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Unsustainable Mining Development and the Collapse of Some Ancient Societies: Economic Reasons

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Abstract: *The literature explaining social collapse mainly focuses on factors such as wars, climate change or disease, as exemplified by numerous examples of collapses which have occurred during the Late Bronze Age in the Near East and in the South-eastern Mediterranean region. This paper aims at demonstrating that collapse can also have economic reasons. Indeed, collapse may be the outcome of an economic growth process which is inherently unsustainable. More precisely, we claim that several ancient societies collapsed because their form of economic development eventually proved to be unable to sustain their standard of living. It is believed that the Únětice societies (which existed in the central European Early Bronze Age) were among those that collapsed for that reason. Two different simple models are presented to demonstrate how agricultural economies of this type which introduced bronze mining and metallurgy were unable to sustain their economic development.*

Keywords: *unsustainable development, Bronze Age, elite, economic surplus, mining productivity, Únětice culture.*

1. INTRODUCTION

It is well known that several ancient societies collapsed because the form of their economic development eventually proved to be unable to sustain their standard of living [1-4]. Examples of such collapses are numerous and include the Mayan civilization in the Southern Lowlands, the northern Hopewell (Eastern North America), the Old Kingdom of Egypt (which disintegrated between 2760 and 2225 B.C.), the end of the Indus Valley – or Harappan–civilization, the episodic political catastrophes in the Mesopotamian alluvium. These collapses have been labelled by Tainter[1] – who also considers eleven possible causes of collapses – under the theme of “resource depletion”. In fact, two major explanations for collapse are subsumed under this theme: the gradual deterioration or depletion of a resource base (usually agriculture), often due to human mismanagement, and the more rapid loss of resources due to an environmental fluctuation or climatic shift. Both are thought to cause collapse through depletion of the resources on which a complex society depends. According to this approach, changing physical factors (e.g. increased volcanism) lead to changing climates, which lead to changing food supplies, and thus to changing human behaviour (wars, migrations, economic upheavals, changing ethics, etc) (see e.g. Drake’s [5] explanation of the Late Bronze Age collapse due to the influence of climate change on agricultural productivity). An alternative resource depletion argument has been offered by Ekholm[6], who ascribes collapse to loss of trade networks, external resources, and imported goods. An economic system becomes fragile when it comes to depend on external exchange over which it has little control. Since some civilizations depend heavily on access to foreign markets, they are intrinsically vulnerable in this regard. Ekholm accounts in this manner for the collapses of the Third Dynasty of Ur and of Mycenaean civilization, and for regional instability in the Near East and the eastern Mediterranean 2300-2200 B.C.

The Bronze Age¹ is a period that spans from 3300 to 1200 B.C. It began in the last centuries of the fourth millennium B.C. in the Near East and the Aegean, around the middle of the third millennium

¹It is the second of C.J. Thomsen’s tripartite division of prehistory into ages of Stone, Bronze, and Iron.

B.C. in the northern Balkans and the Carpathian Basin, and around 2300 B.C. in Central Europe[8]. Followers of the Únětice culture became deeply involved in bronze production and trading in bronze during the Early European Bronze Age(denoted by EBA in the sequel[9]). They suddenly disappeared around 1600 BC. Several reasons have been suggested for their disappearance[10, 11].

The Únětice culture (2300-1600 B.C.), commonly known and associated with Nebra Sky Disk, is currently considered to be part of a wider pan-European cultural phenomenon, arising gradually between the third and second millennium B.C. The development of the Únětice culture was based on bronze production, the latter requiring copper and tin. While copper is widely found, the sole source of tin in central Europe was the Erzgebirge (Ore Mountains) in Bohemia, where the Únětice culture was located (at the present-day border between Germany and Czech Republic). Contrary to the south-eastern Europe and Near-Eastern cultures which collapsed during the Late Bronze Age, the Únětice culture was not a palace economy, even if its society was complex. After eight centuries of prosperity, this culture disappears around 1600 B.C., i.e. at the central European transition between the EBA and the Middle Bronze Age. It is thus likely that the discovery and the exploitation of tin mines by people of the Únětice culture constitutes an example of collapse of ancient societies due to dependence on an unsustainable source of income.

