MODELLING THE SPARTAN CRISIS:  
COMPUTER SIMULATION OF THE IMPACT OF  
INHERITANCE SYSTEMS UPON THE DISTRIBUTION  
OF LANDED PROPERTY

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This article describes a computer simulation which was devised as a means of testing and giving numerical shape to certain hypotheses which I had developed during a study of the controversial field of land tenure and inheritance in ancient Sparta. The subject is of considerable importance to ancient historians, since the flaws in Sparta’s system of property ownership contributed significantly to the collapse of her power structures whose influence had pervaded classical Greek political life. The focus of this paper, however, will rest not so much upon the substantive historical issues – although some discussion will be necessary to provide context\(^1\) as upon the computer simulation employed to examine them, its potential use in other historical studies, the role of the computer in the overall study and (in the Appendix by Sarah Davnall) some of the practical problems and decisions involved in programming the simulation.

The use of computers in historical studies is of course a growing phenomenon. Yet for many historians, especially students of antiquity, it remains alien territory. One reason is the seeming theoretical and technical complexity of many computer projects which make daunting reading for the uninitiated. (Often this apparent complexity is mainly a reflection of the time-consuming process of learning either how to use and adapt commercial software or how to program for oneself.) Another problem – particularly in fields, such as ancient history, for which the sources are frequently not only extremely scanty and incomplete, but also overwhelmingly literary and notoriously unstatistical in nature – is the lack of suitable or sufficient evidence for the construction of the kind of database which forms the cornerstone of most historical computing projects.\(^2\)


\(^2\) For a description, however, of how piecemeal and anecdotal evidence can form the basis of small, specialized databases see D.A. Spaeth, ‘Computing the godly: the application of small databases to anecdotal history’, Historians, computers and data, eds. J. Mawdsley et al. (Manchester and New York: Manchester U.P., 1990), 156–62.
The project described here attempts to meet both these difficulties, having been constructed without either a deep knowledge of computing or a database. First, it was conceived at a time when, as a postgraduate student, I was both computer-illiterate and without access to computing facilities. The essential features of the algorithm (that is, the set of procedural statements specifying the operations to be performed by the computer) were devised then; indeed, I initially commenced the operations in laborious fashion on a pocket calculator before quickly giving up when the impossible complexity of the arithmetical calculations became apparent! Although the project finally came to fruition only when I gained access to the facilities of the Manchester Computing Centre, the principles behind its design are relatively simple and require only the exercise of elementary logical thinking.

Secondly, the project attempts to escape from the inadequacy of ancient evidence through the use of computer simulation. This technique is far less frequently practised by historians than is the exploitation of evidential databases, although the method is more common in the social sciences, especially in demographic studies. In my project an elementary form of the method has been employed to simulate the impact of different inheritance systems upon an artificially constructed population. The results, as I hope to demonstrate, have been illuminating for my subject of study.

THE HISTORICAL PROBLEM

The background to my study is the longstanding controversy surrounding the nature of land tenure in archaic and classical Sparta (c.650–c.350 B.C.). The controversy centres on whether land in the possession of Spartiate citizens was publicly or privately controlled. The detailed issues need not be recounted here. Suffice it to say that in a recent article I argued that a Spartiate citizen would normally transmit his land privately to his children according to the normal Greek practice of partible inheritance.

Although this interpretation has been favourably received, one particular issue remains less certain: the inheritance rights of Spartiate women. The normal assumption has been that, although daughters might receive land through voluntary parental gifts, bequests or

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5 See, for example, A.J. Spawforth, Classical Review, n.s. 40 (1990), 346.
dowries, they had no automatic right to a share of the landed inheritance when there were surviving sons. On this view daughters were entitled to inherit only in the absence of sons – a system which I shall call ‘residual female inheritance’. There is, however, some evidence to the contrary, in particular an intriguing statement by Aristotle (Politics 1270a23–4) that approximately two-fifths of the land was in the hands of women. Now, it can be shown mathematically that, even under varying demographic conditions, a system of inheritance according to which a daughter is entitled to a landed inheritance half that of her brother will tend to produce a distribution of land between the sexes such that the proportion owned by women is indeed approximately 40%. Such an inheritance system – which I shall term ‘universal female inheritance’ – is attested at classical Gortyn in Crete. The hypothesis that universal female inheritance operated also at Sparta would explain Aristotle’s figure.

