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Divining the Unprovable: Simulating the Demography of African Slavery

Since the days of Malthus, demographers, historians, and other students of Africa have sought to assess the impact of slavery on African demography. Malthus, writing as an opponent of the slave trade, acknowledged that the overseas trade removed many Africans from the continent, but he emphasized the regenerative power of African populations. "Notwithstanding this constant emigration, the loss of numbers from incessant war, and the checks to increase from vice and other causes, it appears that the population is continually pressing against the limits of the means of subsistence."[1]

But Malthus, basing his views on no more than a few travelers' narratives, was working in a virtual absence of data. He was attempting to assess the population of an African "black box," as influenced by a large, yet unmeasured emigration of slaves.

The range of historical opinion underlines the difficulty of knowing how the slave trade influenced African population. Pro-slavery propagandists such as Archibald Dalzel, an English merchant and historian, argued that the impact of slavery on the African population was negligible, since the exported slaves would otherwise have been executed in Africa. Thomas Clarkson, a leading propagandist of the successful campaign for British

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1 Thomas Robert Malthus, *An Essay on the Principle of Population* (London, 1817; 5th ed.), I, 208. Malthus touched on many of the issues concerning slavery and African demography: the size of the emigrant slave population; fertility, mortality, natural increase, age, and ratio of males to females in the remaining African population; and the roles of polygyny and famine.

abolition of slave trade, was concerned more with the barbarity induced by the slave trade than with the depopulation of Africa. Thomas Fowell Buxton, his disciple, estimated in 1839 that Africa had suffered severe depopulation because of the mortality brought by slave trade. David Livingstone, the famed missionary-explorer, confirmed Buxton's impression in the course of his observations of the East and Central African slave trades in the third quarter of the nineteenth century.[2]

At the turn of the twentieth century, Henry Hamilton Johnston, a British imperial official, conceded that the demographic impact of slavery was negative, but thought that it was counterbalanced by the benefits of European culture for Africa. Carr-Saunders, in his 1936 survey of world population, estimated that the losses from the slave trade held the African population at 100 million from 1500 to 1700, with a decline to 90 million in 1800, while the populations of other continents grew.[3] All of these arguments, however, were built on a data base little different from that available to Malthus.

Interest in African demographic history was revived recently, as data have become more plentiful and as issues have been clarified. Attention is now focused not only on African patterns of fertility and mortality, but on the migration entailed in the slave trade. It indissolubly linked the population and economy of Africa with the wider Atlantic world. The most plentiful new data, which have come from research on the Atlantic slave trade and on New World slavery, have revealed the size and structure of

2 Archibald Dalzel, *The History of Dahomy* (London, 1793), 216–221. In the passage cited, Dalzel quotes approvingly a speech by the king of Dahomey in support of continuing the slave trade. Thomas Clarkson, *The History of the Rise, Progress, and Accomplishment of the Abolition of the African Slave Trade by the British Parliament* (London, 1968; orig. 1808), 10–15; Thomas Fowell Buxton, *The African Slave Trade and its Remedy* (London, 1968; orig. 2v, 1839, 1840), 199–201; David and Charles Livingstone, *Narrative of an Expedition to the Zambesi and its Tributaries* (New York, 1866), 412–413, 481, 483, 497–498, 586–587, 620–623.

3 Henry Hamilton Johnston, *A History of the Colonization of Africa by Alien Races* (Cambridge, 1913; 2nd ed.), 151–162; Alexander Morris Carr-Saunders, *World Population: Past Growth and Present Trends* (Oxford, 1936), 34–35, 42. See also John C. Caldwell, "The Social Repercussions of Colonial Rule: Demographic Aspects," in Adu A. Boahen (ed.), *General History of Africa. VII. Africa under Colonial Domination 1880–1935* (Berkeley, 1985), 458–461. For an insightful, if hardly encouraging, review of the role of speculation in estimating the volume of Atlantic slave trade, see Philip D. Curtin, *The Atlantic Slave Trade: A Census* (Madison, 1969), 3–13. For the African continent, speculations have been no more responsible.

the emigrating African population, both in transit and on arrival.[4] As a result of this research, we have a *known* transatlantic flow of slaves from Africa.

Further data have come from recent empirical work on African historical demography. Detailed studies for certain regions and certain time periods provide insights into African patterns of fertility, mortality, and migration in the era of the slave trade. When combined with the far more extensive recent work in African political and economic history, these insights can be extended to provide the outlines of demographic change during the slave trade.[5] To pursue the metaphor, we can now peer into sections of the black box and observe the blurred outlines of the demographic contents.

But the new data have not been sufficient to overcome speculative gaps, nor to resolve the basic issues of the size, structure, and growth of the African population in that era. Thus Caldwell has argued that the sixteenth-century population of the western coast of Africa was small and that it grew rapidly, overcoming the losses from slave exports; Inikori, by contrast, has argued that the same population was relatively large and that it was reduced by slave exports. Miller has argued that the population of Angola, the region contributing more slaves to the New World than any other, did not decline despite slave export, whereas Fage has argued that it did fall. According to Fage, the impact of slave exports in West Africa was small; yet Thornton has contended that in both West and Central Africa the population structure was transformed, especially through changes in the sex ratio.[6]

4 On the Atlantic slave trade, see *ibid.*, Herbert S. Klein, *The Middle Passage* (Princeton, 1978); David Eltis, *Economic Growth and the Ending of the Transatlantic Slave Trade* (Oxford, 1987); Jean Mettas (ed. Serge Daget), *Répertoire des expéditions négrières françaises au XVIIIe siècle* (Paris, 1978–1984), 2v.; Paul E. Lovejoy, "The Volume of the Atlantic Slave Trade: A Synthesis," *Journal of African History*, XXII (1982), 473–501. On New World slave populations, see Barry W. Higman, *Slave Populations of the British Caribbean, 1807–1834* (Baltimore, 1984); Klein, *African Slavery in Latin America and the Caribbean* (Oxford, 1987).

5 For a review of the recent literature, see Manning, "The Impact of the Slave Trade: Speculation, Debate, Method, Evidence," *Annales de démographie historique*, forthcoming.

