figure 1 above.

The essence of their article is as follows. Throughout the Stone Age, new technology gradually improved the level of productivity in foraging as well as (latently) in farming. In the short run, as suggested by a combination of Figure 2 and 3, the model is therefore inconclusive with regards to the most efficient method of food provision. However, because of the inherently different property rights associated with farming, the comparative advantage eventually fell to agriculture. The reasoning is as follows:

Common property rights, which are assumed to prevail among foragers, potentially cause incentive failure. Bands of hunters and gatherers have an incentive to ignore certain costs of their activities, which results in over-utilization of resources, causing productivity to decline among foragers. This, the authors assert, is troublesome to the extent that population pressure incites competition over resources among bands of hunters and gatherers. It is argued (p. 237) that '[i]n the world of prehistoric man those bands that attempted to adjust their population to the size of the local resource base would eventually lose out to those bands that encouraged large and increasing populations'. This is so because 'the larger the population, the better its chances of successfully excluding others' (loc. cit.).

In contrast to foragers, primitive farmers, the two authors continue, must have been organized under exclusive communal property rights: 'It is inconceivable that, from the very beginning, the first farmers did not exclude outsiders from sharing the fruits of their labour' (p. 235). Furthermore (loc. cit.), 'the band in principle at least could have exploited its opportunities in agriculture by constraining its members with rules, taboos, and prohibitions, almost as effectively as if private property rights had been established'.[15]

Thus, farming has an advantage over foraging in terms of efficiency of the property rights. In the long-run advances in skill or technology increase the rewards from farming, while temporary advances in foraging are self-eradicating. In terms of Figure 1 above, the short-run impact of higher labour productivity in hunting and gathering initially shifts the MP_{HG}-curve upwards. This attracts labour resources to the foraging sector and hastens the depletion of the stock of wild food held as common property. Thus, in the long run, the MP_{HG}-curve shifts downward to a point below its initial position.[16]

Moreover, with common property rights, there is weaker incentive to acquire superior technology and learning. In contrast, exclusive property rights reward the owners and thereby provide a direct incentive to improve efficiency and productivity. The inherently different property rights, it is argued, therefore eventually tip the comparative advantage in favour of farming, whose labour productivity, in due course, will exceed that of foraging.

Whatever the mechanism, the fundamental force driving the transition to agriculture in the North–Thomas model is the same as that proposed by Binford (1968), Flannery (1969) and Cohen (1977), namely, the persistent pressure of increasing population.

3.3 *Nomadism*

Locay (1989) presents a technical framework that can also be interpreted in terms of the model presented in Figure 1 above. Locay deploys a two-period, overlapping generation model (with children and parents), where parents produce children as well as food from both of which they derive utility. Food production takes place using either hunting–gathering or agriculture. Both the types of food production are subject to constant returns to land and labour, but Locay assumes that hunting–gathering, compared with agriculture, uses land more intensively than labour. Moreover, the costs of producing children, measured in units of food, are presumed to increase with the household's degree of nomadism (see below). Within this framework, Locay considers how the chosen method of food procurement affects the three trivial changes illustrated in Figures 2–4.

The consideration of degree of nomadic existence represents an interesting refinement in Locay's model, bearing the analysis of the transition to farming to a more sophisticated level. Nomadism, i.e. the extent to which the household periodically shifts camp, is thought to influence household behaviour in a number of ways.

Nomadism appears to decrease agricultural productivity, because, in Locay's words (p. 740), 'one cannot farm and move around a great deal'. Moreover, nomadism increases the relative cost of having children, because food scarcity leaves nomad parents with fewer units of food to devote to child rearing relative to their own food consumption.

When nomadism is practised despite these inconvenient features, it is because it confers some benefit in terms of travel distance. The members of a settled community, Locay argues, must at least occasionally travel long distances from the base camp to reach the far-flung parts of their territory. As this cost increases, nomadism becomes more attractive. Shorter travel distances among temporary settlements leaves more time for subsistence activities. Thus, whereas nomadism is assumed to decrease agricultural productivity, it simultaneously increases time spent in obtaining food goods.

Furthermore, the size of a household's land turns out to have a dual effect on food output. On the one hand, more land increases labour productivity by providing more varied species and ecosystem types. On the other hand, increased travel distances across a larger land holding leave less time for actually producing food.

