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Serge Svizzero

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By Serge Svizzero
Universite de La Reunion

Abstract- Is it food shortage or food abundance which explains the transition from foraging to farming? The academic literature is divided. We use the notion of population pressure – defined as the ratio of population density over the stock of wild food resources – to answer this question. We demonstrate that the significant changes of the population pressure are only temporary and have asymmetric effects on hunter-gatherers' behaviors. Food shortages increase population pressure but do not trigger the shift to agriculture. Indeed, the common property regime as well as the common sharing of resources and knowledge hinder any incentive to innovate and to produce more effort. On the contrary, food abundance induces the advent of exclusive property rights, the disappearance of sharing and therefore stimulates effort and innovation. Since food abundance is a feature of complex hunter-gatherer societies, the latter are more likely at the origin of the transition to agriculture.

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I. Introduction

The origin of agriculture is probably the most debated issue in archaeology (Bellwood 2005: 14-28). Despite an abundant literature, there is no consensus about it, i.e. many theories exist and some of them are even non-exclusive (Weisdorf, 2005; Winter halder and Kennett, 2006; Svizzero and Tisdell, 2014). Although they are all different, most of these theories share a common thread, they all refer to the availability of food resources (Svizzero and Tisdell, 2014: 274, table 1).

For a first group of these theories, the transition to agriculture results from food shortages. Indeed, according to a Boserupian process (Boserup, 1965), with scarcer food resources, HG are supposed - i.e. in order to avoid starvation - to have had an incentive to shift from foraging to farming. The reduction of available food resources can be explained by two non-exclusive reasons. The first one is about climate change or, more generally, environmental evolution. This is Childe's (1936) paradigm on environmental determinism. Because the archaeological records of climate changes are easy to detect – especially nowadays with various techniques such as radiocarbon dating – such explanation has found strong support in the past (see Childe, 1936, and his "oasis theory" or "desiccation hypothesis") as well as nowadays (Dow et al., 2009; Bar-Yosef, 2011). The second reason of food shortages is related to the population size (Cohen, 1977). In a given territory, overpopulation may be due to either natural growth or to migration.

In fact both reasons previously stated are intertwined. Although his aim was not the transition to agriculture but the study of complex societies of HG, Keeley (1988) has clearly stated the relationship between food resources and the population size. For such purpose he has defined the concept of "population pressure" (denoted as PP in the sequel) as the ratio of the population density over the stock of wild food resources. Concerning the pre-Neolithic period, the population consisted only of HG and the stock of food resources was extracted by HG from the wild by using various foraging techniques such as hunting, gathering, fishing.

For the second group of these theories, it is the abundance – not the scarcity – of food resources which explains the transition to agriculture. As stated previously, such abundance can be defined as a low level of PP, i.e. it may result from either a relative decrease of the population level or a relative increase of the stock of food resources. The latter is more likely to have occurred. More precisely, such transformation may have occurred during the early Holocene. During that period, postglacial environmental transformations (Roberts, 2004) have led to the diversification of food resources, i.e. to the so-called «Broad-spectrum revolution» (Flannery, 1969). According to this view, many contributions in the literature are emphasizing the role of social competition or feasting to explain the Neolithic transition (see for instance Bender, 1978 or Hayden, 1990). Indeed with more abundant and diverse food resources provided by the nature, HG may have chosen to consume more «luxury or prestige» goods. However, the production of these prestigious goods required more labour and therefore led to an excess demand for basic food resources. In others words, social competition for prestige in HG societies occurred endogenously and it has led, by means of conscious adaptation, to the rise of agriculture. A complementary explanation is that, as a result of ecosystems supporting more abundant and diverse plants and animals, food procurement became easier for HG. Therefore, the latter have had more time for leisure and for experimenting with cultivation and the domestication of plants and

Author: Université de La Réunion, Faculté de Droit et d'Economie. Avenue René Cassin, Saint Denis, France.
e-mail: Serge.svizzero@univ-reunion.fr

animals. Finally, North and Thomas (1997) also consider that food abundance is at the origin of agriculture. These authors demonstrate that food abundance has provided HGs an incentive to shift from an economy with resources in open-access to an economy with exclusive property rights, the latter being a necessary condition for cultivation to occur.