Reasons for collapse of the type of societies which relied on mining to boost their income include:

- Exhaustion of the resource on which their wealth was based or a significant fall in the quantity of output of the mineral related to the effort involved in mining it (declining productivity) [12]and
- If the society is highly dependent on the export of commodities obtained from the relevant resource, a significant fall in the exchange rate for these due, for example, to increased competing supplies becoming available from other societies or the development of substitutes relying on resources which are comparatively scarce in the exporting country.

Here some simple comparative economic statics is used to evaluate influences on the economic development of ancient societies that came to depend heavily on the export of minerals for their wealth.

The paper is organized as follows. Some examples of collapses occurring during the Late Bronze Age, and also earlier, are outlined in section 2. Section 3 provides information on the economic and social structure of Bronze Age societies. The section 4 is devoted to the analysis of the economic transformations implied by the introduction of metallurgy. Section 5 explains why and how these transformations can lead to societal collapse such as the one exhibited by the Únětice culture. Section 6 presents a second model in which there are no food imports and mining and the associated society collapse. Section 7 concludes.

2. THE BRONZE AGE COLLAPSES

During the Late Bronze Age (1500-1200 B.C.), the Eastern Mediterranean boasted a flourishing network of grand empires sustaining sophisticated infrastructures, the likes of which the world would not see again for centuries to come. However, they suddenly collapsed. For instance, in the fifteenth century B.C. the Hittites were powerful, but were fading, while the Egyptian power waxed and then waned. Indeed, an interregional destruction (attested in Greece, Turkey, Israel, Syria, Lebanon and Egypt) known as the Bronze Age collapse occurred and is still one of archaeology's greatest mysteries. Examples of social collapses during this period are numerous and some of them are quite famous.²

2.1. Many Cases of Social Collapse

On the island of Crete and in the early second millennium B.C., the Minoans were extremely influential in the Aegean and eastern Mediterranean, trading textiles, timber and wine to Cyprus for copper and Anatolia for tin. In the early 15th century B.C. Crete was invaded by Mycenaeans from the Greek mainland who absorbed numerous aspects of Minoan culture (such as writing) and occupied the palace at Knossos. Mycenae was the greatest of the Mycenaean cities that flourished in

²E.g. the cities of Troy (in modern northwestern Turkey) was destroyed around 1250 B.C. and Megiddo (in modern north-central Israel) was suddenly destroyed around 1130 B.C.

mainland Greece from about 1600 to 1200 B.C. but all of the Mycenaean cities were destroyed towards the end of the 13th century B.C. or the beginning of the 12th century B.C.

By the mid-14th century B.C., the Hittites became one of the Near East's superpowers, rivalling Egypt in the south and Assyria in the east. Towards the end of the 13th century B.C., however, their kingdom suddenly collapsed and Hattusa, the Hittite capital – located in modern central Turkey - was destroyed.

During the second half of the 14th century B.C., Ugarit – on Syria's Mediterranean coast - experienced a period of great peace and prosperity. Ugarit's merchants traded for Mesopotamian and Lebanese timber, Mycenaean pottery, Egyptian ivory, Cypriot copper and Anatolian tin. Ugarit's golden age ended around 1300 B.C., when an earthquake struck the region and a tidal wave and fire engulfed the city. A century later, invading Sea Peoples from the Aegean disrupted the city's commercial routes and forced much of its population to migrate to other sites.

2.2. Many Possible Explanations

During the Late Bronze Age, there was a power struggle in the eastern Mediterranean over land and resources, especially metals. This period was characterized by the increased desire to possess metal; power depended on it. The rise and fall of civilizations was also defined by it. Indeed, metals equalled commerce and currency, and it made tools to dominate other tribes. Thus, people were in search of ore deposits and a better way of life.