The above argument, although plausible, requires further support, given the extreme paucity of evidence. One test of probability can, however, be applied. We know that by the time of the late fifth and early fourth centuries many poorer Spartiates had come to own so little land as to forfeit their citizen status, thus causing a disastrous decline in Spartiate manpower. The most serious manifestations of that development, however, became evident only after two centuries or so of comparative stability; and there are no solid grounds for thinking that there was any change in the inheritance system during the period in question. In assessing the relative claims of the alternative systems of residual and universal female inheritance, therefore, the more plausible candidate will be the system whose inherent effects were a steady but not too rapid increase in landed inequalities, such as to explain why the twin problems of property concentration and impoverishment reached serious proportions only over a lengthy period.

Now, the inequalities generated by a system of universal female inheritance should in theory tend to be more graded and less sharp than those produced by a system of residual female inheritance. When some land is inherited by every daughter, rather than only by those daughters without surviving brothers, it is divided more evenly among more persons: and when those daughters marry, the combined husband-wife landholdings should show less marked inequalities between one family and the next. On this reasoning a system of universal female inheritance would once again seem to fit in better with what is known about Spartan property holding. It was decided to test and to flesh out this theoretical reasoning by devising a computer simulation to examine the extent to which the implications of the two alternative female inheritance systems were significantly different.

6 Hodkinson, ‘Land tenure’, 400.
THE COMPUTER SIMULATION

A few preliminary words concerning the purpose of simulations are perhaps necessary. First of all, 'Computer simulation is easy to misunderstand, for it is easy to jump to the false conclusion that an experiment must propose to recreate some particular historical reality inside a computer, rather than to recreate and test the ideas that scholars have'. 7 It should be stressed that the simulation was designed to evaluate my hypothesis about the inherent implications of the different systems of inheritance, not to construct a hypothetical Spartan reality. Secondly, the simulation employs several simplifying assumptions, since, as Smith has noted, 'experience with scientific models in general, and computer simulation models in particular, has shown that attempts to produce more and more realistic results usually lead to unwieldy models which contain many ad hoc assumptions and which are impossible to verify and replicate'. 8

The algorithm behind the simulation postulates a model population of 10,000 married couples in which each couple owns one unit of land in what I shall call 'Generation One'. It also employs a Family Composition Distribution model (see Table 1) which specifies the numbers of surviving sons and daughters (up to a maximum of four sons and four daughters) produced by each of the 10,000 couples. This model was calculated by means of binomial expansion on the simplifying assumptions of a stationary population with an equal sex ratio in which the replacement of all members of one generation by the next takes place simultaneously and in which each child born has a 0.5 chance of surviving beyond the deaths of its parents. 9

On the basis of the Family Composition Distribution each family's single unit of land is first divided among their surviving children according to the different rules of the two inheritance systems. Secondly, land belonging to families with no surviving children is reallocated as an 'indirect inheritance' to some of the other families on a 'selective proportional basis'. (There are 2,126 units of such land to be distributed among 7,874 families with surviving children; consequently, 27% \[2126/7874 = 0.27\] of these families each