6 Caldwell, "Major Questions in African Demographic History," in Christopher Fyfe and David McMaster (eds.), *African Historical Demography* (Edinburgh, 1978), 1, 18; Joseph E. Inikori, "The Slave Trade and the Atlantic Economies, 1451–1870," in UNESCO, *The African Slave Trade from the Fifteenth to the Nineteenth Century* (Paris, 1979), 56–87; Joseph C. Miller, "The Significance of Drought, Disease, and Famine in the Agriculturally Marginal Zones of West-Central Africa," *Journal of African History*, XXIII (1982), 30; John

RESEARCH DESIGN AND TERMINOLOGY To resolve these debates, we need a method for divining the demography of African slavery. A research design aimed at revealing the patterns of African demography must include not only a greater stock of documentary data, but also more powerful analytical tools with which to make scarce data more informative. This article explains the operation of such an analytical tool—a simulation model—and a research strategy that incorporates it. The model facilitates the systematic application of both demographic principles and historical data to the study of populations influenced by slavery and slave trade. Through the model, known data and demographic principles can be used to constrain the range of values of variables for which we have no direct data, thereby providing an approximation of real historical data. Our simulation performs an aggregate analysis (appropriate to regional and continental levels rather than local levels), and it performs a long-run analysis (appropriate to decades and generations rather than an individual year). The result is an analysis of the average or generality of the slave trade's impact, rather than of its individual outcomes or its extremes. Although the model is general in this sense, in another sense it introduces a new specificity. Previous studies of slave trade have been largely restricted to the study of crude rates of population growth and migration. Our methodology, by analyzing each population and demographic process in terms of age and sex distribution, provides an essential corrective to earlier approaches, both in the structure of the model and in the conclusions that result from it.

In formulating the research strategy, we have chosen to imagine slave trade as a *process* repeated many times, with a pattern of *outcomes* affecting Africa and the New World. In the discussion that follows, *admissible outcomes* of the slave trade are those which are consistent with the model (that is, consistent with the demographic principles and historical data incorporated into the model at a given level of specification); *real historical outcomes* are the

D. Fage, "Slavery and the Slave Trade in the Context of West African History," *Journal of African History*, X (1969), 400; John Thornton, "The Slave Trade in Eighteenth Century Angola: Effects on Demographic Structures," *Canadian Journal of African Studies*, XIV (1980), 417–427.

actual patterns of African and New World population that resulted from the impact of slavery.[7]

THE SIMULATION MODEL The simulation model accounts explicitly for the relationship of African demography to that of the New World through the slave trade. Explaining the model's operation requires emphasis on the distinctions among data, variables, and assumptions in the analysis. In our data, we distinguish between *input data* (the initial data on African population structure and patterns of enslavement used in the simulation) and *outcome data* (the resultant size and structure of African and New World populations as calculated by the simulation). Outcome data for the initial period of analysis become input data for subsequent periods, and so forth. The simulation involves a large number of variables, including levels of population and rates of fertility, mortality, and migration for several different populations. There is an even larger number of assumptions; these include the limits on the data, on the one hand, and the relationships among the variables, on the other. Such a complex and detailed analysis might appear to lead inevitably toward a morass of contingency and indeterminacy. Paradoxically, because of our emphasis on relationships among the variables, the analysis leads away from indeterminacy and toward a useful narrowing of the range of historical hypotheses, with a concomitant magnification of the explanatory power of scarce data.

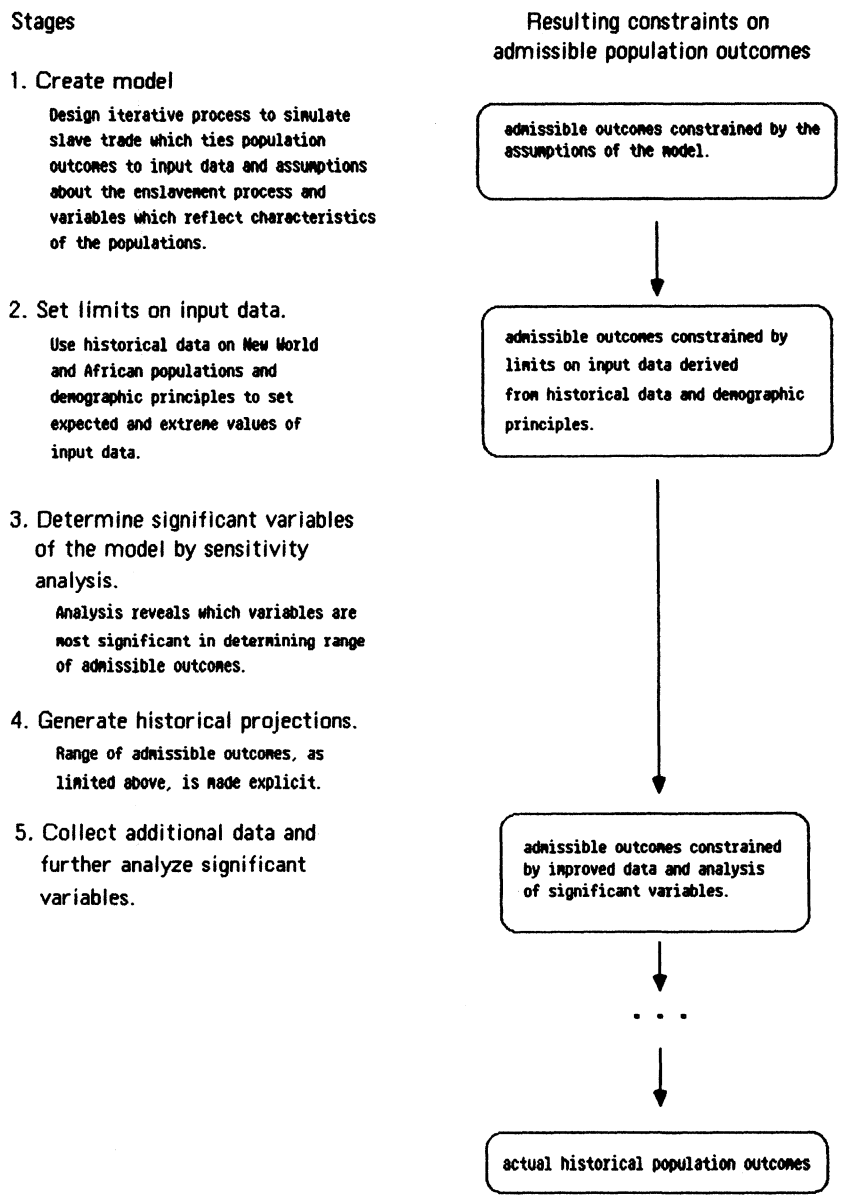
The design of the simulation analysis, as displayed schematically in Figure 1, involves five stages of analysis, which progressively narrow the range of admissible input and outcome data.[8]