The Bronze Age collapse was swift and sudden, ushering in a so-called “Dark Age” of decreased literacy, population and technology decline in much of the Eastern Mediterranean. As stated by Drews [13, Ch. 4], *“Within a period of forty to fifty years at the end of the thirteenth and the beginning of the twelfth century almost every significant city in the eastern Mediterranean world was destroyed, many of them never to be occupied again”*.

In order to explain this collapse scholars have proposed a combination of factors. These include marauding Sea Peoples. Despite numerous debates, most scholars agree that they hailed from Asia Minor, the Aegean, the Balkans, and Cyprus[14]. For instance, a 12th-century inscription describes Ramesses III's defeat of the Sea Peoples - a range of groups including the Philistines - who led raids on the Eastern Mediterranean during the period of the Bronze Age collapse and are often cited as the reason for the collapse. Plagues and earthquakes are other factors leading to a so-called “systems collapse,” in which complex societal networks broke down under mounting interregional economic or demographic pressures.

All the social collapses mentioned above occurred during the Late Bronze Age, i.e. at a period characterized by the transition between Bronze Age and Iron Age. Thus, many authors consider that the introduction of iron was – partly and sometimes completely – responsible of the Bronze Age collapse. For instance, Childe [15] suggested that with the introduction of iron, cheaper and easier to acquire than bronze, peasants and barbarians could obtain weapons that allowed them to challenge the armies of civilized states. The Mycenaean and Hittite collapses followed according to [15, pp. 177-178, 191-193]. The previous explanation is certainly relevant in explaining some of the Late Bronze Age collapses. However, it is not relevant to some collapses that have occurred during the Bronze Age itself. For instance, the Únětice culture collapsed at the transition between the Early and the Middle Bronze Age – around 1600 B.C. – while the commencement of the Iron Age is believed to have roughly occurred in Europe, and nearby, in 1300 B.C., and even later in central Europe. Indeed, the Central European Bronze Age is followed by the Iron Age Hallstatt culture (700-450 B.C.).

3. BRONZE METALLURGY, TRADE NETWORKS AND THE ELITES

The overall period is characterized by the full adoption of bronze in many regions, though the place and time of the introduction and development of bronze technology was not universally synchronous. Despite numerous studies, especially in the recent decades, the provenance of metals as well as the circulation and uses of those same metals remain controversial issues in the academic literature [16]. The Bronze Age was a time of extensive use of metals. Stone tools seem to disappear almost completely during the Bronze Age. While at the beginning of the EBA metal finds were largely made of copper, they were rapidly replaced by bronze tools, even if copper, silver and gold continued to be found. According to Kienlin[17, pp. 420-421], in central Europe (Únětice), the move to tin bronze

was a gradual process that only came to an end well into the second millennium B.C. So, from 2300 to 1800/1700 B.C., it is likely that Únětice people cast various alloys of copper with metals other than tin (arsenic copper, then fahlore copper). After 1800/1700 they produced tin bronze and then they collapsed around 1600 B.C. Man-made tin bronze technology requires set production techniques. The ability to cast dozens of artifacts from a single mold makes it possible to speak of true manufacturing³ as opposed to the individual crafting of each piece. Such emergent specialization would have had profound significance for the agrarian economy, still largely composed of self-sufficient households.

Copper sources are widely distributed in the mountainous zones of Europe, and Central Europe. Copper was probably supplied from the eastern Alpine area, the Harz Mountains in central Germany, the northern Carpathians in eastern Slovakia, and the eastern Carpathians in Transylvania. Whereas copper sources are common, known tin sources are rare[18]. Major sources of tin in Europe are found in Cornwall (Great Britain) and around Bohemian Erzgebirge, or “Ore mountains” on the present-day border between Germany and the Czech Republic. Less significant deposits of tin are present in France (Brittany, Massif Central) and north-western Iberia (Galicia). Tin must be mined (mainly as the tin oxide ore, cassiterite) and smelted separately, then added to molten copper to make bronze alloy.