The first and the second group of theories give opposite reasons about the origin of agriculture. For the first group, it is food shortages – or equivalently a high level of population pressure – which has triggered the transition from foraging to farming. For the second group, on the contrary, it is the abundance of food resources – or equivalently a low level of population pressure - which explains the Neolithic revolution. It is the aim of this paper to study the relationship between food resources – or population pressure – and the transition to agriculture. For such purpose we especially consider the socio-economic features of HG societies in order to determinate under which circumstances – food scarcity or food abundance – the transition to agriculture was more likely to occur.

The paper is organized as follows. The population-pressure is defined in section 2 and the associated various dynamics are explained. The impact of food shortages on HGs' behaviour is detailed in section 3. Section 4 examines the symmetrical situation, i.e. the impact of food abundance on HGs' behaviours. Section 5 concludes.

II. The Dynamics of the Population-Pressure

As clearly stated by Keeley (1988: 373) we consider "*population 'pressure' defined as the ratio between human population density and resources*". In other words, "*It is the relationship between population and resources that is central to the concept of population pressure*" (Keeley, 1988: 376). Given such definition of PP, it is thus possible to compute its rate of growth. A direct computation shows that the PP is increasing (or equivalently its rate of growth is positive) when, in absolute value, the rate of growth (or the density rate) of the population is larger than the rate of growth of the stock of food resources. However, such conclusion must be qualified.

First, the population density as well as the stock of wild food resources may increase or decrease, but at different speeds and, of course, for different reasons.

The population density may increase either slowly – i.e. in the very long-term (over centuries) – due to population growth, or faster – i.e. in the short-term (months or years) – due to immigration in a given territory. In both cases, and in order to be sustainable, such increase requires a simultaneous increase of food resources. It may also decrease either slowly or very rapidly (e.g. in few weeks) due to disease or wars, and also owing to food shortages leading to starvation.

The stock of food resources provided by the nature may increase slowly – in the very long term (centuries and even millennia) – when, for instance, climate and environmental conditions improve. It may increase rapidly (in few months or years) when some technological change occurs and allows HGs to harvest or to proceed a specie (plant or animal) which was previously unknown or inedible. It may also decrease either slowly, or rapidly (e.g. in few weeks) due environmental disasters such as drought or flood.

Second, the population density and the stock of food resources are not independent variables but are linked throughout a predator-prey dynamics. Indeed and as highlighted by Malthus, the population growth depends on the availability of food resources. Symmetrically, and as pointed out by Boserup (1965) for agrarian economies,[1] the availability of food resources depends on the population density because the higher is the latter, the more technological change is stimulated.

Third, a consequence of the previous point is that in the very long-term the PP converges to a stable level – or a steady-state level. Such level can be reached if food resources were initially either scarce or abundant. Therefore, any significant changes of the PP must be considered as temporary. In the sequel of this paper, we consider two of these possible temporary changes. When the food resources become scarcer (see Section 3), the PP increases, i.e. it deviates temporarily from its steady-state value and will converge toward the latter in the very long-term.[2] Symmetrically, when the food resources become more abundant (see Section 4), the PP temporarily decreases.[3] Let us now turn to the consequences of such temporary changes of PP on the possible advent of agriculture.

III. Food Scarcity Leads to Status Quo

Let us start by assuming that in a given territory was living a band of HG. We also assume that initially food resources are quite scarce into this territory. Without adopting Hobbes' (1651) narrow view who claimed that HGs' life was "solitary, poor, nasty, brutish and short", we may however suppose that, because food resources were scarce, HGs had a harsh life. In other words, the biological goal, i.e. ensuring the subsistence, was for sure the main goal of pre-Neolithic foragers (Svizzero, 2016). Thereby we may assume that HGs were nomads, roaming most of the time to get their subsistence. Their technology – foraging – was

[1] But this conclusion can be extended to foraging economies as well.
[2] This situation may also result from a sudden increase of the human population level, such as an inflow of migrants in a given territory.
[3] This situation may also result from a sudden decrease of the population level not linked with the availability of food resources, e.g. induced by wars or diseases.

providing low productivity; thus the food resources harvested were insufficient to sustain population growth. Population changed according to a very slow rate of growth, i.e. it was nearly homeostatic. Such conclusion was reinforced by the transportation constraints associated with the nomadic way of life of these HGs who, therefore, had to space out the birth of young children to every 3 or 4 years.