The first stage is writing the simulation program. Here the demographic logic and structure of slave trade are expressed in

7 If the model is correctly specified, real historical outcomes are a subset of admissible outcomes.

8 For applications of the simulation model which focus more on its historical projections than on its methodology, see Manning, "Local vs. Regional Impact of Slave Exports in Africa," in Dennis D. Cordell and Joel W. Gregory (eds.), *African Population and Capitalism: Historical Perspectives* (Boulder, 1987), 35–49; Manning, "The Impact of Slave Trade Exports on the Population of the Western Coast of Africa, 1700–1850," in Daget (ed.), *Actes du colloque international sur la traite des noirs* (Paris, 1988). For a different use of simulation techniques in demographic history, see Kenneth Wachter, Peter Laslett, and Eugene Hammel, *Statistical Studies in Historical Social Structure* (New York, 1978), 13–27.

Fig. 1 Schema for Narrowing Admissible Outcomes.



the form of an iterative simulation, with each iteration corresponding to one year of the slave trade. Writing the program requires specifying the types of input data that are required for the simulation.

The second stage of the analysis consists of discovering the historical and demographic limits on input data. First we set the *expected* values of the input data, where these are our initial estimates of the long-term average values of input data for the western coast of Africa in the eighteenth century. Using these expected data, we perform an initial simulation. Next we turn to the *extreme* values of the input data: our estimates of the maximal and minimal value which each variable might have had as a long-term average. (These values are less extreme than the limits of individual cases.) Admissible African input data must meet three criteria: 1) calculated New World outcomes (for example, the composition of Atlantic slave cargoes) must remain consistent with known historical limits; 2) assumed input values (for example, the age structures of African fertility and mortality) must remain consistent with demographic principles; and 3) calculated African outcomes (for example, the composition of slave populations within Africa) must be consistent with available historical evidence. The three aspects of this stage, although logically distinct, are in fact performed simultaneously, through a sort of *tâtonnement*, until the input data produce outcomes within the limits of all three sets of criteria.

The third stage is a sensitivity analysis in which all of the input variables are varied singly and in pairs, to determine the significance of their effect on the outcomes of slavery in Africa and the New World. The results of this analysis show that the fluctuation of certain input variables (within known or hypothesized limits) is of particular importance in determining outcomes (African levels of fertility, for instance). For other variables (such as the age structure of the captives), fluctuations are shown to be less significant.

The fourth stage of the analysis is to generate historical projections, using the simulation to prepare hypotheses as to the actual historical changes in the size and structure of African population under the impact of slave exports.

These four stages complete the initial cycle of simulation analysis. The result is a set of historical hypotheses on the demo-

graphic impact of slavery on eighteenth-century western Africa, based on a systematic analytical structure and on accompanying estimates of historical data. Completion of this cycle leads to the fifth stage: reconsideration of the hypotheses, both through the unearthing of additional historical data and through further analysis of the interaction of demographic variables.

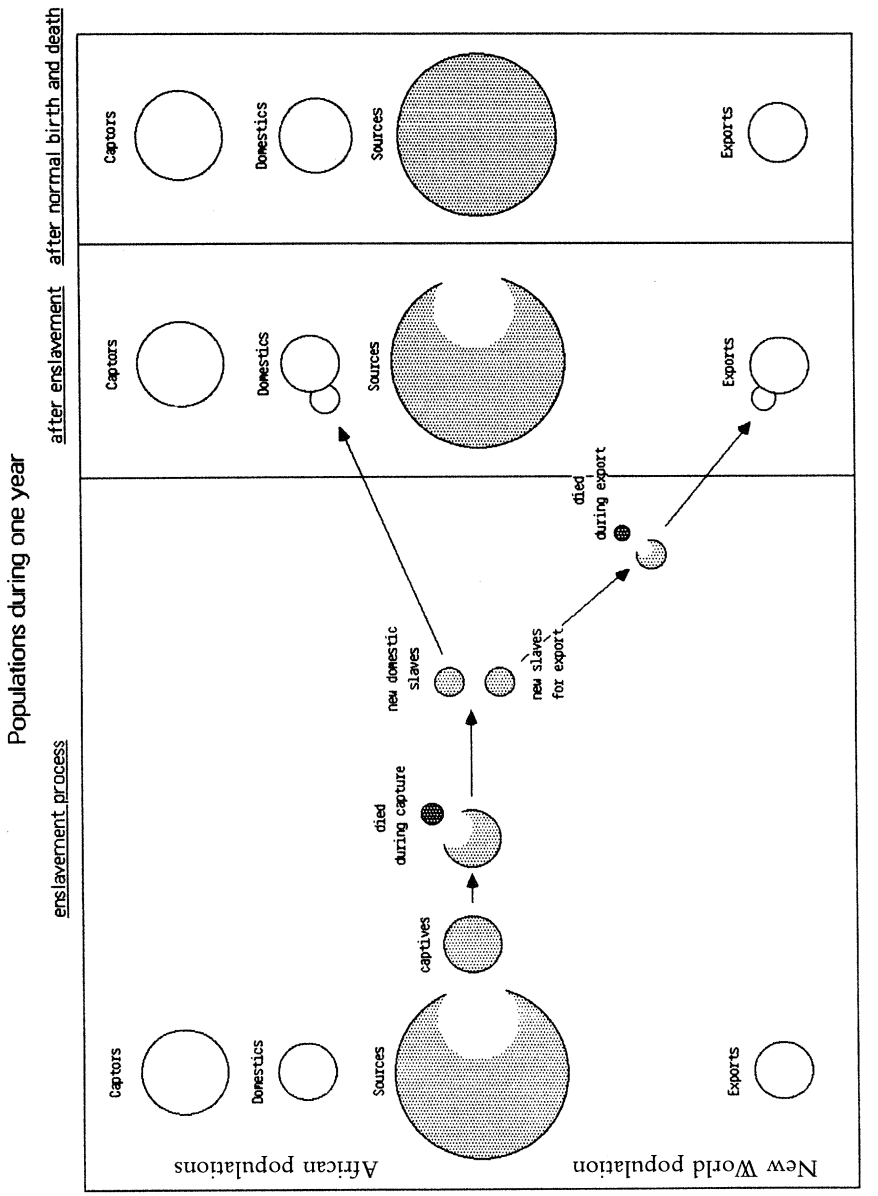
Stage 1. The Demographic Logic of the Slave Trade The simulation is a digital model, written in the Pascal language, in which such events as birth, death, and enslavement take place once a year for any number of years. The steps of the model are displayed schematically in Figure 2. The initial populations defined are the Source and Captor populations (populations are defined by sex and for ages from zero to eighty and above): the Source populations are those that lose more persons to slavery than they gain; the Captors are those who gain more persons as slaves than they lose.[9] Each year, a wave of enslavement takes place and creates a Captive population.[10] This Captive population suffers a severe initial mortality, including loss of life in the course of capture and death as a result of disease and exposure while in captivity. The Captives then undergo a partition in which they are divided into those slaves who are retained in Africa and those who are exported. Those retained in Africa, the New Domestics, are added to the population of Domestic slaves. Those exported undergo another severe mortality, corresponding to the Middle Passage; the survivors become New Exports, who join the Export slave population in the New World.