Because tin was rare, it was necessary to bring it from a considerable distance to others areas, for instance into east-central Europe. Although some prestigious objects or “exotic” ones such as obsidian, amber, jet, alpine jade axes, gold were traded over long-distances during the Mesolithic and the Neolithic periods[19], the long-distance trading networks developed considerably during the Bronze Age. The trade of metals and of other valuables items – mainly salt and wooden textiles – relied on boats⁴ but also made use of wheeled vehicles which appeared in Europe during the Copper Age. Because copper and tin are distributed unevenly, the desire for raw materials bound together European society in a metals trade. Few mining areas produced the bulk of metal to be systematically distributed via long-distance trade to all communities. In other words, such trade was now systematic and thus it contributed to integrating the continuing staple economies of Europe and beyond.

It is a commonplace assertion that in prehistory the development of the metals industry is closely linked to the growth of social complexity. Childe [20], for instance, placed metallurgical technology at the forefront, arguing that it fostered ‘itinerant metal smiths’ and that bronze production facilitated the rise of social elites and complex societies. In fact, the control of copper and tin mines and the subsequent trade in these commodities led to a more powerful elite. Indeed, elites had exclusive access to high-valued goods, such as bronze weapons or ornaments. Moreover, the elites begin to position themselves on the landscape to control access to different resources, such as mines and trade routes. Consequently, the society was increasingly differentiated into elites and commoners. In other words, it is clear that social organization became increasingly complex throughout Europe during the Bronze Age. Indeed, although social stratification already had begun to develop in Neolithic Europe and even before[21], copper and then bronze gave the emergent elites a useful and rare raw material whose control enabled them to consolidate their power as well as a perfect vehicle for display.

Let us consider some economic models that help to explain the possible economic reasons for the collapse of some societies in the Neolithic and the Bronze Ages. In doing so, particular attention will be paid to the collapse of Únětice EBA societies.

4. ANALYSIS OF ECONOMIC TRANSFORMATIONS AND SOCIETAL SUSTAINABLE DEVELOPMENT ISSUES IN THE NEOLITHIC AND THE BRONZE AGES

The ancient society is assumed to depend on a subsistence and barter economy with a dominant elite engaged in managing the economy by command. They monopolize exports and trade and their chief aim is to extract the maximum economic surplus from their resources and their subjects.

³Bronze production on a significant scale first appeared in about 2300 B.C. in the EBA central European Únětice culture.

⁴During the late third and early second millennium B.C. occurred the rapid development of new maritime technologies which for the first time allowed safe sea journeys over longer distances and provided larger ships that carried bulk cargoes across open waters.

4.1. Agricultural Surplus Extraction and Population Levels in a Neolithic Economy

It is supposed that initially a Neolithic society only depends on agriculture for its wealth and that the population of the dominated class increases according to Malthus' law of population increase. In Figure 1, OG is assumed to be the subsistence wage and therefore, GC is the supply curve of agricultural labour. It is in elastic supply in the long-run at this wage rate as originally supposed by Malthus [22] and more recently in the development theories of Arthur Lewis [23]. Line ABC represents the marginal productivity of agricultural labour. The maximum economic surplus which the elite can extract from this economy is equal to the area of triangle AGC. It is in the self-interest of the elite to prevent the population of agricultural labourers increasing beyond \hat{L}_1 by extracting the surplus and not permitting the wage bill to exceed the area of the dotted rectangle shown in Figure 1. In the absence of this extraction, the total agricultural population will increase beyond \hat{L}_1 and the marginal productivity of agricultural labour will be lower than their marginal level of consumption. Rent dissipation will occur. If there is no extraction of the agricultural surplus, it will be completely dissipated by the increased population of agricultural labourers. Their population will increase until their average product equals the subsistence level of income.⁵

