The Rise of Neolithic Agriculture

-

Working Paper in Economics No 57

Dept of Economics, Göteborg University

Ola Olsson*

Department of Economics,

Göteborg University

email: ola.olsson@economics.gu.se

September 25, 2001

Abstract

The article analyzes the economic reasons behind the rise of Neolithic agriculture some 10,000 years ago in consideration of evidence that agriculture was not associated with increasing standards of living. On the basis of archeological and anthropological literature, the article presents a modelling framework that allows for four broad explanations to the agricultural transition; (i) environmental conditions, (ii) population pressure, (iii) cultural influence, and (iv) external factors. It is shown that the introduction of agriculture first increases welfare but then leads to a steady decline. The reason for this deterioration is the switch from a pure Malthusian population growth regime to a partly exogenous regime where population grows without constraints and drive hunter-gatherers into agriculture in a Boserupian manner. When the model is confronted with archeological evidence from the Jordan Valley, it appears that environmental change, population growth, and a uniquely favourable biogeography for domestication led to the introduction of agriculture.

Keywords: agriculture, hunting-gathering, environment, technology, population, transition.

JEL Codes: N55, O33, Q18

1 Introduction

The rise of agriculture some 10,000 years ago is arguably one of the most crucial events in the history of mankind. From having been nomads, following herds

*The paper has benefitted from discussions with Susanna Lundström and seminar participants at Göteborg University. Generous financial support from Jan Wallander and Tom Hedelius' Foundation is greatfully acknowledged.

of wild prey and collecting what nature had to offer, humans became sedentary village-dwellers, relying on domesticated plants and animals for their daily survival. Wherever this shift happened - in China, the Andean highlands, or in the Near East - it soon initiated a development towards centralized power, social stratification, city and state formation, and other marks of what we usually refer to as "civilization".

In the older literature, this process was traditionally regarded as a "revolutionary invention", purposefully made by welfare-maximizing rational individuals in search of a more efficient mode of food production. Agriculture was seen as a natural, almost inevitable step away from the hunter-gatherer lifestyle that the philosopher Thomas Hobbes characterized as "nasty, brutish, and short". However, archeological and anthropological research during the last decades have demonstrated that there are almost no indications of increased standards of living after the agricultural transition. Rather, it appears that the early agriculturists had to work more hours (Harlan, 1995), were more prone to lethal disease and malnutrition (Diamond, 1997; Cohen and Armelagos, 1984), and had to endure less egalitarian social structures than hunter-gatherer societies (Wittfogel, 1957; Fernandez-Armesto, 2000). If this is so, then rather than being a blessing or a sign of maturity, the transition to agriculture seems like something of a curse. What, indeed, is the economic rationale for its occurrence?

In this article, I present a model of the transition to agriculture where utility maximizing stone age individuals allocate their labour either to hunting-gathering or to agriculture. Initially, labour productivity is too low for any agricultural sector to be created. A small fraction of the population becomes sedentary agriculturists when the marginal product in the farming sector matches the marginal product in the hunting-gathering sector. This situation arises as a result of at least one of the following influences, which broadly correspond with the major hypotheses discussed in the scientific literature: (i) Environmental conditions (Childe, 1935; Diamond, 1997), (ii) external effects of hunting-gathering (Rindos, 1989; Smith, 1998), (iii) population pressure (Binford, 1968; Cohen, 1977), or (iv) a cultural preference for agriculture (Hayden, 1990; Fernandez-Armesto, 2000).

Once an agricultural sector has been created, population dynamics switches from a Malthusian regime (Malthus, 1798) - where the level of population is proportional to hunting-gathering labour productivity and levels of subsistence - to a partly exogenous regime where population growth is unconstrained. Increased population pressure then forces an increasing number of hunter-gatherers into agriculture in an irreversible process that eventually makes the hunting-gathering sector infinitesimally small. After an initial increase in output per capita, standards of living gradually decline towards or even fall below the hunting-gathering subsistence level.

The rise of Neolithic agriculture has not been a frequently studied subject in economics. In a classical study of the conditions of agricultural growth, Boserup (1965) argues that exogenous population growth forces farmers to shift from agricultural production systems with low land use intensity such as forest-fallow cultivation, to more and more intensive practices. Although the analysis does not explicitly deal with hunter-gatherers, Cohen (1977) shows that the Boserupian framework easily can be extended to an argument where population pressure is the primary cause of the agricultural transition. In a model of long-run development, Goodfriend and McDermott (1995) assume that exogenous population growth induces people to leave a primitive, non-specialized sector to enter a specialized market sector. This scenario corresponds, according to Goodfriend and McDermott, to the first appearance of cities around 5,000-6,000 year ago.

Boserup's view of population growth as the engine of technological change is the opposite of Malthus' (1798) theory of technology determining the equilibrium level of population. Malthusian economic models of the long-run relationship between technology and population growth include Kremer (1993), Hansen and Prescott (1999), Galor and Weil (2000), and Galor and Moav (2001). Using Kremer's (1993) data on population, Jones (2001) constructs and simulates a model of growth in the very long run. The results suggest that a dramatic upsurge occurred around 5000 B.C. which, Jones argues, coincides with the emergence of civilization in the form of cities, writing, and scientific observation.

Despite their long-run perspective, none of the models above focuses on the transition to Neolithic agriculture. Considering the great importance that historians and archeologists generally attach to this process, the neglect is somewhat surprising. Indeed, it might be argued that the rise of cities - an event which McDermott and Goodfriend (1995) and Jones (2001) view as the first crucial milestone in man's history - was merely a natural consequence of the change in technology for food production.

An exception to the general pattern is Olsson and Hibbs (2000) who provide a long-run model with Malthusian population assumptions but where technological progress is a function of the quality of the surrounding natural environment. Following Diamond (1997), the model predicts that people in regions with many suitable plants and animals for domestication pass a critical agricultural threshold first and then go on to develop intensive irrigated farming, cities, writing, and a non-producing class of specialists, scientists, and kings. Furthermore, Morand (2001) presents an overlapping generations, Nash bargaining-framework where hunter-gatherers switch to agriculture when the marginal utility of the latter exceeds the former. On the basis of an extensive review of the archeological and anthropological literature, Morand concludes that population pressure in combination with climatic stress probably were the factors that tipped the balance in favour of agriculture.

The model presented in this article differs from the existing literature in several respects. First, the model allows for several different explanations for the agricultural transition, including environmental factors, population changes, cultural influences, and unintentional, external effects of hunting-gathering. These explanations correspond to those discussed in archeological and anthropological research. Second, the model provides an explanation to the puzzle why rational hunter-gatherers took up agriculture although it resulted in similar or lower levels of welfare. The key to this result is a synthesis of the Malthusian and

Boserupian views on the links between population and technology. Finally, unlike earlier work, the article confronts the predictions of the model with specific archeological evidence from the Jordan Valley.

The article is organized as follows. Section two elaborates on the distinguishing features of hunting-gathering and agriculture with a particular emphasis on the definition of plant and animal domestication. Section three presents the basic model, whereas sections four and five analyze possible reasons for the transition and the implications for sectoral composition and welfare. Section six presents empirical evidence from the Jordan Valley. Lastly, section seven concludes the article.

2 Hunting-Gathering versus Agriculture

In order to understand the reasons behind the transition from hunting-gathering to sedentary agriculture, it is necessary to relate the differences between these two fundamental technologies of subsistence production. During the long era from the origin of modern human beings in Africa 100,000-200,000 years ago up until around 10,000 B.C., hunting-gathering prevailed everywhere in the world. The practices of these early humans displayed an enormous degree of variation that depended on the character of the natural environment and on the state of technology attained. Furthermore, as pointed out by many authors, to describe the transition to agriculture in Childean terms as a "revolution" (Childe, 1935) is misleading. Rather, what is at hand is an evolutionary continuum of people-plant-animal interaction.

Harris (1989) presents a model of a transition in four stages, where each stage implies an increase in human energy input per unit area of exploited land. The first stage involves *wild plant-food procurement.* The hunter-gatherers in this stage occasionally burn the vegetation, they gather and protect useful plants and fruits and thereby reduce competition between plants and disturb the soil. Human energy devoted to this activity is minimal and the environment is not dramatically changed. Nevertheless, the wild plant-food procurement-economy marks a departure from even more primitive stages, characterized by *immediate return strategies* such as scavenging (Harlan, 1995).