Given the initial context described previously, which is also labelled as "simple HG" in the academic literature (Kelly, 1995), the main question is the following: what is going to happen to such band of HGs if their food resources become scarcer? In other words, if the PP – which was assumed to be already high – becomes higher, is it sufficient or even necessary to trigger the transition from foraging to farming?

In order to answer to such question, let us consider, step by step, what is going on when the PP is increasing. For simplicity, we assume that worse climate conditions tend to reduce the stock of food resources and ultimately the PP tends to increase. According to many theories – e.g. Childe (1936) – environmental changes, such as a drought, lead to the reduction of the stock of food resources and therefore force HGs to settle down in oasis or on the banks of large rivers. However, the last part of the previous conclusion is not obvious at all. Indeed, large rivers as well as oasis were existing before the drought occurs. Thus HGs were able, before the drought, to settle down in these places, i.e. to give up their nomadic way of life. Why should they have wait to be constrained by the drought for deciding to settle down in such an Eden? In fact, the reason is that these places were not as ideal as Childe has assumed. Therefore, we may assume that initially HGs were nomads and that, after the drought, they were still nomads, probably on a larger territory or in the same territory but with more intensive geographic mobility.

a) Common Property Rights and Innovation

When HGs are nomads, the constraints associated with transportation imply that ownership is restricted to the minimum they may carry with them, i.e. to personal belongings (clothes, tools, weapons). In other words, for everything – except personal belongings – HGs were living in an economy where natural resources were in open-access. Because HGs were living in bands, it is more likely that the access to these resources, especially food resources (the animals to be hunted or vegetation to be gathered), was not open to all but was restricted by communal rules (or CPR, for Common Property Rights). Anyway, it is well known that under open-access or CPR, any HG does not have incentive to conserve the resources provided by the wild. Indeed, as stated by North and Thomas (1977: 234), "*unconstrained access to a resource base will lead to its inefficient utilization. This inefficiency as the demand for the resource increases eventually leads to the depletion of the resource*." There is thus an incentive failure caused by institutional – the property rights system – inadequacy. HGs have an incentive to ignore certain costs which result in the resource being over-utilized and perhaps even its continued existence endangered. Another consequence of open-access - or CPR – to resources is about the incentive to innovate. HGs, even during the prehistoric period, were inventive and the main stimulus to technological change was probably experimentation or learning by doing. However, such technological change (e.g. improvements of the weapons and tools used for hunting) has very different consequences in the short-term compared to the long-term. Indeed, in the short-term such improvements enhance HGs' productivity and thus lead to an increase of the amount of food resources harvested. In the long-term however, the additional rewards of hunting are dissipated by the effects upon the resource base of increased effort in that area. We then reach a conclusion similar to the one stated by North and Thomas (1977: 241), "*When common property rights over resources exist, there is little incentive for the acquisition of superior technology and learning*.".

b) Sharing, Effort and Innovation

For HGs, foraging is social and, in addition, it also includes a unique element (compared to what non-human foraging animals do), the creation of resource pooling systems (Delton and Robertson, 2012) also called "sharing" or "common sharing". In this type of social foraging, people contribute when they have excess resources and receive some provisions when in need. The latter may occur either because foraging is very risky - by nature it provides returns featured by high variance – or because injury and illness can prevent a person of foraging for extended periods. At least six different theories have been proposed to explain the existence and patterning of intra-group food sharing (Kaplan & Gurven, 2005; Gurven & Jaeggi, 2015); however the outcome of risk-reduction is consistent with all six. In other words, some foragers adopt risky strategies because they know that if their hunt fail, they will nevertheless have food provided by the members of their band and through the sharing system.