The simulation results display, for each year, the populations (by age and sex) of the Sources, Captors, Domestics, and Exports. In addition, the results display the population of Slave Society

9 Details of the program are available on request from the authors. In an earlier study, the two initial populations were identified as "Raiders" and "Raided." This terminology was abandoned because it tended to imply that all slaves were captured through raids. The present terminology, distinguishing Captor from Source populations, is more general if less felicitous. The logic of the simulation requires that the Source and Captor populations be distinct; in fact, this assumption oversimplifies the historical record, as some populations gathered slaves from outside but also enslaved people within their midst. Manning, "The Enslavement of Africans: A Demographic Model," *Canadian Journal of African Studies*, XV (1981), 504–509.

10 Such an assumption, which would be an oversimplification for any local area within western Africa, is relevant for the continental area as a whole.

Fig. 2 The Simulation Model in Schematic Form.



(the sum of the Captors and the Domestics, who are under Captor control) and the African Regional population (Sources, Captors, and Domestics). Similarly displayed for each year are the populations of the Captives, New Exports, New Domestics, and Lost Captives (the number who died during enslavement). The results of the simulation also include annual statistics with several dimensions: stocks of population at a given year's end, flows of population per year, cumulative totals of Captive populations over a period of years, and various ratios and combinations of these quantities. The stocks, flows, and rates are demographers' figures, whereas the cumulative totals have been of interest to historians.[11] Finally, the program calculates various ratios of sex and age groups as well as rates of birth, mortality, migration, and population growth.

The simulation requires fourteen data files, which set the initial populations, fertility levels, mortality levels, levels of enslavement, and division of Captives between New Domestics and New Exports (see Table 1). The data files are all arrays of numbers, with one dimension being eighty-one rows, for ages zero to eighty and above, and with the other dimension being two columns, for females and males (except for the fertility files, which have no column for males).

Stage 2. Estimating Input Data: Expected Values The expected values, displayed below in graphic form, approximate the conditions of the eighteenth-century Atlantic slave trade for the entire western coast of Africa averaged over a forty-year period. Initial Source and Captor populations (Figure 6), when linked with the appropriate fertility and survival files, have a life expectancy at birth of 27.5 years, a crude birth rate of 42 per 1,000, a crude death rate of 37 per 1,000, and an annual growth rate of 5 per 1,000 or 0.5 percent. The Captor population is assumed to be one third the size of the remaining population, which is placed in the category of the Sources. The initial Regional population (Figure 8) is the sum of the Sources and the Captors.[12]

11 The controversy over the cumulative total of slaves shipped across the Atlantic has drawn little attention from demographers, in part because the cumulative total, lacking a dimension of time, is not comparable with other demographic variables.

12 These data (held in files 1–4, 7, and 8) are based on model South Level 4 of Ansley J. Coale and Paul Demeny, *Regional Model Life Tables and Stable Populations* (Princeton,

Table 1 Input Data Files.

FILE NO.	FILE NAME	DESCRIPTION
1	SourceFile	Source population
2	CaptorFile	Captor population
3	SourceFertFile	Source fertility schedule
4	CaptorFertFile	Captor fertility schedule
5	DomesticFertFile	Domestics fertility schedule
6	ExportFertFile	Exports fertility schedule
7	SourceSurvFile	Source survival schedule
8	CaptorSurvFile	Captor survival schedule
9	DomesticSurvFile	Domestics survival schedule
10	ExportSurvFile	Exports survival schedule
11	CaptiveDomesticSurvFile	Survival schedule for Captives before they are partitioned into Domestics and Exports
12	CaptiveExportSurvFile	Survival schedule for Captives on their way to be Exports
13	EnslaveSizeFile	Percentage of each Source age and sex group to be enslaved
14	PartitionFile	Percentage of each Captive age and sex group to be exported

SOURCE: Files 1–4, 7, and 8 are based on Coale and Demeny, *Regional Model Life Tables*, 686, 734, 782.

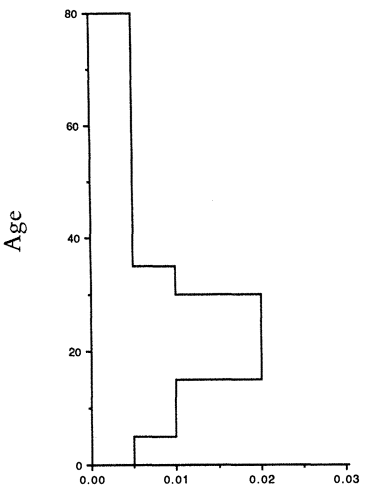
Figure 3 shows the proportion of the Source population enslaved (by age, with equal proportions for males and females) each year. These data are speculative, but the speculations were guided by qualitative descriptions of enslavement in Africa and by quantitative data on the age distribution of slaves reaching the New World.