The second stage is described as *wild plant-food production with some tillage.* This is clearly an important step towards agriculture. Maintenance of plant populations in the wild is carried out and both planting and sowing of wild plants are undertaken, as well as weeding. Seeds from selected plants with desirable characteristics are propagated in new habitats. When harvesting is completed, some of the seed is stored for future use. Although Harris' model deals with the development of plant cultivation, this stage might also be associated with the capturing and keeping of animals. Harlan (1995) describes these kind of activities as *delayed return strategies* since the purpose is always to increase the economic contribution of the environment and to reduce risk over a long time horizon.

The third stage is *cultivation with systematic tillage.* Land is cleared and the food-producing activities that were introduced in the previous stage (sowing, weeding, propagation of plants, etc.) are intensified. The composition and structure of the vegetation are now significantly transformed. The size and density of the population increase and people become sedentary. The new technology for food production is highly energy intensive. The first cultivation of this kind probably had the character of fixed-plot horticulture (Sherratt, 1997). As the selective cultivation of plants proceeds, new genotypes eventually appear that more efficiently serve human needs. Plant domestication thus marks the transition to the fourth and most energy intensive stage in Harris' model; *agriculture*.

A more exact definition of domestication is: "...the human creation of a new form of plant or animal - one that is identifiably different from its wild ancestors and extant wild relatives.//[the new species] have been changed so much that they have lost their ability to survive in the wild." (Smith, 1998, p 18-19). In practice, it is no easy task to determine when a wild plant or animal has been domesticated. Regarding grasses like wheat and barley, important morphological markers for domestication are a relatively large seed size, a thinner seed coat, and packaging in compact clusters at the end of stalks. As for animals, markers of domestication vary between species. The horns of domesticated sheep and goats differ in several respects from those of their wild ancestors, domesticated pigs have smaller teeth, and domesticated cattle are generally smaller than their wild ancestor the auroch (Smith, 1998).

As is shown in Table 1, the hunter-gatherers of the Near East (Fertile Crescent) were probably the first to adopt an agricultural lifestyle around 8500 B.C., based upon the cereals barley and wheat and on domesticated goats and sheep. They were followed by the maize-cultivators of Central Mexico around 8000 B.C. and the rice producers along the Yangtze River around 7500 B.C. Apart from those mentioned in the table, plausible centers of independent transitions to agriculture include New Guinea, Ethiopia, and Tropical West Africa (Diamond, 1997). Recent genetic research has indicated that multiple domestications of the same wild plants and animals probably have occurred more often than previously believed. For instance, it has been shown that apart from in the Near East, the goat was independently domesticated in the Indus Valley (Luikart et al, 2001) whereas cattle was domesticated both in the Near East and in East Asia (Troy et al, 2001).

It should be emphasized that far from all peoples on earth went through the four stages of Harris' (1989) model by their own initiative. In Europe, for instance, agricultural practices were adopted only after the spread of domesticated plants and animals from the Near East. It is now believed that this diffusion process to Europe happened as a result of peaceful trade rather than through conquests or migrations of people from the Fertile Crescent (Smith, 1998). In Africa, however, it appears that Bantu-speaking agriculturalists expanded east- and southward from their West African origin, thereby replacing populations of hunter-gatherers (Diamond, 1997). A few remaining hunter-gatherer groups such as the San of the Kalahari Desert and the Aboriginals of Australia have still not today adopted agricultural production.

Table 1: First attested dates of independent transition to agriculture and the main domesticates.

Region	Date	Plants	Animals
Near East	8500 B.C.	wheat, barley	goat, sheep
Central Mexico	8000 B.C.	maize	turkey
South China (Yangtze River)	7500 B.C.	rice	pig
North China (Yellow River)	6800 B.C.	millet	pig
South Central Andes	5800 B.C.	potato, manioc	llama
Eastern United States	3200 B.C.	sunflower	none
Sub-Saharan Africa (Sahel)	2500 B.C.	sorghum	none

Source: Calibrated calendar dates are derived from Smith (1998). Examples of domesticated plants and animals are from Diamond (1997).

3 The Model

The previous section described *how* the transition to agriculture occurred but not *why*. In particular, why did hunter-gatherers in China, Central America and the Near East - independently from one another and without influence from neighbouring peoples - develop a new technology for food production dependent on domesticated plants and animals? As was mentioned in the Introduction, archeological and anthropological evidence suggest that agriculture was rather associated with a decline in standards of living than with an increase. In this section, I outline a simple model of primitive food production in hunter-gatherer and agricultural economies. As will be demonstrated below, the model offers a framework for analyzing the different theories of agricultural transition.[1]

3.1 Production

Let us assume that there are only two fundamental technologies for food production, hunting-gathering and agriculture, and that agriculture is defined as food production depending on domesticated plants and animals.[2] The population forms a single community in which all food is shared equally. The production function for hunting-gathering is

$$Y_t^H = B_t \left(\gamma_t L_t\right)^{\beta} \tag{1}$$

where Y_t is total output at time t, L_t is total population, $\gamma_t \in [0, 1]$ is the share of the population engaged in hunting-gathering activities at time t, $\beta \in (0, 1)$ describes the (diminishing) returns to labour input, and B_t is a labour productivity factor to be defined below. The assumption that γ_t is allowed to

[1] A similar model, but with overlapping generations and Nash bargaining between generations, is presented in Morand (2001).

[2] The hunter-gatherer technology that is modelled here is meant to describe relatively advanced and mature activities, i.e. such that might be characterized as delayed return strategies and that would fall within Harris' (1989) second and third stages of transition involving tillage and cultivation of wild plants.

lie somewhere in the interval $[0, 1]$ means that a mixed economy is possible.[3] However, the point of departure will be a situation where $\gamma_t = 1$. The output elasticity of labour is diminishing. Output per capita from hunting-gathering is therefore given by $y_t^H = B_t \gamma_t^\beta L_t^{\beta-1}$, implying a Malthusian negative relationship between total population increases and food per person. Time is discrete and the interval between t and $t+1$ might be thought of as a century.

Total agricultural output, based on domesticated plants and animals (Harris' fourth stage), has the following linear production function:

$$Y_t^A = A_t (1 - \gamma_t) L_t \tag{2}$$

In this expression, A_t is labour productivity at time t and $(1 - \gamma)$ is the share of the population active in agriculture. In these early times of farming, the returns to increasing the labour force are not subject to diminishing returns. Hence, output per capita from agricultural production is not a decreasing function of labour; $y_t^A = A_t (1 - \gamma_t)$.

3.2 Population

The size of the population follows the following law of movement:

$$L_{t+1} = L_t [1 + \gamma_t \rho (B_{t+1} - B_t) + (1 - \gamma_t) \eta] + \varepsilon_{t+1} \tag{3}$$

The new parameters in this equation are $\rho < 1$ that captures the strength of the Malthusian effect on the hunter-gatherer population, $\eta > 0$ which is the exogenous growth rate of the agricultural population, and the normally distributed error term $\varepsilon_{t+1} \sim (0, s_\varepsilon)$ that reflects random, exogenous events such as migrations or invasions of people from other environments or catastrophes caused by nature or war.

The key feature of (3) is that it describes two distinct population growth processes. The first one is the Malthusian process that prevails among hunter-gatherers. The expected population growth rate in this sector $\rho (B_{t+1} - B_t)$ depends linearly on the growth in labour productivity from t to $t+1$. Hence, a sustainable increase in the expected level of population is only possible through an increase in labour productivity. Should labour productivity decline so that $B_{t+1} - B_t < 0$, "preventive checks" such as abortion, infanticide and other conscious methods at keeping the population low, and "positive checks" such as disease and famine, interact to force a necessary reduction in population (Malthus, 1798)

The population growth rate in the agricultural economy η is exogenous and independent of labour productivity levels. Furthermore, during normal years, it will be the case that $\eta > \rho (B_{t+1} - B_t)$, i.e. the expected growth rate is higher in the agricultural sector. This corresponds to a stylized fact emphasized repeatedly in the literature (Harris, 1977; Harlan, 1995; Diamond, 1997). The primary reason for this inequality is that farmers, in general, are sedentary

[3] Even in recent times, hunting of big mammals and gathering of wild berries and fruits remain important sources of food for many farmers.

whereas hunter-gatherers are not. Being almost constantly on the move, following wild prey or searching for edible fruits, the hunter-gatherer opportunity cost of having babies who have to be carried along is substantial. Hence, women develop "preventive checks" for keeping long intervals between births. The transition to a sedentary life in farming villages significantly reduces the opportunity cost of raising children. In addition, a sedentary man spends many more hours under the same roof as his woman than does a nomadic hunter. Evidence cited above also suggests that life in densely populated communities increases mortality due to disease. Despite these losses, the net result was clearly a more rapid increase in population.[4]

Further empirical support for a distinction between hunter-gatherer and agricultural population growth can be found in prehistorical population data from Kremer (1993). The time series presented there strongly suggest that a transition from a pure Malthusian to a higher and partially exogenously driven population growth occurred as a result of the introduction of sedentary agriculture. Figure 1 shows how the annual world population growth rate lingered between 0.0004 and 0.0045 percent in the era 300,000-10,000 B.C., whereupon growth rates suddenly increased dramatically sometime around 5000 B.C. to lie in the range 0.03-0.13 percent with a cluster around 0.06. The contention of this article is that such a change is not compatible with Malthusian growth, dependent on increases in labour productivity. It would suggest that labour productivity started increasing enormously around 5000 B.C. Even though this time period, as noted by Jones (2001), saw the emergence of agriculture, cities, and civilization in some parts of the world, archeological evidence cited in this article do not indicate a labour productivity shock of such a magnitude. The fundamental change was rather the new pattern of sedentary agriculture that allowed much higher population densities. Sedentism, in turn, initiated a new population regime and a Boserupian process which rapidly pushed people out of hunting-gathering and speeded up technological progress to previously unprecedented levels.