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7 Statistical studies, Wachter et al. (eds.), xix.
8 J.E. Smith, 'The computer simulation of kin sets and kin counts', in Bongaarts et al. (eds.), *Family demography*, 249-66.
9 The distribution used in this study derives from the work of Professor E.A. Wrigley and Dr R.M. Smith, who have produced a number of distribution tables employing varying assumptions regarding fertility and mortality rates and rising, stationary and declining populations: cf. E.A. Wrigley, 'Fertility strategy for the individual and the group', *Historical studies of changing fertility*, ed. C. Tilly (Princeton: Princeton U.P., 1978), 135–54, Tables 3.1–3.3 = E.A. Wrigley, *People, cities and wealth* (Oxford and New York: Basil Blackwell, 1987), 197–214. Tables 8.1–8.3; *Land, kinship and life cycle*, ed. R.M. Smith (Cambridge: C.U.P., 1984), 44ff., Tables 1.2–1.7. Table 1 represents my own extrapolation from these published tables, which I have extended to cover combinations of surviving daughters as well as sons. This extrapolation has been cross-checked against similar, unpublished calculations made by Dr Smith, then subjected to minor adjustments to render the population stationary.
TABLE 1: FAMILY COMPOSITION DISTRIBUTION

receive one extra unit.) 10 This additional land is then divided among the children of these families in the same way as the families' original landholdings. The individual men and women who form Generation Two of the model population are now grouped (separately) into different male and female 'landholding sets', each set comprising those holding identical amounts of land.

The following operation pairs off these men and women to form Generation Two families. (The assumption is made that all individuals will marry, but only once.) This pairing is also performed on a selective proportional basis, such that an identical proportion of

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10 So, for example, of the sixteen couples with four sons and four daughters, four couples will receive an extra unit of land in addition to their original holding \[16 \times 0.27 = 4.32\].
women from any given landholding set is partnered with the members of any given landholding set of men, and vice versa. (Since our purpose is to examine the inherent consequences of the inheritance systems rather than to construct a hypothetical reality, it is of course necessary to avoid introducing 'real life' factors such as a tendency towards marriages between persons of similar wealth.) It is then possible to calculate the combined landholdings of each new Generation Two family and to group these families into landholding sets. The cycle now recommences with the application of the Family Composition Distribution model, again on a selective proportional basis, to each of these Generation Two family landholding sets, in order to produce the individual men and women of Generation Three, whose personal landholdings are then calculated and ranked in landholding sets as before.

Up to this point manual methods of performing the required mathematical computations are just about feasible. From this stage onwards, however, introduction of the computer was necessary to cope with the complexity of the required calculations. (Various minor adjustments to the above procedures necessitated by the use of the computer are described in the Appendix.) To date the routines described above have been applied across a number of generations as far as Generation Thirteen. Information about the distribution of land can be extracted at each generation in two forms: (i) computer-drawn graphs and (ii) print-outs which specify the numbers of families and of individual men and women within each landholding set. The graphs reproduced below, however, are restricted for the sake of clarity to holdings up to two units in size. This restriction omits only the very richest members of the population, in order to focus upon poorer families and individuals the rate of whose impoverishment and loss of citizen rights is the key development requiring elucidation.

Figures 1 and 2 indicate the outcome of land distribution among families at the stages of Generations Two and Seven, respectively. The graphs show for the two inheritance systems the number of families (on the horizontal axis) who possess equal to or less than the units of land indicated on the vertical axis. Three main points merit attention. First, the graphs show that, although all Generation One families started with equal landholdings, already by Generation Two marked inequalities have begun to emerge under both systems of inheritance. By Generation Seven these inequalities have become even more firmly established.

Secondly, in the generations beyond Generation Seven there is little perceptible alteration to the graphs. (The raw numbers in the print-outs do show some slight but balancing alterations and there is some more significant fluctuation at the wealthy end of the scale where the number of families is rather smaller; but the overall picture is one of stability.) This stabilization of property distribution, a phenomenon known in the sciences as 'dynamic equilibrium', is not surprising
FIGURE 1: FAMILY LANDHOLDING IN GENERATION 2

FIGURE 2: FAMILY LANDHOLDING IN GENERATION 7
given the unchanging character of the four key variables postulated by the algorithm (population level, total landholding, family composition distribution and inheritance systems). The variations in land distribution in the early generations seem to reflect evolution from an initial distribution (one unit per family) not generated by the inheritance systems; as the inheritance systems take hold through the generations these variations diminish. It is interesting, however, that the universal female inheritance graphs stabilize into the mould of their ultimate pattern more rapidly than those of residual inheritance only.