Figure 4 displays the survival rates for the slaves during the Middle Passage. This Survival Schedule yields a crude mortality of 150 per 1,000, about the average for Middle Passage mortality in the eighteenth century.[13] It was generated by starting with the normal survival schedule (file 7 in Table 1), raising each entry to

1966), 30, 659, 686, 734, 782, 832. Fertility and mortality schedules for Source and Captor populations (not shown) are drawn from the same source.

13 See, for instance, Johannes Postma, "Mortality in the Dutch Slave Trade, 1675–1795," in Henry A. Gemery and Jan S. Hogendorn (eds.), *The Uncommon Market: Essays in the Economic History of the Atlantic Slave Trade* (New York, 1980), 251–255; Klein, *Middle Passage*, 56–57, 162, 195; Miller, "Mortality in the Atlantic Slave Trade: Statistical Evidence on Causality," *Journal of Interdisciplinary History*, XI (1981), 399–400.

Fig. 3 Enslavement Size

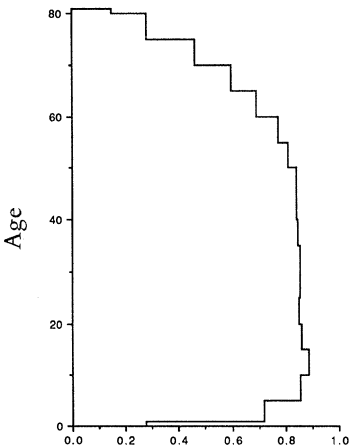


the fifth power to suggest five years' mortality at once (thus striking the young and the old with particular force), and then subtracting an additional 8 percent of each remaining age group to account for an across-the-board mortality which struck young adults as heavily as others.

The same Survival Schedule is applied to the Captives each year before the Middle Passage: it corresponds to the proportion of Captives for each age and sex surviving capture and transport within Africa. The Captives who remain in Africa to become New Domestics suffer this initial mortality of 150 per 1,000; the New Exports who undergo the Middle Passage undergo a double mortality, thus suffering a crude mortality of nearly 300 per 1,000. The crude mortality of all Captives is roughly 220 per 1,000.

The final file of input data is the Partition Schedule, shown in Figure 5, which divides the Captives surviving the initial mortality by proportions, for each age and sex, into those to be exported and those to remain in Africa. These data are speculative, like those in Figure 3, but, as before, the speculation is aided by qualitative accounts of enslavement in Africa and by quantitative data on the age and sex of slaves reaching the New World.

Fig. 4 Captive Survival Schedule

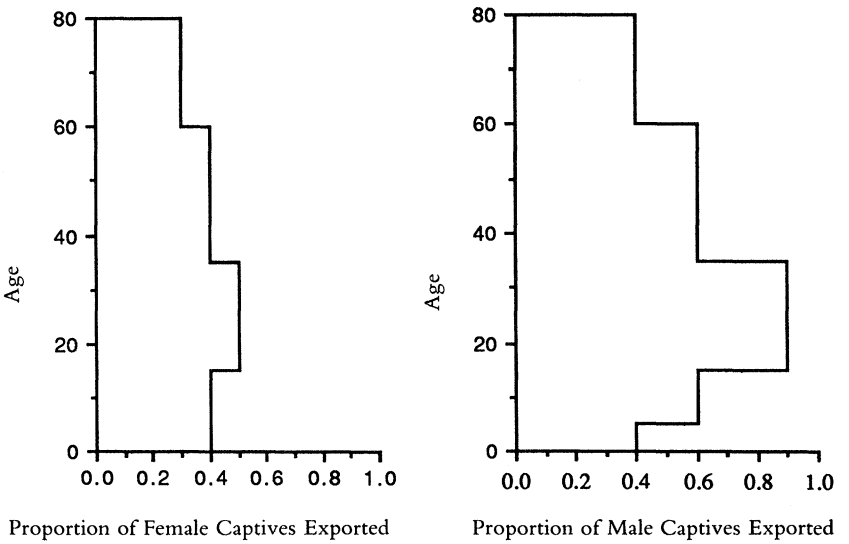


The figures in the remainder of this section display the outcomes, in Africa and in the Americas, of a forty-year simulation using the expected levels of input data presented above. Figure 6 shows the population pyramids for the Sources and the Captors after forty periods. The growth of the Captors has continued at an annual rate of 5 per 1,000, while the Source populations has declined.

The pyramids in Figure 7 show the populations of Domestics (in Africa) and Exports (in the Americas) after forty years. These populations include new slaves added in year forty, slaves added in previous years, and the surviving children of females added in previous years. These slave populations show the anticipated characteristics: the Exports are dominantly male and of relatively young age, though with few children, whereas the Domestics are dominantly female, of relatively young age, and with many children.

In Figure 8, the pyramid for Slave Society is skewed toward the female side, reflecting the addition of many female slaves to the society dominated by the Captors. The Regional population is skewed to a lesser degree; it shows a modest decline in size over forty years.

Fig. 5 Partition Schedule



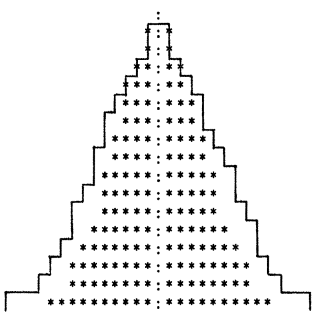
The output for the Captives in Figure 9 refers to the enslaved in the fortieth year. The age pyramid for the Captives shows them to be of all ages, but concentrated among young adults. Lost Captives are concentrated in that same age group, despite their lesser mortality rates, because of the large number of young adults initially enslaved. As shown in Figure 10, New Domestics are heavily weighted toward females, and New Exports are heavily weighted toward males.

Since the New World outcomes from this sample simulation are historically admissible, then, according to our rules of procedure, the African outcomes and African input data are also historically admissible, unless they can be excluded by further evidence. But since other combinations of input data and African outcomes can also produce admissible New World outcomes, the question remains as to how wide a range of African inputs and African outcomes is consistent with admissible New World outcomes.

Stage 2. Estimating Input Data: Extreme Values The input data include figures for fertility, mortality, and migration for each

Fig. 6 Year 40: Source and Captor Populations (with initial levels in outline).