Sharing is a feature of any group of foragers. Indeed, it is commonly agreed that sharing was a central feature of pre-Neolithic societies in which HG were "pure foragers" (because agriculture has been introduced later). Moreover, sharing is remained the central feature of "modern HG" societies, even though foraging was not for them the only method they use to get food resources (Lee, 2004; Lee and Daly, 2004). In fact, and even when food resources become scarcer, sharing has two important implications relative to the purpose of the present article.

First, the sharing rules can be interpreted as an implicit tax on the food resources harvested by HGs (Chakraborty, 2007). Such tax lowers the marginal return to resource harvesting, which reduces effort and increases the stock of wild resources. In other words, foraging does not necessarily lead to overexploitation of wild resources: sharing avoids waste of food and favours resource conservation because it reduces foragers' incentives to extract wild resources.

Second, a fundamental input in the foraging process is Local Ecological Knowledge (LEK) and its transmission among foragers is closely associated with the norm of sharing. Because foraging is risky, any HG has a strong incentive to share his LEK with the members of his band. Indeed, if in some circumstances his hunt fails, he may nevertheless get some food - through the sharing system – provided by another HG with whom he has previously shared his LEK. Thereby LEK is clearly a public good; its production and transmission across foragers and generations of foragers is socially beneficial. However, and as any public good, any HG has no incentive to innovate, i.e. to produce "new LEK" because the rewards of such innovation have to be immediately shared with all the others HGs. We may thus conclude by claiming that LEK is likely under-produced in HG societies.

c) The Lack of Incentives

The sharing system, which is ubiquitous in HG societies, reduces the incentive to do additional work as well as the incentive to innovate through, for instance, the invention of new LEK. Furthermore, the latter is even lowered because resources – and especially food resources – are under open-access or a CPR. Such conclusion holds even though the food resources available to a given band of HGs were quite scarce and become scarcer after a while. One should however noted that the transition to agriculture requires the opposite, i.e. additional effort as well as innovation. Indeed, the development of agriculture requires substantial effort, especially in its early ages, for forest clearance, irrigation system, tillage (…). Likewise, the transition to agro-pastoralism requires innovation in order to ensure the taming and the domestication of wild animals (e.g. wild goat, sheep…) as well as the cultivation of wild plants (e.g. wild cereals, pulses…). Thus, without incentive to innovate and to produce more effort, when food resources are initially scarce and even become scarcer, the foraging economy is more likely leading to status quo rather than to the transition to farming.

IV. Food Abundance may Promote Effort and Innovation

In this section we assume that, contrary to the previous section, the food resources are initially quite abundant. In other words, and compared to the situation of the previous section, the PP is relatively low. Thus, the same question prevails: starting from such situation, is the HG's economy able to trigger the transition to farming? At first sight, the answer seems to be obvious and negative. Indeed, if food resources are abundant, HGs may live without making too much effort. Since agriculture is time-and-effort consuming, especially in its early ages (Bowles, 2011; Berbesque et al., 2014), one may wonder why HGs should accept to work more – when they shift to cultivation - for a lower return? In fact, the situation we assume is similar to the principle observed in ethnographic studies of HG societies in the second part of the twentieth century. For instance, this principle was articulated succinctly by the !Kung bushman who was asked by an anthropologist why he had not turned to agriculture (as his neighbours had done). His reply was: 'Why should we plant when there are so many mongongo nuts in the world?' (Lee and DeVore 1968: 33). The !Kung realise that agricultural innovations would be detrimental to their subsistence, simply because it takes more energy for less payoff.