3.3 Productivity

Total output per capita y_t equals the sum of output from hunting-gathering and agriculture. Furthermore, all output is consumed:

$$y_t = y_t^A + y_t^H = A_t (1 - \gamma_t) + B_t \gamma_t^{\beta} L_t^{\beta - 1} = c_t \tag{4}$$

Equation (4) highlights the crucial influence of the labour productivities B_t and A_t for food production. What determines the levels of these variables? The answer is *man's ability* and the *quality of his environment.*

[4]There are, however, important exceptions to this simple distinction between hunter-gatherer and agricultural population dynamics. The Jomon hunter-gatherers in the Japanese islands lived in villages and could develop dense populations due to intensive exploitation of a very abundant wild plant (Harlan, 1995). I will return to the effect of sedentism on population size below.

The most fundamental factor is probably the natural environment. The natural environment, in turn, depends on *biogeography* and *climate*. On a given land area, one hunter-gatherer is obviously more productive the greater the number of edible plants and animals, the greater their abundance, the higher their nutritional value, and the easier their procurement and preparation. Likewise, agricultural labour productivity depends on the number of species suitable for domestication, their abundance in the wild, their ease of domestication, their nutritional value, and the quality of the soil and climate. To formalize this notion, let N^H denote an index of environmental quality for hunting-gathering that captures the factors mentioned above and let N^A be an index of agricultural environmental quality.

It should be pointed out that N^H and N^A are not necessarily independent of each other. The wild plants and animals that eventually became domesticated were often hunter-gatherer favourites that had yielded a vital source of food before domestication (Smith, 1998). Similarly, a favourable climate and a fertile soil are beneficial to both hunting-gathering and agricultural production. Hence, all else equal, it should often have been the case that the higher the quality of the environment for hunting-gathering (N^H), the greater the potential for agriculture $\left(N^A\right)$.

Apart from a favourable physical environment, labour productivity also depends on the state of technological knowledge. Needless to say, in Paleolithic and Early Neolithic times, there was no research sector of the kind that plays such an prominent role in modern endogenous growth theory. Technological progress during these times is better described as *learning-by-doing* or simply a result of *evolution*.[5] But even this process was painstakingly slow during most of human history. Not until the "Great Leap Forward" around 50,000 years ago - coinciding with the population of Europe by modern "Cro-Magnon" people - did the pace of technological advance reach perceptible levels (Diamond, 1997).

When some hunter-gatherer economies in environments favourable for agriculture reached the cultivation stage in the late Paleolithic era, the transition to agriculture was partly only a matter of time. After decades of selective experimenting with the most nutritious plants, the genetic structure eventually changed. The necessary genetic changes were sometimes very small. For instance, a single-gene mutation in wild wheat prevents the stalks from spontaneously shattering, which makes the human collection of its seeds much easier (Diamond, 1997). A new kind of crop evolved surprisingly quickly in response.[6] As discussed above, this early domestication of plants was largely unintentional and must have astonished the people who experimented with grass cultivation.

In light of all this, I propose that the labour productivities in hunting-

[5] Galor and Moav (2001) outline a model where a mutation in the human species introduces a genotype that favour child quality before child quantity. Such households have an evolutionary advantage in early history and gradually increase their numbers. Technological advance eventually takes off when the share of "quality-types" is large enough. See also Rindos (1989) for a discussion of the role of Darwinism in plant and animal domestication.

[6] Smith (1998) cites evidence suggesting that morphological changes might appear already within a couple of centuries.

gathering and agriculture might be viewed as functions of natural environment and time:

$$B_t = B\left(N^H, t\right) \qquad A_t = A\left(N^A, t\right) \tag{5}$$

The partial derivatives and discrete changes of these general functions have the following assumed signs:

$$\begin{gathered} \frac{\partial B\left(N^H, t\right)}{\partial N^H} > 0, \qquad \frac{\partial A\left(N^A, t\right)}{\partial N^A} > 0, \\ B\left(N^H, t\right) \leq B\left(N^H, t+1\right), \qquad A\left(N^A, t\right) \leq A\left(N^A, t+1\right), \\ B\left(N^H, t+1\right) - B\left(N^H, t\right) > B\left(N^H, t+2\right) - B\left(N^H, t+1\right) \end{gathered} \tag{6}$$

Hunter-gatherer labour productivity $B(\cdot)$ increases with increases in N^H and t, holding the other variable constant, but the mere effect of time is gradually diminishing ($B_{t+1} - B_t > B_{t+2} - B_{t+1}$) so that the marginal increment tends to zero. This reflects the notion that without domestication, hunter-gatherers' further learning of a particular environment must sooner or later cease. Agricultural productivity increases with N^A and with time. However, the time path of A_t is otherwise left unspecified. The reason is that I allow for the possibility of a segment of time where the development of $A(\cdot)$ jumps in a discontinuous fashion. This is meant to capture the stage when hunter-gatherers have started experimenting with exceptionally potent wild species in a manner that causes a rapid genetic change that greatly improves yields.

3.4 Utility

The utility function for a representative agent in this stone age economy is assumed to be a simple linear function of current per capita consumption c_t and of the level of γ_t:

$$U_t\left(c_t, \gamma_t\right) = c_t + \alpha\gamma_t \tag{7}$$

α measures the strength of preference for a high share of the population in hunting-gathering. As was discussed in the Introduction, a cultural preference for agriculture - perhaps for religious reasons - would imply an $\alpha < 0$. Just as plausible, however, would it be to imagine that people feel a certain resistance toward dramatic social changes, even when a decline in material standards calls for a change. There are indeed many examples in history of a conservative bias in this respect (see, for instance, Mokyr, 1990). In this situation, we would have $\alpha > 0$. An individual whose only concern is her level of consumption would have $\alpha = 0$, i.e. γ_t affects her utility only indirectly through its effect on c_t.

The representative agent's only control variable is the allocation of labour between hunting-gathering and agriculture, γ_t. All other variables - the subsistence level of output, the quality of the natural environment, the speed of learning, and the level of the population - are beyond her direct influence. Hence, the utility-maximization problem for the representative individual is to find the optimal level γ_t^* where marginal utility is zero. Substituting in (4) and (5) into (7), the first-order condition for an interior maximum is

$$\frac{\partial U(c_t, \gamma_t)}{\partial \gamma_t} = -A\left(N^A, t\right) + \frac{\beta B\left(N^H, t\right)}{\left(\gamma_t^* L_t\right)^{1-\beta}} + \alpha = 0 \tag{8}$$

with the second-order condition being $\frac{(\beta-1)\beta B\left(N^H,t\right)}{L_t^{1-\beta}\gamma^{2-\beta}} < 0$ as required. The expression in (8) is simply the sum of the marginal products of γ_t in agriculture and in hunting-gathering, plus the hunting-gathering preference-parameter α. However, an interior solution does not necessarily exist. The expression in (8) might be positive at all γ_t due to too low levels of $A\left(N^A, t\right)$, implying a boundary solution where $\gamma_t^* = 1$. The emergence of an interior solution - i.e. when some fraction of the population is engaged in agriculture - is the issue that will be treated in the next section.