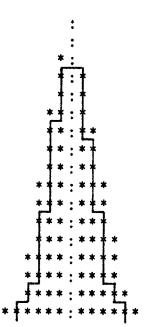
Group: Source



	female	male
80+	0.25	0.21
75-79	0.63	0.58
70-74	1.35	1.20
65-69	2.10	1.88
60-64	2.71	2.46
55-59	3.11	2.92
50-54	3.47	3.35
45-49	3.82	3.68
40-44	4.29	4.22
35-39	4.58	4.60
30-34	4.80	4.84
25-29	5.30	5.36
20-24	6.09	6.19
15-19	7.01	7.06
10-14	7.61	7.64
5- 9	8.10	8.34
0- 4	9.78	9.91
total	75.02	74.46

TotalPop:	149.48
0-14 as % Pop:	0.34
60-80+ as % Pop:	0.09
Standardized adult sex ratio:	0.98

Group: Captors



	female	male
80+	0.10	0.09
75-79	0.26	0.24
70-74	0.56	0.50
65-69	0.92	0.83
60-64	1.28	1.16
55-59	1.58	1.48
50-54	1.85	1.79
45-49	2.09	2.01
40-44	2.36	2.32
35-39	2.61	2.62
30-34	2.86	2.88
25-29	3.13	3.16
20-24	3.45	3.51
15-19	3.79	3.82
10-14	4.08	4.09
5- 9	4.42	4.55
0- 4	5.54	5.61
total	40.87	40.65

TotalPop:	81.52
0-14 as % Pop:	0.35
60-80+ as % Pop:	0.07
Standardized adult sex ratio:	0.98

Fig. 7 Year 40: Domestics and Exports Populations.

Group: Domestics

	female		male
80+	0.02	:	0.01
75-79	0.05	:	0.03
70-74	0.11	:	0.07
65-69	0.18	:	0.10
60-64	0.28	:	0.12
55-59	0.41	:	0.14
50-54	0.57	*:	0.20
45-49	0.76	*:	0.27
40-44	0.97	*:	0.36
35-39	1.21	*:*	0.54
30-34	1.47	*:*	0.82
25-29	1.66	**:*	1.11
20-24	1.77	**:*	1.39
15-19	1.80	**:**	1.65
10-14	1.87	**:**	1.87
5- 9	2.09	**:**	2.17
0- 4	2.68	***:***	2.81
total	17.91		13.66

TotalPop:	31.56
0-14 as % Pop:	0.43
60-80+ as % Pop:	0.03
Standardized adult sex ratio:	0.50

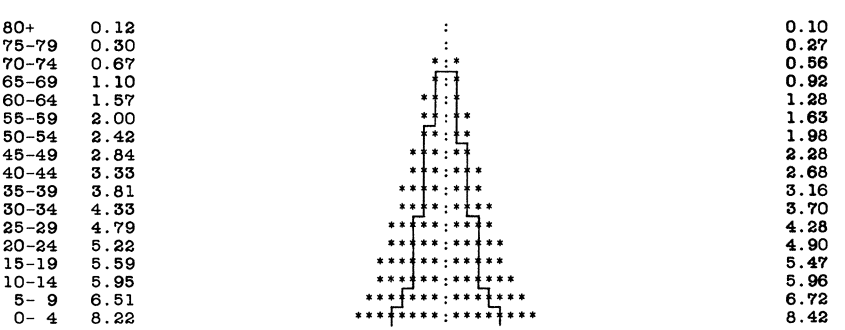
Group: Exports

	female		male
80+	0.01	:	0.01
75-79	0.02	:	0.03
70-74	0.05	:	0.08
65-69	0.11	:	0.17
60-64	0.20	:	0.33
55-59	0.31	:*	0.55
50-54	0.44	:*	0.78
45-49	0.57	*:*	0.97
40-44	0.73	*:*	1.24
35-39	0.92	*:**	1.52
30-34	1.14	*:**	1.75
25-29	1.26	*:**	1.81
20-24	1.31	*:**	1.73
15-19	1.29	*:**	1.53
10-14	1.34	*:*	1.47
5- 9	1.54	**:**	1.63
0- 4	2.01	**:**	2.11
total	13.25		17.70

TotalPop:	30.95
0-14 as % Pop:	0.33
60-80+ as % Pop:	0.03
Standardized adult sex ratio:	1.43

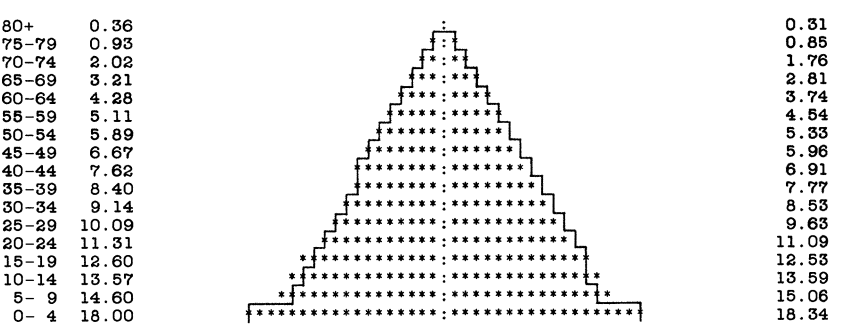
Fig. 8 Slave Society and Regional Populations (with initial levels in outline).

Group: SlaveSociety



Total Pop: 113.08
0-14 as % Pop: 0.37
60-80+ as % Pop: 0.06
Standardized adult sex ratio: 0.82

Group: Regional



Total Pop: 262.56
0-14 as % Pop: 0.35
60-80+ as % Pop: 0.08
Standardized adult sex ratio: 0.91