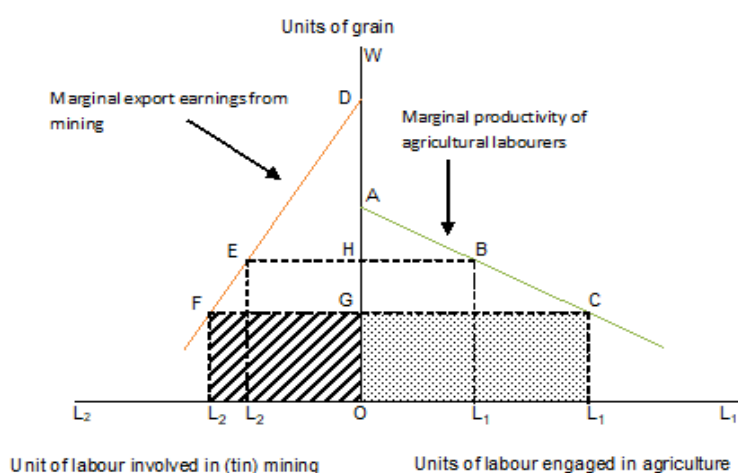


Figure 1: Diagram to illustrate aspects of unsustainable economic development in some ancient societies

One of the reasons why a Neolithic agrarian society of this type can collapse is because of the ecological collapse of its food production. This can result in a major (and sometimes relatively rapid) change in its food availability leaving little or no scope for the ruling elite to extract an economic surplus from economic production as well as triggering an over population crisis. In Figure 1, it would result in a significant shift downwards in line ABC which represents the marginal productivity of labour engaged in agriculture.

4.2. Surplus Extraction and Population Levels in a Bronze Age Economy (Food Imports Possible)

Now suppose that as in the Bronze Age, a new production possibility (mining and metal manufacture) other than in agriculture emerges, for example, in tin mining, the products of which are mainly for export. Let grain act as the numéraire and assume that DEF represents the marginal productivity of tin mining in terms of grain imports for which it can be exchanged. Now the total production of the economy would be maximized initially by allocating the available labour so that the marginal productivity of labour is the same in mining as in agriculture. In the absence of any increase in the labour supply this would call for \bar{L}_2 of labour being allocated to mining and the amount of labour engaged in agriculture being reduced to \bar{L}_1 . However, members of the elite need to bring this reallocation about in a way that will increase their economic surplus by keeping the wage rate as close to OG as is possible.

⁵For further theoretical discussion of the extraction of the economic surplus in pre-industrial economies, see Tisdell and Svizzero[24].

In other words, this short-run solution is not the one that maximizes the surplus of the elite. They will gain from a population increase. This might be achieved by capturing slaves, or by allowing natural population increase or immigration, or by any combinations of these three means. Natural population increase depends on the wage being maintained about the level OG until the desired level of population is obtained at which point it should return to OG. In this long-run equilibrium, the wage bill will be equal to the dotted plus the shaded areas. There is no change in agricultural output and the amount of labour engaged in agriculture compared to the original situation. This economy is likely to depend substantially on food imports for its sustainability.

The surplus available to the elite (the sum of areas AGC and DGF) may be used for a variety of purposes[25]:

- The production and import of luxuries for their own consumption.
- War and defence.
- The employment of servants.
- Potentially for value adding to the mined product for exports.
- Capital accumulation.

As a result of the mining bonanza, the total population of the society increases substantially, that is, by \hat{L}_2 plus those employed as servants and in similar capacities by the state (the elite).

5. UNSUSTAINABLE MINING DEVELOPMENT AND SOCIAL COLLAPSE

For Tainter[1, Ch. 4], societal collapse is fundamentally a process which relates to the socio-political sphere; “A society has collapsed when it displays a rapid, significant loss of an established level of sociopolitical complexity”. In other words, in order to qualify for a social collapse, it is first necessary that a society has developed a significant level of complexity. According to Tainter[1, p. 23], “Complexity is generally understood to refer to such things as the size of a society, the number and distinctiveness of its parts, the variety of specialized social roles that it incorporates, the number of distinct social personalities present, and the variety of mechanisms for organizing these into a coherent, functioning whole. Augmenting any of these dimensions increases the complexity of a society”. As it is implied by the previous definition, the development of complexity is a continuous variable, and so is its reverse. In other words collapse is a process of decline in complexity: a society that has collapsed is suddenly smaller, less differentiated and heterogeneous, characterized by fewer specialized parts, it displays less social differentiation, and it is able to exercise less control over the behaviour of its members.