<table>
<thead>
<tr>
<th>Units of Land</th>
<th>Number of Families</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Universal F. I.</td>
</tr>
<tr>
<td>0.5 or less</td>
<td>2837</td>
</tr>
<tr>
<td>0.4 or less</td>
<td>1927</td>
</tr>
<tr>
<td>0.3 or less</td>
<td>1084</td>
</tr>
<tr>
<td>0.2 or less</td>
<td>420</td>
</tr>
<tr>
<td>0.1 or less</td>
<td>62</td>
</tr>
</tbody>
</table>

**TABLE 2: NUMBERS OF IMPOVERISHED FAMILIES IN GENERATION 7**

Thirdly, under both systems the majority of families own holdings smaller (many much smaller) than the one unit held by their ancestors. As predicted, however, the higher starting-point and the flatter graph of universal female inheritance indicate a less unequal distribution of land than the more sharply-rising graph of residual female inheritance. The differences between the effects of the two inheritance systems are especially marked at the low end of the property-holding scale. This is apparent from Table 2 which specifies the precise numbers of families within the poorest Generation Seven family landholding sets indicated in Figure 2. For example, under residual female inheritance over 13% of families within the overall population own landholdings as small as 0.1 unit or less in comparison with fewer than 1% under universal inheritance; and over 21% own only 0.2 units or less compared with just over 4%.

This picture is reinforced by Figure 3 which shows that among the male portion of the population (considered alone) universal female inheritance produces not only less relative inequality, but also fewer very poor men in absolute terms (only 1,288 men with 0.1 unit or less as against 1,927 men under residual female inheritance). This latter result is at first sight unexpected, since males own considerably less land under universal female inheritance (57.6% of the total as against 74.9%). The key to this paradox seems to be that, among the poorer sections of the population, men generally gain more land through inheritance from their mothers (most of whom would own no property
under residual female inheritance) than they lose by sharing the parental holdings with their sisters.

CONCLUSIONS AND POTENTIAL APPLICATIONS

Although a simulation is a fiction, 'like a good fictional story . . . it does claim to be understandable in terms of the real world and to be useful in shedding light on the operation of that world'. The results of the simulation lend support to the idea that Sparta practised a system of universal female inheritance. The fact that it produces smaller numbers of very poor families and individuals suggests that the operation of such a system at Sparta would help explain the lengthy timescale over which the phenomenon of impoverishment developed into a serious problem. (In real life of course, without the constraints imposed by the algorithm, the static impoverishment indicated in the simulation would be a gradual, ongoing process.) The more rapid early stabilization of the universal inheritance graph may indeed be indicative of a less volatile system better able to withstand short-term perturbations to the landholding structure such as might be caused by factors like natural disasters.

If, moreover, one were to take account of one important variable which was expressly excluded, namely the 'real life' tendency towards marriages between partners of comparable wealth, the divergent consequences of the two inheritance systems would be magnified.

11 Smith, 'Computer simulation'. 250.
Under residual female inheritance the minority of women who inherited land (as sole heiresses in the absence of brothers) would tend to be acquired as wives by men of wealth; poorer men would normally have to make do with landless brides. When, however, all daughters inherit something, even the poorest men gain some addition of land with their wives. The implications of the simulation are, therefore, not mere theory, but would apply with even greater force in real life.

The elementary simulation described above has been able to contribute to the solution of two different historical problems: first, to the identification of the character of female inheritance rights in an ancient society about which the quantity of written evidence is limited; secondly, to the elucidation of the causes of certain long-term trends of property distribution whose explanation has long been problematic.