Fig. 9 Year 40: Captives and Lost Captives.

```
Group:  Captives

        female                                                        male

80+     0.001                              :                          0.001
75-79   0.003                              :                          0.003
70-74   0.007                             +:+                         0.006
65-69   0.011                             +:+                         0.010
60-64   0.014                             +:+                         0.013
55-59   0.016                            ++:+                         0.015
50-54   0.017                            ++:++                        0.017
45-49   0.019                            ++:++                        0.019
40-44   0.021                            ++:++                        0.021
35-39   0.023                            ++:++                        0.023
30-34   0.049                         +++++:+++++                     0.049
25-29   0.107                   ++++++++++++:++++++++++++             0.108
20-24   0.123                 ++++++++++++:++++++++++++               0.125
15-19   0.141               ++++++++++++++:++++++++++++++             0.142
10-14   0.077                    ++++++++:++++++++                    0.077
 5- 9   0.073                     +++++++:++++++++                    0.075
 0- 4   0.049                       +++++:+++++                       0.050
-------------------------------------------------------------------------------
TOTAL   0.751                                                         0.753

Total Pop:                          1.504
0-14 as % Pop:                      0.27
60-80+ as % Pop:                    0.05
Standardized adult sex ratio:       0.78


Group:  LostCaptives

        female                                                        male

80+     0.001                              :                          0.001
75-79   0.002                              :                          0.002
70-74   0.003                              :                          0.003
65-69   0.004                              :                          0.004
60-64   0.004                              :                          0.004
55-59   0.004                              :                          0.005
50-54   0.004                              :                          0.005
45-49   0.004                              :                          0.005
40-44   0.004                              :                          0.005
35-39   0.004                              :                          0.005
30-34   0.010                             +:+                         0.012
25-29   0.021                            ++:+++                       0.027
20-24   0.025                            ++:+++                       0.033
15-19   0.027                           +++:+++                       0.030
10-14   0.011                             +:+                         0.013
 5- 9   0.013                             +:++                        0.019
 0- 4   0.019                            ++:++                        0.018
-------------------------------------------------------------------------------
TOTAL   0.160                                                         0.190

Total Pop:                          0.350
0-14 as % Pop:                      0.27
60-80+ as % Pop:                    0.08
Standardized adult sex ratio:       1.03
```

Fig. 10 Year 40: New Domestics and New Exports.

Group: NewDomestics

	female		male
80+	0.000	:	0.000
75-79	0.001	:	0.001
70-74	0.002	:	0.002
65-69	0.005	:	0.003
60-64	0.007	+:+	0.005
55-59	0.007	+:	0.004
50-54	0.009	+:+	0.005
45-49	0.010	+:+	0.006
40-44	0.011	+:+	0.007
35-39	0.012	+:+	0.008
30-34	0.021	++:	0.004
25-29	0.046	+++++:+	0.009
20-24	0.052	+++++:+	0.011
15-19	0.061	++++++:+	0.013
10-14	0.041	++++:+++	0.027
5- 9	0.038	++++:++	0.025
0- 4	0.018	++:++	0.019
TOTAL	0.338		0.149

Total Pop:	0.486
0-14 as % Pop:	0.34
60-80+ as % Pop:	0.05
Standardized adult sex ratio:	0.26

Group: NewExports

	female		male
80+	0.000	:	0.000
75-79	0.000	:	0.000
70-74	0.000	:	0.001
65-69	0.001	:	0.001
60-64	0.002	:	0.002
55-59	0.004	:	0.005
50-54	0.005	:+	0.006
45-49	0.006	+:+	0.007
40-44	0.006	+:+	0.009
35-39	0.007	+:+	0.010
30-34	0.018	++:+++	0.032
25-29	0.039	++++:+++++++	0.070
20-24	0.044	++++:++++++++	0.080
15-19	0.052	+++++:++++++++++	0.099
10-14	0.024	++:++++	0.036
5- 9	0.022	++:+++	0.030
0- 4	0.008	+:+	0.009
TOTAL	0.237		0.398

Total Pop:	0.634
0-14 as % Pop:	0.20
60-80+ as % Pop:	0.01
Standardized adult sex ratio:	1.28

age and sex, and for each year of the simulation. For the convenience of running the simulation, the data are entered in the form shown in Table 1 and Figures 3 through 5. For purposes of comparative demographic analysis, we have reorganized the fourteen input files into sixteen demographic variables made up of the files. These demographic variables can then take on extreme values (minima and maxima) as well as the expected values discussed above. The actual content of each variable at each level is an array of data (for example, fertility rates varying by age), but each is given a summary description with a parameter which reflects the outlines of its variation (for example, average age of mother at birth). Table 2 displays these variables, and gives the minimal, expected, and maximal values estimated. The discussion of the

Table 2 Input Variables: Extreme and Expected Levels.

VARIABLE	DEFINITION	PARAMETER LEVELS			INPUT FILES
SRCMORT	Source population mortality level	2	4	6	1,3,7
SRCGROW	Source population annual growth rate	.000	.005	.010	1,3
SRCAGEF	Source population average age at maternity	25	27	29	3
CPTMORT	Captors mortality level	2	4	6	2,4,8
CPTGROW	Captors annual growth rate	.000	.005	.010	2,4
CPTAGEF	Captors annual age at maternity	25	27	29	4
DOMGROW	Domestics annual growth rate	−.010	.000	.005	9
CAPDOSUR	Domestic Captives survival: crude mortality rate	.10	.15	.25	11
CAPEXSUR	Export Captives survival: crude mortality rate	.10	.15	.25	12
ENSLPCT	Crude capture rate	.008	.010	.012	13
ENSLAGE	Inequality of Captive age distribution: kurtosis of Captive age distribution	.002	.006	.010	13
ENSLSEX	Ratio of females to males enslaved	0.5	1.0	2.0	13
PCSIZEF	Proportion of female Captives exported	.36	.45	.54	14
PCAGEF	Inequality of female age partition: kurtosis of partition coefficient distribution	.000	.072	.223	14
PCSIZEM	Proportion of male Captives exported	.56	.74	.81	14
PCAGEM	Inequality of male age partition: kurtosis of partition coefficient distribution	.000	.188	.357	14

table summarizes the reasoning used in estimating the minimal and maximal levels.

As noted above, estimating the extreme values is a three-way process, in which limits are placed on input data through Atlantic and New World historical data (that is, New World outcomes of slave trade), through demographic principles which place direct limits on input data, and through African historical data (which suggest limits on African outcomes of slave trade).

The limits to be established are the maximal and minimal estimates of the *aggregate* value of each variable, not the limits on individual cases. Thus, the maximal value for mortality in the Middle Passage is taken as 20 percent of the captives and the minimal value is taken as 10 percent, even though the limits for individual voyages are known to have ranged from 0 to 100 percent.