Let us go back to Figure 1 and now suppose that DEF shifts downwards sharply. The society is thrown into disarray. Its level of population can no longer be supported and the elite suffer a large reduction in their economic surplus. This sows the seed for the collapse of this type of society.

Reasons why a shift downward in the marginal productivity of mining based on its exchange rate with grain (a downward shift in DEF in Figure 1) can occur are as follows:

- Mining deposits are exhausted or more likely the effort required to mine the minerals increases substantially after a period of production. The latter type of effect was predicted by Ricardo [26], and Jevons [27] paid attention to the first possibility.
- The foreign exchange rate of the mineral for grain falls. This may occur because there is increased supply of the mineral from other territories or competitive substitutes for the mineral are found e.g. iron.

The first development could explain the collapse of Únětice societies[12]. In the case of Únětice societies, it is possible that those deposits of tin which were most easily mined were mined first and therefore, the productivity of labour engaged in mining fell with the passage of time. Such sequence is clearly confirmed for copper extraction in central Europe [17, p. 425]. It can be interpreted in terms of geology and technological progress, since the earliest miners and smelters are thought to have worked the upper, oxidized regions of their mines with relative simple technology. By contrast the exploitation of the deeper, sulphidic ore bodies required advances both in mining and smelting techniques. The same evidence exists for tin extraction. At the beginning of the EBA, tin was most likely won from alluvial stream deposits carrying tin-oxide minerals. Indeed, recent research and

examination of the geology of the area, has revealed that primary lodes of cassiterite are limited to the upper part of the granite and this zone has been subject to considerable erosion due to the harsh climate. The result of this has been the production of placer deposits of stream tin which occur in the area of almost all the primary tin ore deposits. Although tin was easily mined at the beginning, this changed with the passage of time. Indeed, most of the deposits in the Ore Mountains are located in veins of granitic rock, thus their extraction would have required advanced techniques and technology and more effort for Bronze Age miners. Presumably, this enabled other suppliers of tin and copper increased opportunities to market their products.

The second reason could be that although the demand for tin, copper and bronze did not cease with the commencement of the Iron Age, the development of iron in other regions (Southeast Europe, Near East) reduced the demand for these products in central Europe.

Note also that societal collapse of an economy that has become increasingly dependent on mining and metallurgy may come about if it experiences a substantial decline in the level of its domestic food production[see e.g. 5]. In the case shown in Figure 1, this decline would be reflected in a major downward shift in line ABC in this figure. In these circumstances, the elite would have an incentive to shift excess agricultural labour into mining and production. However if the amount of excess agricultural labour is large, a labour excess will emerge for the whole economy thereby sparking a population crisis. This will happen if the amount of labour displaced from agriculture is a result of its falling productivity exceeds $\hat{L}_2 - \bar{L}_2$. If more than $\hat{L}_2 - L_2$ of labourers are transferred from agriculture to mining, their marginal productivity in terms of grain imports will be less than their subsistence wage.

6. A SECOND ECONOMIC MODEL (NO FOOD IMPORTS)

We can also consider by means of an economic model, the case of an ancient society which develops mining and metallurgy but does not engage in external trade, or does not do so to a significant extent. Figure 2 illustrates this case (by relying on comparative economic statics) assuming a two sector set of production possibilities. The level of production of two sectors, namely (1) agriculture (food) and (2) mining and metallurgy are considered. It is supposed that initially the society under consideration has the production possibility function illustrated by curve DEFG in Figure 2. The economy is imagined to be under the centralized command of its elite who only pay commoners a subsistence wage. Given the level of labour available in the economy, this results in a total wage both equal to OA. The difference between production possibility curve DEFG and the line AL represents the surplus available to the elite in terms of food (when food is the only product). The elite can trade off (forgo) their surplus in terms of food in order to increase mining and metallurgy output. For example, to obtain a level of mining and metallurgy production of x_1 , they would forgo CD in food output (and in their food surplus) as a result of sufficient labour being re-allocated to mining and metallurgy production to supply an output of x_1 of minerals and metals.