There are other problems for which the simulation might prove useful. Had, for example, the system of inheritance been known but little information been available concerning the distribution of holdings, the simulation could have been used to deduce probable trends of landownership. In addition to the overall distributions of land given in Figures 1–3 other types of calculations are possible, such as comparisons between the holdings of men and women, or information concerning the proportion of land owned by specified landholding sets. Aspects of the algorithm could also be altered to broaden the range of situations for testing. Application of a different Family Composition Distribution would permit examination of the implications of growing or declining populations or of different levels of mortality. Or the procedures for matching males and females could be modified to replicate patterns of marriage-making in known historical populations. Similarly, other modes of property devolution could be tested than the partible inheritance systems considered here.

The relative simplicity and adaptability of the simulation may make it potentially useful for the scrutiny of varying historical problems in different times and places. I do not wish to overemphasize this point, since the simulation is not devoid of culture-specific characteristics which limit its transferability. Its most ‘natural’ field of application is to societies in which inheritance of landholding rights (or of cultivation rights, in the case of dependent populations), whether pre- or post-mortem, dominates over voluntary lifetime transfers and is not significantly affected by the intervention of outside authority. It is therefore less applicable to societies with an extensive market in land, although in so far as the frequency of lifetime exchanges was a response to the working of the inheritance system the simulation might be advantageously employed to define the problems which stimulated that response.12 Similarly, it would be inapplicable to some dependent populations, such

as the Tuscan tenant farmers of post-unification Italy, whose household composition and labour force were subject to frequent landlord manipulation; but it could be applied to other subordinate groups such as Sparta's helots, who may generally have inherited cultivation rights/obligations to specific plots of land according to common Greek inheritance procedures. These qualifications aside, there remain many situations for which the simulation might be of assistance in giving more precise shape to the inherent effects of inheritance systems, given the fundamental importance of problems of land distribution and inheritance to the study of historical demography and economy.

Finally, what of the role of the computer in the overall study? My study falls squarely within the category of projects which 'are simply defined, and simply answered, with the computer... acting as nothing more or less than a workhorse'. Simple as its 'workhorse' role has been, use of the computer has in two important respects added greater clarity and a wider dimension to the overall study. First, its demand for a precise and formally defined algorithm has compelled a more consciously explicit theory about the nature of the historical problem and its possible solution. Secondly, the unexpectedness of some of the simulation's results (such as its revelation that fewer poor men are created by the inheritance system in which men in general own considerably less land) has illuminated aspects of the subject hitherto obscured by insufficiently penetrative thinking. Rather than a source of mystification, use of the computer can be a stimulus towards the logical thought and spirit of enquiry which are the hallmarks of outstanding research within the humanities.

ABOUT THE AUTHORS

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14 Editorial introduction to Historians, computers and data, eds. Mawdsley et al., xi.
In 1986, when this exercise was first proposed, there was, as far as we knew, no suitable software already in existence. A program, therefore, had to be written. Because of the programmer's expertise, the programming language chosen was Fortran 77, and the program runs on the University of Manchester's general-purpose mainframe. Initially, this was a CDC Cyber 176, which was subsequently replaced by an Amdahl 5890.

The procedure was relatively simple to code, because it can be expressed very clearly. A few decisions had to be made. For example, in second and subsequent generations, how was land indirectly inherited from childless families to be handled? In the first generation the quantities were summed and the total divided equally between the receiving families, a straightforward matter because all childless families had the same amount of land, one unit. In subsequent generations their landholdings varied, and we had to decide whether we should take account of this, and how. We decided to keep the model simple, calculating and redistributing the average holding of the childless families.

We had some problems when the program was actually run, because of the way the computer performed the calculations. Two categories of number are recognised by computer programs: integer, or whole, numbers; and real numbers, with fractional parts. It was clearly sensible to handle the numbers of families and children as integers and the landholding values as reals, but both sets of numbers caused certain difficulties.