4 Transition Analysis

The first-order condition for maximum in (8) can be easily rewritten into:

$$\frac{\beta B\left(N^H, t\right)}{\left(\gamma_t^* L_t\right)^{1-\beta}} = A\left(N^A, t\right) - \alpha \tag{9}$$

As indicated above, what this equilibrium expression says is that the marginal product of an increased share of the population in hunting-gathering (MP^H), evaluated at $\gamma_t = \gamma_t^*$, must equal the marginal product in agriculture (MP^A) minus the hunting-gathering preference parameter α. By taking the derivative of MP^H with respect to γ_t, we receive the second-order condition $\frac{(\beta-1)\beta B\left(N^H,t\right)}{\gamma_t^{2-\beta} L_t^{1-\beta}}$ which we know is negative at all $\gamma_t \in (0, 1]$. MP^A, on the other hand, is independent of γ_t. Thus, if the solution to (9) is $\gamma_t^* < 1$, we must have that MP^H evaluated at $\gamma = 1$ is smaller than $MP^A - \alpha$. This intuitive and important result can be restated in the following Proposition:

Proposition 1 *The transition to agriculture* ($\gamma_t^* < 1$) *will be initiated when the Agricultural Transition Condition (ATC)* $\frac{\beta B\left(N^H,t\right)}{L_t^{1-\beta}} < A\left(N^A, t\right) - \alpha$ *is satisfied.*

If the *Agricultural Transition Condition* is not fulfilled so that the expression on the right-hand side is too low to motivate any transition to agriculture, then the whole population will be hunter-gatherers and we will have the corner solution where $\gamma^* = 1$. This situation - which indeed prevailed everywhere in the world before 10,000 B.C. - is depicted in Figure 2. There we have initially that $\frac{\beta B_t}{L_t^{1-\beta}} > A_t - \alpha$ and $\gamma_t^* = 1$. Due to an upward shift in A, possibly caused by an increase in N^A, we have in the following period that $\frac{\beta B_{t+1}}{L_{t+1}^{1-\beta}} < A_{t+1} - \alpha$ and that a certain fraction $\left(1 - \gamma_{t+1}^*\right)$ of the population makes the transition to sedentary agriculture.

The ATC is thus the condition that determines the rise of Neolithic agriculture. Note that an increase in A is not the only factor that might fundamentally change the economy. The inequality expression implies that there are at least four potential forces that might push the economy into $\beta B\left(N^H,t\right)/L_t^{1-\beta} < A\left(N^A,t\right) - \alpha$: Environmental changes that affect N^H and N^A, an increase in L, a decrease in α, or an increase in $A(\cdot)$ as an external effect of normal hunting-gathering activity. These scenarios coincide with the explanations for the agricultural transition that were discussed in the Introduction. Let us discuss each case in turn.

4.1 Environmental Conditions

Environmental change is one of the most frequently discussed factors in the literature on the agricultural transition. In the model above, an increase in N^H means that the quality of environment for hunting-gathering increases. From (6), we know that such an increase would cause an improvement in hunter-gatherer labour productivity $B(\cdot)$. But from (3), we also know that increases in $B(\cdot)$ affect the level of population in a Malthusian way. By substituting in the expression for L_t into the left-hand side of the ATC, we receive

$$\frac{\beta B\left(N^H,t\right)}{L_t^{1-\beta}} = \frac{\beta B_t}{\left(L_{t-1}\left(1+\rho\left(B_t - B_{t-1}\right)\right)+\varepsilon_t\right)^{1-\beta}}.$$

$B(\cdot)$ appears both in the numerator and in the denominator. Simple calculus shows that the effect on this expression of an increase in $B(\cdot)$ is ambiguous and depends crucially on the strength of the Malthusian link, ρ. The closer ρ is to zero, the greater the likelihood that an increase in $B(\cdot)$ increases the expression above and hence decreases the likelihood of a transition to agriculture.

An improvement in agricultural environmental conditions N^A, on the other hand, has unambiguous implications; labour productivity $A(\cdot)$ increases and the ATC is closer to being fulfilled.

An obvious reason for changes in N^H and N^A might be changes in climate. It is well known that the retreat of the glaciers after the glacial maximum in the Northern Hemisphere around 18,000 years ago initiated a general warming trend. The deserts and tundras that had been relatively extensive now gave way for grasslands and forests with a greater biodiversity. Melting glaciers also meant rising sea levels and expanding aquatic habitats (Roberts, 1989). The late Pleistocene should thus generally have been an era of increasing N^H and N^A and of more favourable conditions for both hunter-gatherers and prospective agriculturists.

However, this warming trend was temporarily interrupted by a period of drier and colder climate, usually referred to as the Younger Dryas, around 9500 B.C. (Smith, 1998). This climatic downturn also coincided with the extinction of several big mammals, including mammoth, the woolly rhino, the mastodont, and the sabre-tooth tiger (Roberts, 1989). Whether this wave of extinctions was the result of human overexploitation ("overkill hypothesis") or because of climatic changes, is still a subject of debate within the scientific community.[7] In any case, from having been steadily increasing for millennia, it is most likely that the environment for hunter-gatherers deteriorated in most parts of the world during the Younger Dryas. According to Childe's (1935) "propinquity"-hypothesis , this worsening of conditions forced hunter-gatherers, plants and animals alike to retire to a few resource-rich oases. The forced proximity led to adaptations within the ecosystem that eventually resulted in plant and animal domestication.

The propinquity-hypothesis that agriculture was adopted out of "necessity" is captured in my model as declining levels of N^H and $B(\cdot)$ with a ρ close to zero. Thus, the left-hand side of the ATC would fall. However, a general worsening of climate should also have affected N^A negatively. If the decrease in N^A was as great as the decrease in N^H, then the net effects would cancel out and no transition would occur. So how did N^A evolve?

It appears that environmental conditions for prospective agriculturists did not deteriorate as much as conditions for hunting-gathering during the Younger Dryas. No wave of extinction of domesticable animals took place. In the longer term, the expansion of wetlands and fertile grasslands improved conditions for cultivation of annual plants like wild rice, as well as providing a reliable source of wild food stuffs. In reviewing the common characteristics of the independent transitions to agriculture in the Levantine corridor, Southern Sahara, and Northern United States, Smith (1998) emphasizes that experiments of domestication seems to have been carried out by relatively affluent hunter-gatherers in proximity to lakes, rivers, and marshes. Hence, rather than being a "necessary" step, the transition to agriculture according to this view was driven by "opportunity" (Diamond, 1997). This hypothesis also emerges from the ATC; the greater the number of species suitable for agriculture and the more favourable the climate $\left(N^A\right)$, the greater the labour productivity in agriculture $(A(\cdot))$ and the greater the likelihood of a transition to agriculture.

4.2 Population Pressure

The second explanation for the agricultural transition emphasizes population pressure as the main causal factor. As can be deduced from the ATC in Proposition 1, an increase in L_t decreases the marginal product of hunting-gathering and might push the economy into agriculture. However, the equation for the level of population in (3) shows that the expected level of population during hunter-gatherer times is proportional to the strength of the Malthusian link ρ and to increases in labour productivity $B(\cdot)$. In line with the discussion above, an increase in population caused by an increase in labour productivity therefore has ambiguous effects on the transition decision.

[7] It appears that as many as 79 mammals with an adult body weight of more than 44 kg were extinguished in newly populated North and South America during the terminal Pleistocene (Roberts, 1989). The much lower extinction rates in Europe and Africa might be explained by the fact that animals there had had a longer period of adaptation and coexistence with humans (Diamond, 1997).

The hypothesis that exogenous population growth was the primary determinant of the transition to agriculture in Neolithic times is associated with Cohen (1977), who borrowed many arguments from the more general theory of population and agricultural growth advanced by Boserup (1965). In Cohen's view, the Malthusian population function for hunter-gatherers as described in (3) is false. Population growth throughout history is better captured by setting ρ to zero and removing the γ:s so that $L_{t+1} = L_t (1 + \eta) + \varepsilon_{t+1}$. During most of history, hunter-gatherers could simply migrate into virgin territory when population pressure created resource shortage. No preventive checks were necessary. However, by around 10,000 B.C. such migrations were no longer possible since all major continents had been populated. The transition to agriculture was therefore made out of necessity due to a prehistorical food crisis. Cohen's hypothesis would also explain why people started to domesticate plants and animals independently from each other in several parts of the world.

Cohen's model has not been well supported by the data (Harlan, 1995). A food crisis just before agriculture was adopted would imply that the hunter-gatherers of the late Pleistocene should have had a poorer health status than the first agriculturists. As mentioned above, a general conclusion from the contributions in Cohen and Armelagos (1984) is quite the opposite; hunter-gatherers had a better health status than the early agriculturists.

In this article, population growth during hunter-gatherer times is modelled as Malthusian and dependent on the technology variable $B(\cdot)$. Nevertheless, given an ATC that is close to being fulfilled - i.e. the term $(A(\cdot) - \alpha)$ on the right-hand side is almost high enough for a transition to be plausible - then a random positive population shock ($\varepsilon_t > 0$) might indeed push hunter-gatherers over the threshold so that some fraction $(1 - \gamma_t)$ is forced to adopt agriculture.