With the inclusion of nomadism and its effects on the costs of childbearing, the transition to agriculture in Locay's model has important implications for both the standards of living and the growth rate of the population. In terms of Figure 3, Locay shows that an increase in agricultural productivity provokes a decrease in the degree of nomadism, which in turn makes parents substitute away from food consumption and towards raising more children. Indeed, in some cases, Locay argues, decreasing nomadism may increase the relative costs of parental food consumption, consequently leaving parents with an overall decrease in utility from adopting agriculture (p. 746–747). This conclusion seems to accord well with archaeological evidence.

With regard to decreasing labour productivity among hunters and gatherers as illustrated in Figure 4, Locay, like Smith (1975) and North and Thomas (1977) before him, assumes over-hunting eventually provides the impetus to take up agriculture. More interesting, also with regard to Figure 4, Locay presents a scenario where persistent population growth among hunters and gatherers eventually decreases the land holdings of the individual household, thus creating population pressure. In Locay's model, the direct effect of declining land holdings per household is to undercut productivity gains from nomadism, inducing the household to increase its degree of settlement. The effect of smaller land holdings on the number of children is therefore ambiguous. The less land that is exploited, Locay assumes, the lower the benefits from nomadism on subsistence activities. Less land therefore, on the one hand, decreases parents' food output. This causes both the number of children and the parental consumption to decline. On the other hand, the lower degree of nomadism at the same time has a positive effect on the number of children, because a more sedentary lifestyle reduces the relative costs of child rearing. Locay then reaches the astonishing conclusion that if the latter effect is the strongest, then population pressure actually makes parents increase their level of fertility. Population pressure in turn becomes more pronounced, thus further decreasing the household's land holdings and increasing the degree of sedentism, which favours agriculture over hunting–gathering.

Locay's result of increasing sedentism among hunters and gatherers prior to the adoption of agriculture fits well with the archaeological evidence (e.g. Bar-Yosef and Belfer-Cohen, 1989). Moreover, because of the more intensive use of land in hunting–gathering, decreasing land holdings makes agriculture relatively more attractive. Thus, population growth among hunters and gatherers in Locay's model spurs on the rise of agriculture.

3.4 *Biogeography*

From the contributions of the 1970s and 1980s, we now turn to the latest economic theories on the origins of agriculture. In attempting to explain the dominance of what he calls Eurasian societies, Diamond (1997) argues convincingly that geography has affected both the productivity and the prosperity of contemporary nations. This inspired Olsson and Hibbs (2004b) to study the effect of biogeography on long-run economic development. The term biogeography will be explained below.

Although they deal directly with the rise of Neolithic agriculture, Olsson and Hibbs devote little energy to the question of why agriculture was adopted. They take for granted that once affluent societies of hunters and gatherers discover the capacity of seeds to germinate, an event that probably happened incidentally, '[m]ore conscious experimentation was presumably [. . .] carried out' and '[o]bserving the immediate and impressive gains from such experiments, a transition then follows within a relatively short span of time' (p. 8).

With this in mind, Olsson and Hibbs set out to explore a possible link between initial biogeographical endowments, such as species of plants and animals suitable for domestication, and subsequent economic development. The authors suggest that biogeographical endowments are crucial to the timing of the transition to agriculture.[17] Because the surplus generated from agricultural production made possible the establishment of a non-food-producing sector whose members significantly promoted development in knowledge and technology (e.g. Diamond, 1997), regions that adopted agriculture at an early point in time accordingly achieved an initial advantage over less well-endowed regions. Olsson and Hibbs assert that the impact of this lead is still detectable in the contemporary global distribution of wealth.

Constructing a theoretical framework that captures the features suggested above, the authors correlate present income per-capita in 112 countries to measures of prehistoric geographic conditions and biogeographical endowments. They arrive at the remarkable result that variation in these variables explains as much as half of the international variation in per-capita income.

3.5 *Inter-Family Exchange*

Turning to a purely theoretical paper, Morand (2002) develops a model to relate population characteristics to modes of production from the Stone Age and beyond. His analysis extends from early hunting–gathering to modern industrial production. While the shift from agriculture to industry is examined in a large number of recent articles (see, e.g. Galor and Weil, 2000; Jones, 2001; Kögel and Prskawetz, 2001; Hansen and Prescott, 2002; Kalemli-Ozcan, 2002; Lucas, 2002; Tamura, 2002; Lagerlöf, 2003; Weisdorf, 2004a), our interest here solely concerns Morand's explanation of the transition from foraging to farming.