An advantage of using real numbers is that calculations can be performed to a high degree of precision. This precision, however, caused some problems because it resulted in a large number of landholding sets with values differing from one another by minute fractions – for example, some twenty different variants all approximating to one-third of a unit. Indeed, the landholding sets became so numerous after a few generations that on the Cyber-176 the memory was insufficient to process them. Equally seriously, the number of families in each landholding set became too small for useful subdivision. In each generation, therefore, following the distribution of direct and indirect inheritance, we grouped the sets on the basis of landholding values held to one decimal place. (E.g. sets with values 0.50–0.149 were combined into a set deemed to have a landholding value of 0.1.) These grouped sets were then used in the subsequent stage of the process. Because, however, the simple one-decimal-place value was in effect an arbitrary one, it was not appropriate for the subsequent calculations; in these we used the average value of the sets which formed the recombined set.

With the integers, our problem was one of insufficient precision.
A calculation with integers will lose any fractional part which has been generated by a division. We addressed this to some extent by ensuring that the integers were converted to real numbers for all such calculations, the results being subsequently rounded to the nearest integer; statistically, viewing the calculations simply as calculations, any resulting distortions probably balanced one another out. However, in this exercise the calculations are not simply sums: each has an impact on the next stage of the inheritance process.

For example, in the Family Composition Distribution the proportions of the families with large numbers of children are small. When, in the subdivision of the landholding sets, we applied these proportions to a landholding set which was itself small, the calculations would produce results which rounded to integer zero, with the effect that a relatively sizeable contribution of children to the next generation was not made. Most of the time, the numbers of children contributed by the other subdivisions of the set compensated for the lack of children from these small groups (as is the intention of the model), so the effect was slight (it also fluctuated). Nevertheless, over the twelve generations the population total had a tendency to decline. We therefore judged it appropriate to check the population structure at each generation after the subdivision of the landholding sets and, where necessary, to adjust the number of families within those subdivisions to ensure that across all landholding sets the sums of the families with particular combinations of children matched the numbers in the Family Composition Distribution. Incidentally, a similar adjustment was necessary, when the land from childless families was redistributed, to ensure that the number of indirectly inheriting families matched exactly the number of childless families. These adjustments seemed, in turn, to cause small fluctuations (generally increases) in the total landholding, for which we corrected by adjusting the average landholding value of each set. Although artificial, these adjustments were too insignificant to have any effect on the landholding structure: the landholding values calculated to one decimal place remained the same and the landholding sets were preserved.

The range of landholding values could also be significantly influenced by calculations with low-value integers. At first the program operated on a total population of 10,000, with the result that after two generations the numbers of families in the wealthier landholding sets were down to single figures. Most of these sets disappeared when they were subdivided according to the Family Composition Distribution because the only proportion which produced a non-zero result was that for families with no surviving children (2126/10000). Their landholdings were then divided up among the indirectly-inheriting section of the remaining population. A similar effect was also apparent in the process by which the men and women were matched to form the new generation families. The male and female landholding sets were
subdivided for this on the basis of the proportion of females in each landholding set. As before, where the numbers or the proportions were small, they would produce an integer result of zero, with the result that no marriage would take place. Thus, generally, men from the small wealthier landholding sets married women from the larger poorer ones and vice versa, so it was rare for a new family to have a landholding significantly larger than average.

As a consequence the range of landholding values was rather narrow. Although the model was never intended to be a replica of reality, we nevertheless felt that the very small numbers in the wealthier landholding sets were having an unduly depressing effect on the landholding range. We therefore increased the population, by a factor of 100, to one million, with the result that the landholding range roughly doubled. The figures have been scaled back down again for the graphs in this article. Of course, the scaling down has caused any set with fewer than fifty families to disappear through rounding down to integer zero. Nevertheless, the landholding range remains roughly one and a half times greater than before; and since the disappearing sets are, as always, those at the wealthier end of the scale, they are not relevant to the graphs in the text, which concentrate on those holding two units of land or less.

The checking and adjusting of the figures were by far the most effort-consuming parts of the programming, not least because the first suspicion was always that the inaccuracies were caused by an error in the program. Some errors there were at first, of course; but careful checking has failed to find such causes of the fluctuations discussed above, so we believe that our adjustments were common-sense responses to problems which were an inevitable result of using the computer.