In a famous essay, Binford (1968) argues that such a shock was indeed one of the primary causes of the shift to agriculture. Environmental changes at the end of the Pleistocene, such as those mentioned above, had led to the extinction of many big mammals and to the expansion of wetlands. People therefore settled down in permanent villages by the shores of lakes and rivers to catch abundant fish and fowl. These settlements soon created a population density beyond the critical level and some groups had to emigrate into the hinterland where more primitive hunters-gatherers roamed. This unexpected influx of people from the fishing villages created a disequilibrium in the interior region and a strong pressure towards more efficient modes of food production. In Binford's view, it was in these areas that agriculture was eventually adopted.

4.3 Cultural Influences

In the beginning of the twentieth century, Edouard Hahn proposed that domestication of animals might have been carried out for religious reasons (Harlan, 1995). The evidence motivating such a theory was primarily the observed sacredness with which cattle had been treated by many prehistorical peoples in the Old World. The famous 15,000-years-old paintings in the Lascaux cave in France shows impressive aurochs reproduced in a manner that suggests that they had a very special place in prehistorical human minds. In the early Neolithic town of Catal Hüyük in modern Turkey, around fifty excavated shrines featured sacred bulls in one form or another (Harlan, 1995).

Hayden (1990) argues that agriculture might have been adopted due to "competitive feasting" between rivaling groups of people. Yet another cultural hypothesis has been proposed by the historian Fernandez-Armesto (2000). Fernandez-Armesto argues that an "informed calculation" of the ratio of effort to return would never have induced the switch to the kind of early agriculture practiced in the river valleys of the Old World. More important than material considerations was man's innate desire to transform and assume control of his natural environment. The domestication of plants and animals should be seen as a result of a spontaneous "itch to civilize nature" rather than as a conscious move by economic man.

In the utility function, the parameter α allows for different cultural interpretations. If $\alpha < 0$, the representative individual would have a preference for having a large fraction of the population engaged in agriculture, perhaps for religious reasons as indicated above. The ATC shows that a decrease in α implies a lower right-hand side and a greater likelihood of a transition. However, I believe it would be wrong to underestimate the conservatism of people in the face of major technological change. As discussed by Mokyr (1990), more recent history suggests that vested interests often result in strong resistance to technological change. Many people during the late Pleistocene surely felt disinclined to give up nomadic life for settlement in cramped villages and backbending work in the fields. Thus, it is just as possible to imagine a $\alpha > 0$ that might indeed have risen rather than declined and thus delayed the agricultural transition.

4.4 External Effects

The last explanation for the agricultural transition focuses, loosely speaking, on the various external effects on agricultural labour productivity $A(\cdot)$ that are simply a function of time elapsed. The most fundamental force in this context is the evolution of the human species. Since the emergence of modern *homo sapiens* in Africa 100,000-200,000 years ago, natural selection should have given rise to a gradual increase in labour productivity. Galor and Moav (2001) argue that a genotype of humans that favoured child quality before child quantity grew in relative importance until their share of the population was large enough to trigger a technological "take-off". Although Galor and Moav have the Industrial Revolution in mind, the same kind of evolutionary argument could be made for the rise of Neolithic agriculture.

But even without changes in human genotypes, the accumulation of experience over the millennia should also have a positive effect on labour productivity. Rather than being anything near what modern people would label as education or research, this process is probably best described as learning-by-doing. The growth of this kind of empirical knowledge presumably also depends on the complexity and variety of the surrounding environment.[8]

As discussed above, there is also a threshold behaviour in labour productivity once hunter-gatherers have started experimenting with the right species. After a relatively short time, selective cultivation leads to genetic changes in species like emmer wheat that greatly improve their usefulness to humans. As suggested by Rindos (1989), Diamond (1997), and Smith (1998), the domestication of plants and animals was probably to a large extent an unconscious or "incidental" positive externality from intensive use of certain species. It further appears that a critical level of one or two domesticated staple crops was all that was required to set the agricultural process in motion[9]. Thereafter, the domestication of some animal and more plants typically followed.

5 Dynamic Welfare Analysis

Let us assume that, for one reason or another, the ATC is fulfilled so that an agricultural sector has been created ($\gamma^*_{t+1} < 1$). What will happen then? The archeological record from the Near East shows that from the first evidence of domesticated plants at Tell Abu Hureyra in present Syria, around 8500 B.C., the agricultural package of emmer and einkorn wheat, barley, goat and sheep appears fully developed all around the Fertile Crescent just a couple of millennia later (Harlan, 1995). Developments in the river economies of China followed a similar pattern. Considering the painstakingly slow pace of technological progress during the first 100,000 years or so of homo sapiens' existence, this transition was certainly something of a revolution. In this section, I will offer a dynamic mechanism through which agriculture - once it had been introduced - rapidly replaced hunting-gathering as the dominant technology for food production despite the fact that agriculture did not result in rising standards of living.

The key to the story can be found in (3). When γ^* gets smaller than 1, the pure Malthusian regime switches to become partly exogenously driven. From having been totally dependent on hunter-gatherer productivity $B(\cdot)$, the population growth rate is now an increasing function of the share of the population in agriculture, $(1-\gamma_t)$, as discussed above.

If, as in Figure 2, agriculture is introduced at time $t+1$ due solely to an increase in $A(\cdot)$, output per capita changes from $y_t = B_t L_t^{\beta-1}$ to $y_{t+1} = A_{t+1}\left(1-\gamma^*_{t+1}\right)+B_t\left(\gamma^*_{t+1}\right)^{\beta} L_t^{\beta-1}$.[10] In Figure 2, output per capita at t is equivalent to the area under the falling curve for MP^H, $y_t = \int_{\gamma=0}^{1} \beta B_t \left(\gamma L_t\right)^{\beta-1} d\gamma$. Output after the transition equals the joint area under the two curves; $y_{t+1} = \int_{\gamma=0}^{\gamma^*_{t+1}} \beta B_t \left(\gamma L_t\right)^{\beta-1} d\gamma + \int_{\gamma=\gamma^*_{t+1}}^{1} A_{t+1} d\gamma$. In the latter case, we have assumed for simplicity that $\alpha = 0$. Comparing the two areas in the figure makes it apparent

[8] See Olsson and Hibbs (2000) for a model where the growth rate of technological knowledge is proportional to the quality or variety of the environment.

[9] Such a threshold level is modelled explicitly in Olsson and Hibbs (2000).

[10] The subscripts of B_t and L_t are left unchanged to indicate that they do not change between t and $t+1$.

that the joint area for output at $t+1$ is greater than the area at t so that $y_{t+1} - y_t > 0$.[11] The net gain is the dotted grey area in Figure 2.

Proposition 2 *Ceteris paribus, an increase in* $A(\cdot)$ *at* $t+1$ *that satisfies the ATC implies that* $U_{t+1}(c_{t+1}) > U_t(c_t)$.

In other words, the creation of an agricultural sector initially gives rise to an increase in per capita output and in welfare.

Let us now assume that no further changes in $A(\cdot)$ or $B(\cdot)$ occur, that $\alpha = 0$, and that there is no random shock to the size of the population ($\varepsilon_{t+1} = 0$). Will the small agricultural sector then remain at the same modest level as at the time of the first transition, $t+1$? The answer is no. By utilizing (9), we can obtain the expression for the optimal γ^*_{t+n} (where $n > 1$) as:

$$\gamma^*_{t+n} = \frac{1}{L_{t+n}} \left(\frac{\beta B}{A} \right)^{\frac{1}{1-\beta}}. \tag{10}$$

Note that the time subscripts for B and A have been dropped to indicate that labour productivities are regarded as constant. The expression shows that γ^*_{t+n} is a decreasing function of L_{t+n}. Since we know from (3) that the level of population will be growing at all n ($L_{t+n} > L_{t+n-1}$), the hunting-gathering sector steadily diminishes. This is shown in Figure 3 where the fact that $L_{t+2} = L_{t+1}\left(1 + \eta\left(1 - \gamma_{t+1}\right)\right) > L_{t+1}$ pushes the MP^H-curve to the left while the MP^A-curve remains unchanged. Thus, even in the absence of, for instance, increases in agricultural labour productivity, the hunting-gathering sector shrinks due to population growth.[12] This movement towards more intensive use of the environment is very similar to the theory outlined by Boserup (1965). The model predicts that the decline of hunting-gathering will continue until the fraction of hunter-gatherers is infinitesimally small. This important result provides one explanation for the relatively rapid increase of the share of the population in agriculture witnessed in prehistory.