A central theme in Morand's model is the relationship between the modes of production and the nature of transfers between the members of a household. There are three kinds of household agents: children, adults and elders. The type of intergenerational exchange depends on the mode of production: Foraging is only efficient and realistic for adults who, according to a sharing rule arrived at through bargaining, share their food with the elder members of the family. Farming, by contrast, allows both adults and elders to participate in the food quest, meaning that the sharing rule is abandoned, once farming is adopted.

Inter-family exchange also characterizes the relationship between adults and their children. Adults can invest in both the quantity and the quality of their children, the latter being measured in terms of human capital. Morand only allows for human capital accumulation among farmers; hence, foraging adults care only about the quantity of children. However, in the light of the sharing rule and its attendant bargaining process, children again have an ambiguous effect on the well-being of the foraging adult. More children increase the adult's expected old-age consumption but at same time weaken the adult's bargaining power vis-à-vis his children.

Under these constraints that children place on the different modes of production, adults choose an optimal level of consumption as well as a level of fertility. Next, the adult compares the expected utility from foraging and farming, respectively. Assuming an initially low expected utility from farming, foraging becomes the chosen food procurement method. That is, we are at $L = L_1$ in Figure 1 above. From here, changes that tip the balance in favour of farming are considered.

The key parameter influencing the behaviour of foragers, Morand argues, is the availability of natural resources. In terms of Figure 1, the availability of wild resources influences the horizontal position of the MP_{HG}-curve. Natural resources may be adversely affected by changes in environmental conditions. Morand assumes that foragers primarily respond to such changes in three ways: by increasing their mobility, by broadening their diet and by decreasing their fertility (or, if possible, the costs of child rearing).[18] At the dawn of agriculture, all the three strategies were presumably used. Morand envisions the following causation, which resonates with the proposals in the archaeological literature: Increased climatic variation during the late Pleistocene caused hunters and gatherers to broaden their diet (the 'broad spectrum revolution' mentioned in Section 2). However, a climatic downturn during the early Holocene interrupted the warm trend of the Pleistocene (the 'Younger Dryas' mentioned in Section 2), bringing drier and cooler weather. This limited the availability of wild resources and prompted hunter–gatherers to contract to a few resource-rich watering holes (the 'oasis' hypothesis mentioned in Section 2). The concentration of people around these oases at a time when mobility was no longer an option and diets had already broadened to accommodate available foodstuffs left hunters and gatherers with the one possibility, to take up farming.

In keeping with 'human–plant symbiosis' (see Section 2), Morand envisions that sedentism in the small oases (p. 13) 'generated a change in the interaction between people, plants and animals that gradually increased the expected returns or yields of agricultural production'. This, in Morand's model, translates into an increase in utility from farming, shifting the MP_{A}-curve upward as in Figure 3. This mechanism suggests that agriculture arose as a response to opportunity, while the former (in the paragraph above) indicates a response to necessity.

Morand's framework expands the list of parameters that can be used to explain the rise of agriculture. By including the probability of surviving to old age, Morand is able to account for mortality risks of different types of foraging activities (e.g. big game hunting versus tuber gathering). Furthermore, in Morand's model, war against competing groups in areas subject to population pressure, a theme also important in the North–Thomas model above, is likely to lower the probability of surviving to old age.

3.6 *Non-Food Producing Specialists*

A model that, in contrast to Morand's, deals exclusively with the rise of agriculture is presented by Weisdorf (2004b). Weisdorf's model departs from other research in recognizing that a community of hunters and gatherers, with a stable population and abundant resources, may decide to take up agriculture despite an increase in the time required per unit of food produced. The reason, it is argued, is that agriculture makes food producers capable of supporting a sector of non-food-producing specialists who in turn compensate them, by providing non-food goods, for the loss of leisure time that farming entails.

The representation relies on a simple model of a closed economy that produces and consumes food and possibly non-food goods. Each individual demands a given amount of food, but once food needs are fulfilled, utility is derived from leisure time as well as non-food goods.

Foods can be collected using hunting and gathering or cultivated using agriculture. Under agriculture, growth in the stock of the community's botanical knowledge is assumed to affect the stock of foods per unit of land, whereas it does not affect the natural stock of foods on which hunters and gatherers subsist.