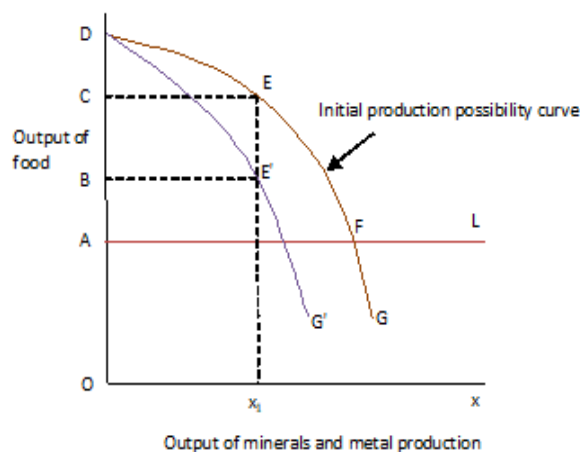


Figure2: A diagram to illustrate a second model of the possible unsustainable mining development of an ancient society

Now suppose that the productivity of the mining and metallurgy sector declines but that of agriculture remains unaltered. This results in the clockwise rotation (on the fixed point, D) of the production possibility curve, for example, to DE'G'. A greater sacrifice of the food surplus is required to sustain the production of minerals and metals at x_1 , namely a reduction by an amount BD in this case. The elite is left with little in the way of a food surplus and may be forced to cut their production of minerals and metals substantially and transfer labour back to the agricultural sector. This may adversely affect the social prestige of the ruling class.

However, the situation is more serious if the productivity of agriculture as well as that of the mining and metallurgy sector declines. This would result in the production possibility curve shifting downwards and rotating clockwise at the same time. The available surplus can as a result of this, be substantially reduced. The elite may be forced to cease (or to almost cease) their production of minerals and metals and at the same time may have a much lowered food surplus. In the worst scenario, the political and social power of the elite is eroded and an over population crisis could emerge of a type that may have been experienced by Silesian Únětice communities, which probably contributed to their disappearance [28].

7. CONCLUSION

Several reasons have been proposed in the literature for the collapse of ancient societies but the economics behind these collapses has received little attention. We explored in the article, using economic modelling, reasons for the collapse of Únětice culture which occurred at the transitional stage between the Early and the Middle Bronze Age. In our view, its demise cannot be attributed to the commencement of the Iron Age. The collapse was most likely calamitous because as a result of its bronze production, Únětice's population was able to increase considerably and the elite were able to develop a lavish lifestyle. Neither of these could be maintained once the mining of tin became much less productive.

Whereas the agrarian Neolithic economy was mono-sectorial, the introduction of mining and metalworking transformed the Bronze Age economy into a two-sector economy. As a result, balanced sustainable economic growth of such economy required particular conditions to be satisfied in both economic sectors. More precisely, since labour is the only (the main) input of both sectors, any significant change of the labour productivity in any single economic sector induces unbalanced economic growth. As we have illustrated by means of two simple models, even if the elite re-allocates the labour input between both sectors and/or modifies the level of the whole labour input, the situation can be unsustainable in the long run. Indeed, while the level of the labour input can be reallocated relatively rapidly, this is not true for variations in the level of the population. Thus, an excess population level compared to the food resources necessary for its subsistence inevitably leads to a social collapse. It is even possible for both sectors of this type of two-sector economy to simultaneously experience a significant decline in labour productivity, thereby adding to the severity of its social collapse.

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