What are the effects on welfare? We established earlier that an initial effect of the transition was that $y_{t+1} > y_t$ and hence $U_{t+1} > U_t$. A comparison between y_{t+2} and y_{t+1} can be made on the basis of Figure 3. Since output per capita at $t+2$ is the area below the MP-curves up to γ^*_{t+2} and since the MP^H-curve is shifted to the left due to the increase in population, it must be the case that $y_{t+2} < y_{t+1}$. The difference is equivalent to the dotted grey area in Figure 3.

Proposition 3 *Given constant levels of* $A(\cdot)$ *and* $B(\cdot)$, *it will be the case that* $U_{t+2}(c_{t+2}) > U_{t+3}(c_{t+3}) > ... > U_{t+T}(c_{t+T})$.

As population keeps on growing, more and more people will be forced into agriculture, but this does not prevent output per capita from falling. Thus,

[11] A formal proof is available upon request.

[12] The primitive sector in Goodfriend and McDermott's (1995) model shrinks in a similar fashion due to population growth. However, unlike in Goodfriend and McDermott, who assume an upper bound to marginal productivity in the primitive sector, it is worth pointing out that the hunting-gathering sector is never completely abandoned in this model.

after an initial increase in utility, the agricultural transition will imply a steady decline in welfare.

Output per capita in the extreme limit of the transition process is simply

$$\lim_{\gamma^*_{t+n}\to 0} y_{t+n} = \lim_{\gamma^*_{t+n}\to 0} \left(\int_{\gamma=0}^{\gamma^*_{t+n}} \beta B \left(\gamma L_{t+n}\right)^{\beta-1} \cdot d\gamma + \int_{\gamma=\gamma^*_{t+n}}^{1} A \cdot d\gamma \right) = A. \tag{11}$$

With $A(\cdot)$ constant, it seems likely that this level of output per capita will be below or in the vicinity of the level of subsistence. With the painful transition completed, welfare per capita might thus actually be lower than during hunter-gatherer times. It should be remarked that the last result hinges on the fact that $A(\cdot)$ was assumed to be constant. In reality, $A(\cdot)$ presumably grows as a result of learning-by-doing. As can be inferred from Figure 3, a gradual increase in $A(\cdot)$ would imply an even faster disintegration of the hunting-gathering sector and would offset some of the negative effects on output per capita brought by the steady population growth.

In summary, the dynamics of the model above describes a process where hunting-gathering initially prevails for tens of thousands of years. An increase in agricultural labour productivity (driven by environmental change or by external effects of hunting-gathering), a positive shock in the level of population, or an increase in the preference for agriculture might then push the economy over the threshold so that a small agricultural sector is created. Welfare initially rises, which encourages the few agriculturists to persevere, but the new sedentary lifestyle also creates an exogenous engine of increasing population growth which rapidly forces people out of hunting-gathering and diminishes output per capita and welfare. Without offsetting increases in labour productivity, farmers and the remaining hunter-gatherers might even be worse off than their ancestors.

The model provides an intuition to the puzzling question why Neolithic hunter-gatherers switched to agriculture although it was not associated with higher standards of living. It also shows why the process became irreversible.[13] Once an agricultural sector was created and the population started growing, the rest of the population had no choice but to take up cultivation and animal husbandry.

6 Archeological Evidence: The Jordan Valley

The general model above allows for several different explanations for the transition from hunting-gathering to agriculture. Modern archeological research suggests that there does not exist one universal explanation for the transition that applies to all regions. Hence, the four broad hypotheses of the model will

[13] The process could theoretically have come to a halt if a negative population shock just after an agricultural sector had been created pushed the few agriculturists back into hunting-gathering. In Figure 2, such a shock would be illustrated by a sudden shift to the right of the MP^H-curve.

be confronted with evidence from a specific region with one of the earliest known instances of Neolithic agriculture; the Jordan Valley.

6.1 Background

The Jordan Valley and the Damascus basin form the Western part of the Fertile Crescent. It is distinguished from the Northern and Eastern parts mainly for the very early domestication of grasses like wheat and barley. The area of greatest archeological interest within the Jordan Valley is a small piece of land no more than 15 km in radius, situated on the northern edge of the Dead Sea. This small area contains three important archeological sites; Gilgal, Netiv Hagdud, and Jericho. In prehistorical times, all three sites were situated in close proximity to aquatic resources like wadis, swamps and lakes, but were otherwise surrounded by steppe grassland (Bar-Yosef and Kislev, 1989).

Recent evidence from the DNA structures of modern humans suggests that a small number of *homo sapiens* individuals left Africa and migrated into the Near East and the Jordan Valley some 50,000 years ago (Ingman et al, 2000). As the climate gradually improved during the later part of the Pleistocene, hunter-gatherers expanded from the Mediterranean coastal ranges to the inland. By around 10,000 B.C., the so called Natufian culture spread across the Jordan Valley and even into the drier Middle Euphrates and Negev regions. The Natufians were largely sedentary and lived on fishing, wild cereals and fruits, and hunted animals like gazelle, fallow deer, and ibex. Ample evidence of sickle blades and grinding tools suggest that the Natufians were heavily reliant on wild grasses and probably even cultivated some species (Bar-Yosef and Kislev, 1989).

The earliest known sites for plant domestication are Abu Hureyra by the Middle Euphrates and Aswad in the Damascus basin where seeds of domesticated emmer wheat and barley have been dated to approximately 8500 B.C. (see Table 2). Clear evidence of domesticated plants have also been found in Jericho from around 8300 B.C. Although no certain evidence of domesticated seeds can be established for the very old Netiv Hagdud site in the Jordan Valley, a number of circumstances suggest that barley was indeed cultivated as early as 8700 B.C. (Smith, 1998). A notable feature of Table 2 is that all four mentioned sites belonged to the so called Levantine Corridor, which therefore seems to have been the area for the earliest transition to agriculture in the Near East and in the world. Domesticated plants in the central and eastern parts showed up a couple of centuries later together with domesticated animals like goat and sheep (Çayönü and Ganj Dareh).

Table 2: Earliest known sites of plant domestication in the Near East.

Site	Region	Date	Plant
Netiv Hagdud	Jordan Valley	8700 B.C.	(wild?) barley
Abu Hureyra	Middle Euphrates	8500 B.C.	emmer, barley
Aswad	Damascus basin	8500 B.C.	emmer, barley
Jericho	Jordan Valley	8300 B.C.	emmer, barley
Çayönü	Central Fertile Crescent	8000 B.C.	emmer
Ganj Dareh	Zagros Mountains	8000 B.C.	barley

Source: Harlan (1995, Table 4.1); Smith (1998, in text).

6.2 Environment

The climatic downturn during the Younger Dryas (9500 B.C.) that temporarily brought drier conditions, in addition to the simultaneous extinction of several big mammals, affected the Natufian culture in the Jordan Valley in a number of ways. The gradual settlement of the desertic areas now came to an end and people started living in larger, permanent communities near alluvial fans, lakes and rivers (Bar-Yosef and Kislev, 1989). However, a wetter climate soon resumed after only a couple of centuries. By 9000 B.C., just before the agricultural transition in the Levant, there is no convincing evidence of a food crisis. Biological data on human skeletal remains do not indicate any substantial health deterioration from the Early to the Late Natufian period (Belfer-Cohen et al, 1991). Hunter-gatherers in Abu Hureyra, north of the Jordan Valley, could collect as many as 157 wild food-plants (Hillman et al, 1989). In late ninth millennium Netiv Hagdud, sedentary people consumed mollusks, moles, snails, crabs, frogs, lizards, fallow deer, gazelle, and wild pigs. Among the plant remains were wild barley, canary grass, emmer wheat, fruits, nuts, and vegetables (Smith, 1998).

The striking characteristic of the environment in the Jordan Valley is rather the abundance of suitable wild plants, or grasses, for domestication. Obvious candidates for domestication are grasses that have relatively heavy and voluminous grains, that are locally common, and whose genetic structure might easily be changed. According to Blumler (1992, Table 12.1), among the world's 56 heaviest-seeded wild grasses (with a kernel weighing more than 10 mg), as many as 20 species (35,7 %) have their native distribution in the Near East area. As for the Jordan Valley, there are 14 grasses with grains weighing more than 10 mg and 9 of these are rather/very common (Bar-Yosef and Kislev, 1989, Table 40.1). This group includes the wild ancestors of important crops like emmer wheat, barley, and oats, as well as for instance goatgrass and darnel.