In addition to the time that it takes to collect or cultivate the foodstuffs, Weisdorf assumes that foragers incur a time-cost of travelling in search for food, a cost that farmers, because of their sedentary lifestyle, are spared. Farmers, on the other hand, have to defray a recurrent fixed time-cost of land preparation before foods can be cultivated, a set of costs that foragers are not exposed to. Furthermore, the communities in Weisdorf's model can choose to support a sector of non-food-producing specialists. However, parameter values are chosen such that hunters and gatherers, in accordance with evidence, do not avail themselves of such non-food producers, a fact that Weisdorf attributes to a loss of efficiency because of their nomadic lifestyle.

At first glance, agriculture appears to have the advantage over hunting and gathering; an advantage that seems to be amplified by the fact of accelerating botanical knowledge. But by adding the restriction that the time-costs of pursuing farming exceed those of foraging regardless of the level of botanical knowledge, Weisdorf's model captures an issue that has puzzled the scientific community since the 1960s. Namely, if time left over after food-generating activities is valuable, then why take up agriculture?

To begin with, parameter values are set such that $L = L_1$ in Figure 1. Weisdorf then shows how demographic and climatic pressures force the community to take up agriculture. Climatic pressure reduces the natural stock of foods upon which hunter–gatherers subsist, causing a downward shift in the MP_{HG}-curve as in Figure 2. Demographic pressure translates into an expansion in the size of the labour force as illustrated in Figure 4. In both the cases, agriculture in Weisdorf's model emerges because the pressures eventually push the time-costs of foraging above those of farming.

Meanwhile, Weisdorf insists – and this is the core result of his model – that agriculture may be adopted despite being relatively time-cost inefficient; that is, in the absence of climatic or population pressures. It is demonstrated that if food producers are capable of supporting a sector of non-food specialists that can compensate them for lost leisure by providing non-food goods, then the shift to agriculture simply occurs when a given level of botanical knowledge is reached. In principle, this corresponds to an upward movement in the MP_{A}-curve as in Figure 3.

Weisdorf's framework also serves to explain why increasing population densities are observed in relation to the rise of agriculture. Whereas population concentration among hunters and gatherers translates to increased time spent on the search for food, a larger, sedentary farming community means that the time-costs of land preparation can be distributed among more people. The transition from foraging to farming thus alters the effect of population concentration on time left after food-generating activities from decreasing it to increasing it.

3.7 *Demographic Growth*

A model that deals specifically with demographic changes in relation to the rise of agriculture is found in Olsson (2001), who, like Locay (1989), sets out to compare a number of archaeological and anthropological explanations for the emergence of agriculture. In Olsson's model, the individual's only concern is to allocate his labour between foraging and farming in an optimal manner. In optimum, a condition which Olsson refers to as the 'agricultural transition condition' (ATC), individuals allocate their labour such that the marginal product of labour in farming equals that in foraging. Initially, although, parameter values are chosen such that the marginal product from foraging exceeds that of farming, i.e. such that the ATC is not fulfilled. In terms of Figure 1, this corresponds to a situation where $L = L_1$.

Olsson's model introduces a number of features not discussed above. One aspect concerns the growth rate of the population among foragers and farmers, respectively. Olsson assumes that individuals involved in foraging are subject to 'Malthusian' population growth. That is, population growth is possible only when labour productivity improves. Because labour productivity in foraging responds mainly to changes in the natural environment (and possibly to time), an increase in the forager's family size is left more or less to chance. By contrast, Olsson identifies the population growth among farmers as 'Boserupian'. Because of their sedentary lifestyle, which reduces the costs of raising children, and to the fact that land suited to agriculture was not constrained at the time, individuals involved in farming are assumed to increase the size of their families regardless of whether or not productivity improves, i.e. in an exogenous manner.[19]

In order to reach an interior solution where both foraging and farming are practised, the ATC needs to be fulfilled. In Olsson's model, four types of underlying factor can potentially bring about the three changes illustrated in Figures 2–4: these are environmental, demographic, cultural and external. Environmental and demographic changes are the factors traditionally expected to affect the marginal product of labour and the size of the labour force, respectively. Cultural and external changes account for some of the alternative explanations of the origins of agriculture.