If relative abundance of food resources also leads to status quo, such conclusion does not hold when food is strongly abundant. Indeed, we may consider that below a certain threshold of the level of the PP, the behaviour of HGs evolves and that such change may trigger the shift to agriculture. This behavioural evolution is influenced by three mechanisms.

a) Sharing and Abundance

First, we have recall in the previous section that HG societies were featured by the common sharing of food resources as well as of knowledge useful for foraging (LEK). We have demonstrated that under the sharing system, HGs were not willing to innovate and to work more - as required by agriculture - because they did not own privately the returns of their innovation and effort. Thus the status quo was the logical outcome of such situation. However, this conclusion depends on the existence of the sharing system which is itself dependent on the scarcity of food resources. In other words, when the food resources are strongly abundant, the foraging activities are no more risky and thus the sharing system is given up by HGs. In fact, one may consider that the sharing system is gradually disappearing as long as the PP is decreasing (due to the growing abundance of food resources). When the sharing system has disappeared completely or is almost ineffective, any HG has now incentives to innovate and to work more, as required by the transition to agriculture.

b) Local Abundance and Ownership

Second, we have assumed that food resources were strongly abundant. Such assumption is more likely to occur in a given territory or in particular "hotspots". In other words, when food resources are strongly abundant, it is a local abundance (in the geographical

sense) which can be annual or seasonal. Most of the time such abundance is seasonal but is always locally defined. Terrestrial examples are provided by fields of wild cereals, orchards of fruit trees, snails, migrations routes of large mammals (e.g. reindeers) or fowl. Examples of marine resources are also numerous: the annual run of anadromous fish (e.g. salmon, trout), shellfish, sedentary as well as migratory sea mammals (e.g. whales, seals).

In any of the previous examples, the local abundance of food resources has two interconnected consequences. On the one hand, HGs are not constrained to maintain a nomadic way of life. Instead, they may settle down where the resources are strongly abundant and even if they are not completely sedentary, they may transit from close base camps (each base camp being associated with a seasonally abundant food resource). On the other hand, since they are now sedentary or quasi-sedentary, HGs may have possessions beyond what were their personal belongings when they were nomads. Indeed, they may now own privately some food resources, especially those that can be stored (Testart et al., 1982), and other resources such as weapons, tools, clothes, watercrafts, dwellings, pit houses. Furthermore, exclusive property rights will be applied to land, especially to the hotspots where food resources are abundant. With the advent of exclusive property rights, the behaviour of HGs has changed because they had new incentives. As stated by North and Thomas (1977: 241), "… *exclusive property rights which reward the owners provide a direct incentive to improve efficiency and productivity, or, in more fundamental terms, to acquire more knowledge and new technique*". Such new incentives were necessary for the transition to farming (Bowles et choi 2013)

c) The Malthusian Principle

Third, with abundant food resources, one may not assume that the population is stable or homeostatic in the long-term. Indeed abundant food resources which are in excess compared to the (biological) subsistence level are consumed. This leads to an increase of the population level as well as of the rate of growth of human population. Moreover, and according to T. Malthus, human population tends to grow at a faster rate than the availability of food. In other words, after a while, the PP - which was very low – reverts and tends to increase. Population increase outpaces the scope for hunting and gathering to feed this increasing population. Therefore, more productive methods are required, such as those involved in agriculture.

V. Conclusion

We have demonstrated that it is food abundance, and not food shortage, which implies changes of HGs' behaviours and that, if plants and animals suitable for domestication exist, such changes might trigger the transition to agriculture. As North and Thomas (1977) did - who have reached the same conclusion as our – food abundance fosters the shift from common to exclusive property rights. In addition to such mechanism, we have also pointed out that the common sharing system – a central feature of HGs societies – vanished when foraging became less risky, as implied by the abundance of food resources.

It should be noted that food abundance is a feature of complex HG societies, some of them have persisted long after the Neolithic revolution (Svizzero and Tisdell, 2015). In these societies, and except the fact that food resources are harvested and not produced, the socio-economic features are very close to the ones observed in agrarian societies. Indeed, complex HGs are usually described as follows (Testart, 1982; Price and Brown, 1985; Sassaman, 2004): they adopt a sedentary way of life, socio-economic inequalities are ubiquitous and the population density is high. Given such features, complex HGs are often considered as bridging the gap between simple HGs and agriculturists (Finlayson, 2009). The present paper goes one step further by explaining why such bridge is likely to have occurred.

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