The centuries immediately preceding the transition to cereal agriculture must therefore have been characterized by a high N^H, at least in the aquatic neighbourhoods where semi-sedentary Natufians lived. After the extinction of several large mammals some centuries earlier, the species that were exploited by hunter-gatherers in the Jordan Valley were increasingly such that their acquisition did not require a nomadic lifestyle. However, the key environmental feature of the Jordan Valley appears to have been that the number and abundance of species suitable for agriculture were unusually high, indicating impressive levels of N^A and $A(\cdot)$.

6.3 Population

Cohen's (1977) often cited hypothesis of the agricultural transition proposes that exogenous population growth explains why hunter-gatherers in several regions of the world had to develop more efficient systems for food production in the Early Neolithic era. The transition was made out of necessity and was presumably preceded by a food crisis. On a general level, Cohen's pure hypothesis of a population growth that drives development in a Boserupian fashion does not seem to receive strong support. As mentioned before, Figure 1 suggests that no such process seems to have been in place in Pre-Neolithic times. Neither are there much evidence of a general Late Paleolithic food crisis (Cohen and Armelagos, 1984) or, for that matter, in the Jordan Valley (see above).

A population shock due to a "budding off" of people from permanent fishing villages to the hinterland, as hypothesized by Binford (1968), does not seem likely either. The early instances of plant cultivation/domestication in Netiv Hagdud and Jericho were both made on the fertile soil of alluvial fans and riverbanks. Some decades ago, many believed that the first walls of Jericho, built as early as 8300 B.C., were an indication of possible warfare between nomadic hunting-gathering tribes (Kenyon, 1957). Could such a war have brought a population shock that caused the subsequent transition to sedentary agriculture? Bar-Yosef (1986) convincingly argues that this is surely not the case. The walls of Jericho, he shows, were not structures meant to defend the town from human enemies but rather from the floods and mudflows from the nearby wadis and wetlands. Indeed, Bar-Yosef claims that there is no evidence of social aggression in the Levant before the 6th millennium B.C.

However, population pressure does seem to have played a key role. A model based upon Harris (1977) offers a plausible scenario for the transition to agriculture in the Jordan Valley. Environmental changes around 10,000 B.C. - above all the megafaunal extinction - induced altered economic strategies which resulted in the sedentism of the Late Paleolithic Natufians. Sedentism, in turn, reduced the opportunity cost of children and made traditional population controls obsolete. The resulting rapid population growth then forced the settled Natufians to adopt a more intensive use of their favourite plants; barley and emmer wheat. In terms of the model above, an exogenous population growth mechanism similar to that in (3) thus seems to have been in place already before the transition to domesticated plants and indeed seems to have been one of the driving forces in the transition process.

6.4 Culture

The hypothesis of a cultural preference for agricultural practices is naturally extremely hard to validate. Beliefs in peoples' minds are not easily reconstructed on the basis of physical archeological remains. There are no equivalents of the Lascaux paintings indicating a ritual significance of certain plants or animals. Indeed, the relative insignificance of animals in the domestication process in the Jordan Valley speaks against a religious reason for the transition. Neither are there any evidence of competitive feasting of the kind suggested by Hayden (1990).

On a general level, one might argue that what Fernandez-Armesto (2000) refers to as the "itch to civilize" appears to have been particularly strong among the first Neolithic inhabitants of Jericho, around 8300 B.C. In defiance of nature, a village of around 300 people was created near a spring and fertile riversoils. Oval houses, built of mud bricks on stone foundations, provided permanent shelter (Smith, 1998). As mentioned above, a town wall was erected and ditches were dug to keep the nearby wadis from overflowing the village area. The circular stone tower, some eight meters high, is perhaps one of the most impressive signs in prehistory of an urge to dominate nature. Was this urge a result of a culture that differentiated the Natufians and their descendants from other contemporary peoples in the world and that eventually led to plant domestication? The issue is virtually impossible to resolve.

Nevertheless, excavations in the Jordan Valley have produced fascinating glimpses into the mental world of its Early Neolithic inhabitants. One of the most interesting findings from Jericho is human skulls with cowrie shells in the eye sockets and flesh modelled in plaster. Kenyon (1957), who made the findings, suggests that the skulls indicate a worship of ancestors while Smith (1998) goes even further and argues that the skulls might have been used ritually to reinforce long-standing claims of land ownership. Smith also proposes that the small clay figurines found in the Jordan Valley might point to an increasing role for women as cultivators in this early farming society. The presence near the old tower in Jericho of storage facilities and certain structures which appeared to be of ceremonial significance, point to the possibility of a ritual center (Bar-Yosef, 1986).

However, all these examples of religious worship are from the Neolithic period when people had already become farmers. Thus, all that this evidence shows is that agriculture is associated with altered spiritual conceptions. It does not prove the hypothesis that some cultural preference for agriculture - based on religion or an exceptionally strong urge to dominate nature - were primary determinants of the rise of agriculture.

6.5 External Effects

The fourth category of explanations is basically concerned with the external effects of doing what people so far had always done, i.e. hunting, gathering, and fishing. Might the rise of intensive food production in the Jordan Valley be explained by the random appearance of a genotype of homo sapiens that favoured sedentary agriculture before hunting-gathering, as (implicitly) suggested by Galor and Moav (2001)? The available literature does not seem to discuss the prevalence of observable genetic differences between Neolithic people in the Levant and in, say, Spain or the Andes. What might have been present is a kind of "cultural selection", not observable from archeological remains, that increased the fitness of the first sedentary cultivators and then induced other hunter-gatherers to become farmers (Rindos, 1989). But such a hypothesis conflicts with the findings in, for instance, Belfer-Cohen et al (1991) and Cohen and Armelagos (1984) where it is shown that individual fitness rather declined than improved after the agricultural transition.

An undisputable and important fact is that the level of food processing technology had reached high levels already in Late Paleolithic times. In Netiv Hagdud, just a few generations before the first appearance of domesticated plants, the ample remains of sickle blades, grinding bowls, and storage structures are clear indications of a society that was well prepared for the change that was going to come. Was this level of sophistication a result of the Natufians' superior inventiveness and intellectual capacity? Almost certainly, the key reason for the highly developed tool industry for grass harvesting and preparation in the Jordan Valley was rather the dominant role of grasses in the local flora. Equally sophisticated but distinct technologies were developed elsewhere in the world, adapted to the unique characteristics of local environments.

It has already been emphasized that grasses with heavy grains were very natural candidates for domestication experiments in the Jordan Valley due to their abundance in the wild. But apart from being very common and having the second heaviest grains after emmer wheat, wild barley (*hordeum spontaneum*) is further the plant with the most favourable genetic structure for successful domestication. Research by Bar-Yosef and Kislev (1989) shows that among the abundant, large-seeded grasses, barley is almost unique in having the basic diploid number of chromosomes. As a general rule, the higher the ploidy level, the smaller the chances of domestication. Even in emmer wheat (*triticum dicoccoides*), a single gene mutation is enough to prevent the stalks from shattering, a trait that greatly facilitates harvesting and cultivation. Hence, it turns out that the stone age inhabitants of Netiv Hagdud had focussed on the two plants that modern research methods have established as the "best" material for domestication efforts. The observation gives an idea of the extraordinary knowledge about plants and nature that the people in this small Neolithic village possessed and leaves even a present day observer in awe of what our supposedly "primitive" ancestors were able to achieve more than 10,000 years ago.

7 Conclusions

The model in this article tries to explain various aspects of the rise of Neolithic agriculture. I show that the transition to agriculture will happen when an Agricultural Transition Condition is satisfied. The ATC, in turn, follows intuitively from the assumption of marginal product equalization in the hunter-gatherer and agricultural sectors. In accordance with a broad survey of the archeological and anthropological literature, the ATC allows for four basic explanations for the agricultural transition; (i) environmental change, (ii) population pressure, (iii) cultural influence, and (iv) external factors such as evolution and learning.

An important theoretical result is that the transition causes rising utility in the first period, whereupon utility steadily declines despite a rapid disintegration of the hunting-gathering sector. This feature is consistent with historical evidence showing non-increasing standards of living after agriculture has been introduced. The driving force behind this result is the switch in population growth regime from a pure Malthusian process during hunter-gatherer times, when population growth is proportional to labour productivity growth, to a process where the agricultural population grows exogenously. The rapid growth of the agricultural population forces people out of hunting-gathering and into agriculture in a Boserupian manner.