Cultural changes are embodied in a parameter in the individual's preference function. The magnitude of this parameter reflects the degree to which agriculture is preferred or opposed. Such preferences, Olsson mentions, could for instance be founded on religious beliefs (p. 14). In terms of the illustration in Figure 1, changes in this cultural parameter shift the MP_{A}-curve upward (in the case of 'preferred') or downward (in the case of 'opposed'). In consequence, Olsson's construction suggests that cultural changes alone are capable of causing the transition to agriculture.

External changes, in accordance with the 'people–plant interaction' hypothesis (see Section 2), may appear as incidental positive externalities arising from human intervention with plants and animals. Such changes include, for example, genetic alterations that improve some species' suitability for domestication. This, in Olsson's model, translates into an increase in labour productivity in farming, i.e. an upward movement in the MP_{A}-curve as illustrated in Figure 3.

An important refinement in Olsson's model compared with some of the others presented here consists of the recognition that, once the ATC, for whatever reason, is fulfilled, the labour force is bound to increase. This is because groups who undertake farming become subject to Boserupian rather than Malthusian growth. Thus, once farming has been introduced, population expansion gradually increases the share of labour involved in agricultural activities. This, in Olsson's model, has important implications for standards of living in the aftermath of the transition to agriculture. Olsson considers a community that shares its total food production equally among its members. From a situation where the entire labour force are engaged in foraging, a sudden increase in agricultural labour productivity allows the ATC to be fulfilled, immediately increasing standards of living of the community members. This is illustrated in Figure 5, where the area B is the additional total output available to the community when agriculture is adopted.

However, after the introduction of agriculture, standards of living may eventually decline as the size of the community's population gradually increases. This occurs when foraging workers, whose total number is not influenced by the increase in the size of the total labour force, remain more productive than farmers. The extra output that the foragers are capable of generating (the area marked A in Figure 5), when equally distributed, yields progressively less per individual the more there are to share it.

Because there are no 'positive checks' among farmers, i.e. growth in the size of the farming household is not correlated with household consumption levels, standards of living may eventually fall below those prevailing prior to the

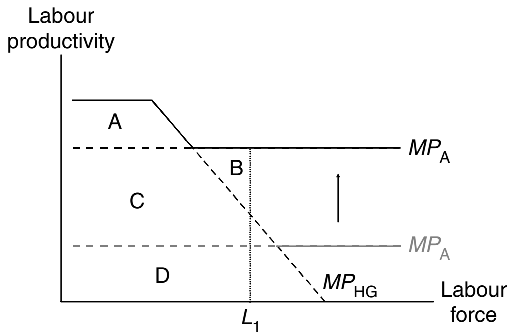

Figure 5. Olsson's (20001) Result.

adoption of agriculture. In terms of Figure 5, this is the case if the average marginal product of foraging labour (which asymptotically approaches the marginal product of farming labour, MP_A, when L increases) is smaller than the average productivity of the L_1 workers prior to the upward shift in MP_A (i.e. the area A + C + D). Olsson's population dynamics thus enable him to answer the puzzling question of why still more people went into agriculture despite falling standards of living.

In the final part of his article, Olsson confronts his model with evidence from one of the earliest farming sites, the Jordan Valley. He concludes that environmental factors, along with genetic changes in the species suitable for domestication, at least for this specific region, were the factors most likely to have paved the way for agriculture.

4. Concluding Remarks

The purpose of this article was to acquaint the reader with the main theories and evidence on the origins of agriculture. Section 2 provided a brief historical survey of the leading hypotheses that have appeared in the archaeological and anthropological literature, while Section 3 offered a more detailed review of the related contributions in the economic literature.

What has the economic literature contributed so far? Economists are more accustomed than other social scientists to dealing with issues of constrained choice. Hence, perhaps the most important contribution by economists is the introduction of explicit theoretical frameworks. These allow a more detailed discussion of the effects of changing various parameters, thus enabling a form of empirical testing that is difficult to perform in the absence of explicit modelling.[20] The introduction of explicit frameworks also allows for multiperiod analysis suitable for studying transitional dynamics.

There seems to be widespread agreement that no single model so far proposed is entirely satisfactory (e.g. Harlan, 1995; Smith, 1995; Fernandez-Armesto, 2001), and for the theorist interested in rationalizing the transition from foraging to farming, new evidence is constantly appearing. For instance, there is evidence that indicates that sedentism occurred prior to and independent of the transition to agriculture (Bar-Yosef and Belfer-Cohen, 1989, 2000) and that tools for agricultural production were already available to the foragers who eventually took up farming (Bar-Yosef and Kislev, 1989). Evidence also suggests that agriculture appeared in relatively complex, affluent societies, where a wide variety of foods were available (e.g. Price and Brown, 1985; Bar-Yosef and Kislev, 1989; Smith, 1995) and that these societies were circumscribed by other societies whose environmental zones were poorer in resources (Smith, 1995). It also appears that the egalitarian nature of foraging societies was replaced by hierarchical social structures among agriculturalists (e.g. Price, 1995; Diamond, 1997; Fernandez-Armesto, 2000) and that bands of hunters and gatherers had a communal organizational structure, whereas household level organization prevailed among farmers (e.g. Gebauer and Price, 1992).

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Notes

1. The term 'Neolithic Revolution' was introduced by the reputable archaeologist Childe (1936). Some writers prefer the term 'agricultural revolution'. It is important, although, not to confuse the Stone Age agricultural revolution with the period of rapidly increasing agricultural productivity in the centuries prior to the Industrial Revolution.
2. The aim of the current article is to survey the theories in as neutral and unbiased a manner as possible. For a more critical review of some of the major theories on the origins and spread of agriculture, see Pryor (2003).
3. According to Gebauer and Price (1992), there are at least 38 distinct and competing explanations of how farming emerged.
4. According to Deevey (1960), the number of humans on the planet 300,000 years ago is estimated to be a total of one million. At the time of the Neolithic Revolution, some 10,000 years ago, there was an estimated 5 million people. At the time of the Roman Empire, roughly 8,000 years later, there were 133 million people worldwide. This implies that the population grew 70 times more rapidly during those 8 millennia than the previous 300,000 years. If we include the 2 millennia taking us to the present day, the average annual growth rate over the past 10,000 years has been more than 123 times that prior to the Neolithic Revolution.
5. Still other evidence seems to indicate that population growth was the consequence rather than the cause of the adoption of agricultural (see, e.g. Brorson, 1975).
6. Unless specifically noted, all dates are un-calibrated radiocarbon years.

7. See also Lemmen and Wirtz (2003) for an article that examines climatic variability in relation to the rise of agriculture.
8. 'Modern' economic growth refers to growth since the first Industrial Revolution (see Kuznets, 1966).
9. Archaeologists refer to this as an 'open donor system' (see Binford, 1968, pp. 329–330).
10. The same conclusion would be reached in a situation with diminishing returns to labour on agriculture. The only additional requirement would then be that the labour productivity in agriculture decline marginally less than hunting–gathering productivity.
11. Note that agricultural *specialization* arises only when changes in the marginal product of labour are so pronounced that labour productivity in farming exceeds labour productivity in foraging regardless of the size of the labour force.
12. Obviously, Smith's hypothesis came prior to evidence of a missing link between animal extinction and the rise of agriculture (see Section 2).
13. Smith (1992) again touches upon the subject of prehistoric economic development but does not focus on the rise of agriculture; rather he deals more broadly with the emergence of humankind, with the importance of human capital accumulation and with how we were shaped by economic principles.
14. A similar version of their article is found in North (1981). See also Pryor (2003) concerning the subject of property rights and the rise of agriculture.
15. The weak link in this theory, as pointed out by Persson (1988, p. 20), is the implicit assumption that foragers fail to develop similar territoriality.
16. This conclusion is analogous to that in Smith (1975), although Smith's model generates the result in a somewhat more sophisticated manner.
17. This idea is related to Braidwood's 'nuclear zones' (see Section 2), defined as areas where plants and animals were naturally better suited to domestication than others (Braidwood, 1963).
18. In effect, one response may affect the other; for instance, increasing mobility may, because of the immobility of pregnant and lactating women, increase the costs of childrearing (p. 11).
19. Olsson does acknowledge, however, that the population growth among agriculturalists will eventually assume a Malthusian trajectory once the agricultural economy becomes so widespread that it runs up against the land constraint.
20. One of the main weaknesses of many of the theories about the origins and spread of agriculture put forwards in the archaeological and anthropological literature, as pointed out by Pryor (2003), is that they are difficult to test.

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