When the hypotheses above concerning the reasons behind the agricultural transition are confronted with archeological evidence from the Jordan Valley, the following causal relationship emerges. Due to environmental changes like the extinction of big mammals and worsened climate during the Younger Dryas, the late Paleolithic Natufians became sedentary. Sedentism greatly reduced the alternative cost of having children and made traditional population control systems obsolete. A switch to an exogenous population growth process therefore ensued which led to a rapid decline in hunter-gatherer marginal productivity. In search of more efficient methods for food production, the Natufians naturally turned to abundant wild grasses like barley and emmer wheat which they had already consumed for thousands of years. Selective and intensive cultivation of these highly nutritious grasses then quickly and partially unintentionally led to the genetic changes that defined domestication and that greatly increased returns. The feed-back from an even faster population growth then caused a fast decline of the hunting-gathering sector. Just a thousand years or so after the first appearance of domesticated barley in Jericho, the hunter-gatherers had more or less disappeared from the Jordan Valley.

References

Bar-Yosef, O. (1986, April). The walls of jericho: An alternative interpretation. *Current Anthropology 27*(2), 157–162.

Bar-Yosef, O. and M. Kislev (1989). Early farming communities in the jordan valley. In D. R. Harris and G. C. Hillman (Eds.), *Foraging and Farming: The Evolution of Plant Exploitation*, London, pp. 632–642. Unwin Hyman.

Belfer-Cohen, A., L. A. Schepartz, and B. Arensburg (1991). New biological data for the natufian populations in israel. In O. Bar-Yosef and F. A. Valla (Eds.), *The Natufian Culture in the Levant*, Ann Arbor, pp. 411–424. International Monographs in Prehistory.

Binford, L. R. (1968). Post-pleistocene adaptations. In S. R. Binford and L. Binford (Eds.), *New Perspectives in Archeology*, Chicago, pp. 313–341. Aldine Publishing Company.

Blumler, M. (1992). *Seed Weight and Environment in Mediterranean-Type Grasslands in California and Israel*. Ph. D. thesis, Univ. of California, Berkeley.

Boserup, E. (1965). *The Conditions of Agricultural Growth*. London: Earthscan.

Childe, V. G. (1935). *New Light on the Most Ancient East.* London: Routledge and Paul.

Cohen, M. N. (1977). *The Food Crisis in Prehistory: Overpopulation and the Origins of Agriculture.* New Haven: Yale University Press.

Cohen, M. N. and G. J. Armelagos (1984). *Paleopathology at the Origins of Agriculture.* New York: Academic Press.

Diamond, J. (1997). *Guns, Germs, and Steel: The Fates of Human Societies.* New York: W.W. Norton and Company.

Fernandez-Armesto, F. (2000). *Civilizations.* London: Macmillan.

Galor, O. and O. Moav (2001). Evolution and growth. *European Economic Review 45*, 718–729.

Galor, O. and D. Weil (2000). Population, technology and growth: From the malthusian regime to the demographic transition. *American Economic Review 89*(4), 806–828.

Goodfriend, M. and J. McDermott (1995). Early development. *American Economic Review 85*(1), 116–133.

Hansen, G. D. and E. C. Prescott (1999). Malthus to solow. *Federal Reserve Bank of Minneapolis, Research Department Staff Report 257.*

Harlan, J. R. (1995). *The Living Fields: Our Agricultural Heritage.* Cambridge University Press.

Harris, D. R. (1977). Alternative pathways toward agriculture. In C. Reed (Ed.), *Origins of Agriculture*, The Hague, pp. 179–243. Mouton Publishers.

Harris, D. R. (1989). An evolutionary continuum of people-plant interaction. In D. R. Harris and C. C. Hillman (Eds.), *Foraging and Farming: The Evolution of Plant Exploitation*, London, pp. 11–26. Unwin Hyman.

Hayden, B. (1990). Nimrods, piscators, pluckers, and planters: The emergence of food production. *Journal of Anthropological Archeology 9*, 31–69.

Ingman, M., H. Kaessman, S. Pääbo, and U. Gyllensten (2000). Mitochondrial genome variation and the origin of modern humans. *Nature 408*, 708–713.

Jones, C. I. (2001). Was an industrial revolution inevitable? economic growth over the very long run. *mimeo.*

Kenyon, K. (1957). *Digging Up Jericho.* London: Benn.

Kremer, M. (1993). Population growth and technological change: One million b.c. to 1990. *Quarterly Journal of Economics 108*(3), 681–716.

Luikart, G. (2001). Multiple maternal origins and weak phylogeographic structure in domesticated goats. *Proceedings of the National Academy of Sciences 98*, 5927–5932.

Malthus, T. R. (1798). *An Essay on the Principle of Population.*

Mokyr, J. (1990). *The Lever of Riches: Technological Creativity and Economic Progress*. Oxford University Press.

Morand, O. F. (2001). Population, technology and growth. *mimeo*.

Olsson, O. and D. A. Hibbs (2000). Biogeography and long-run economic development. *Working Paper No. 26, Department of Economics, Göteborg University*.

Rindos, D. (1989). Darwinism and its role in the explanation of domestication. In D. R. Harris and G. C. Hillman (Eds.), *Foraging and Farming: The Evolution of Plant Exploitation*, London, pp. 27–41. Unwin Hyman.

Roberts, N. (1989). *The Holocene: An Environmental History*. Oxford: Basil Blackwell Ltd.

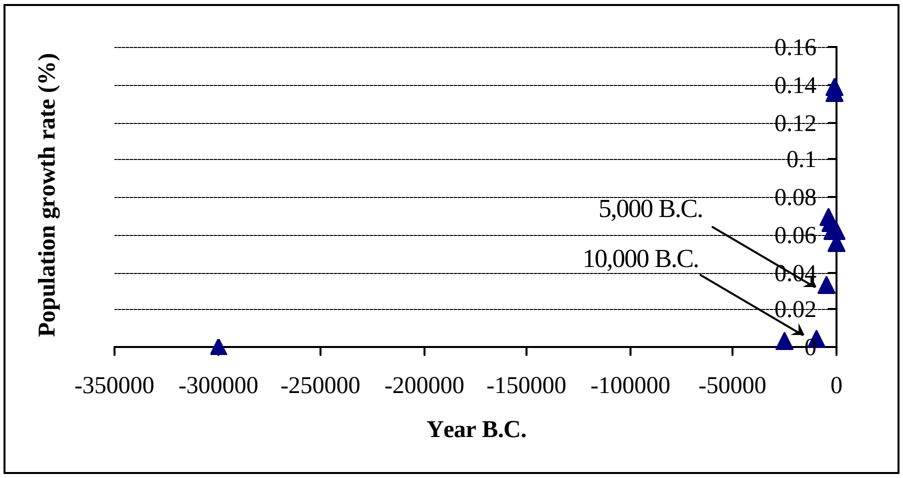
Sherratt, A. (1997). Water, soil and seasonality in early cereal cultivation. In A. Sherratt (Ed.), *Economy and Society in Prehistoric Europe*, Edinburgh, pp. 85–101. Edinburgh University Press.

Smith, B. D. (1998). *The Emergence of Agriculture*. New York: Scientific American Library.

Troy, C. (2001). Genetic evidence for near eastern origins of european cattle. *Nature 410*, 1088–1091.

Wittfogel, K. (1957). *Oriental Despotism*. New Haven: Yale University Press.

Figure 1: World Population Growth Rate 300,000 B.C. – 1 A.D.



Based upon data from Kremer (1993, Table 1).

Figure 2: The Transition to Agriculture

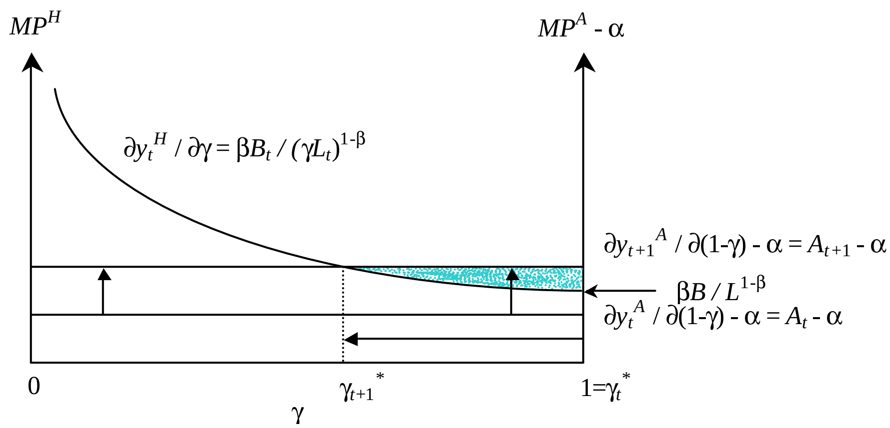


Figure 3: The Disintegration of the Hunting-Gathering Sector