Data on New World *outcomes* are the most reliable. We know that slaves sent across the Atlantic were dominantly male, with a male-female ratio of nearly 2:1, and that slaves were dominantly young adults. In practice, we set limits on two measures of the New World outcome of the slave trade: the ratio of female New Exports to total New Exports is kept in the range from 0.3 to 0.4; and the ratio of New Exports aged 0–17 to total New Exports is kept within the range from 0.2 to 0.3[14] Any combination of input data producing outcomes beyond these limits was discarded as historically inadmissible.

Demographic limits could be set on African input data based on what is known of populations in general. For instance, the regional model life tables and stable populations of Coale and Demeny were used to set the form of the age pyramids, the age distribution of fertility rates, and the age distribution of mortality rates (here calculated as their complement, survival rates). Demographic principles were also useful for estimating the mortality of slaves in transit. Historical analysis of slave mortality has concentrated on crude mortality rates, often not properly calibrated for time.[15] But demographic principles emphasize the age-specific nature of mortality rates: in particular, the very young and the

14 Manning, "Enslavement of Africans," 517.

15 Coale and Demeny, *Regional Model Life Tables*, 30, 659, 686, 734, 782, 832. On the importance of accounting for the length of the Atlantic voyage in calculating slave mortality rates, see Miller, "Mortality in the Atlantic Slave Trade," 385–397. In addition, a full account of slave mortality would distinguish rates by age and sex. For a study of mortality rates by age and sex, see Postma, "Mortality in the Dutch Slave Trade."

old underwent high mortality rates, whereas young adults had the lowest mortality rates. For the limits on life expectation and on the growth rate of the African Source and Captor populations, we combined historical and demographic approaches: we have relied on European data for the same time period, and on some African data on population structure.[16]

Demographic principles are of little help in determining the composition of the population enslaved each year, or its partition into slaves exported and retained. These variables were estimated (beyond the limits imposed by known New World outcomes) through a reading of qualitative sources on slavery in Africa.[17] For instance, we assumed that equal proportions of males and females were enslaved at each age, and that there was a relatively high incidence of enslavement for ages fifteen to twenty-nine.

With further manipulation of data, we estimated the ratio of the annual outflow of slaves from Africa to the stock of total population from which they came. The annual flow of slaves is a known New-World outcome; the estimated stock of African population was derived from a combination of historical data and demographic principles, and was calculated by backward projection from twentieth-century population figures. Based on these results, we kept the ratio of total New Exports to total African Regional population within the range from 0.002 to 0.0035.

Stage 3. Analytical Limits on Input Assumptions In this portion of the analysis we seek to discern which of the many input variables would cause the greatest variation in simulated African and New World outcomes. We have previously placed limits on the range of variation of input variables; now we analyze the implications of fluctuations of input variables within the limits we have set. That is, we now seek to limit the range of speculation further by restricting the assumptions as well as the data. The

16 E. Anthony Wrigley and Roger S. Schofield, *The Population History of England, 1541–1871* (Cambridge, Mass., 1981), 183–184, 214; Thornton, "An Eighteenth Century Baptismal Register and the Demographic History of Manguenzo," in Fyfe and McMaster (eds.), *African Historical Demography*, I, 409–411; Thornton, "Slave Trade in Eighteenth Century Angola," 420–421.

17 For a range of sources containing data addressing this issue, see Manning, "Enslavement of Africans," 504–509.

results will not tell us which input variables fluctuate the most, but which fluctuations (within established limits) cause the greatest change in outcomes. To this end, we have performed a sensitivity analysis on the significance and interactions of the input variables.[18]

In the sensitivity analysis, we utilized the sixteen input variables discussed above, with each set at minimal, expected, and maximal values. They were then treated as dummy variables in a multiple regression analysis of the results of multiple simulation runs. The variables were varied one and two at a time, to estimate first-order and second-order (interaction) effects. The analysis included three measures of outcome as dependent variables, one on the Atlantic slave trade and two on the demography of Africa. The first variable was the ratio of current slave exports to the total population of Western Africa (EXPRATIO). The second variable was the average growth rate of the African Regional population over forty years (GROWTH), and the third variable was the ratio of adult males to females in the Slave Society population of Africa (SEXRATIO).

The main results were to identify the input variables whose fluctuations did most to cause changes in the level of the (dependent) outcome variables. For the determination of EXPRATIO, three input variables provided most of the explanatory power: 1) the ratio of females to males enslaved, 2) the proportion of male Captives exported, and 3) the proportion of Source populations enslaved. That is, the sex composition of the enslaved population and the nature of the partition of Captives into domestic and exported slaves have the greatest impact on the size of EXPRATIO—greater than the effect of changing African rates of growth or mortality rates in transit.

The African rate of growth under slave trade (GROWTH) depended overwhelmingly on the intrinsic growth rate of the Source and Captor populations. This growth rate depended, in turn, on the levels of fertility and mortality of African populations.

18 The analysis is not general, but is for a given historical situation. For instance, a sensitivity analysis of a simulation for the trans-Saharan slave trade might show different input variables to be of greatest significance, since for the trans-Saharan trade most exports were female rather than male. For details, see *idem*, "Impact of Slave Trade Exports."

For the African sex ratio (SEXRATIO) the determining input variables were the sex ratio of Captives and the proportion of male Captives exported. Since these same variables are limited by the bounds on outcomes of EXPRATIO, this result suggests that it may be possible to predict the aggregate African sex ratio from what is known about the composition of the New Export slave population.

Through sensitivity analysis we can narrow the range of speculation and focus the need for further research on a few key variables. Variations of age distribution within known limits, for instance, turn out not to be a crucial factor, but sex distribution (both on enslavement and on export) is of great importance in determining the overall impact of slavery on Africa.[19] The issue of whether the African population grew or declined in the slave-trade era can be resolved, according to these results, by further research on levels of mortality and fertility in Africa.

Given that the logic of the model is acceptable and that the range of assumed data is appropriate to the conditions of eighteenth-century Africa, the results suggest that the model is remarkably determinate. Even when numerous interaction terms are included in the regressions, virtually all of the variance in each dependent variable is explained by its correlation with linear variations in the independent variables. Further, most of the variance is explained by a small number of the independent variables. The most significant variables define the sexual composition and the size of Captive populations, the proportion of male Captives exported, and the intrinsic growth rate of African populations. Although their levels are known within a certain degree of tolerance, this analysis should focus the attention of researchers on discovering more about them. Other factors, too, are important as determinants of the demographic impact of slave exports—Captive mortality and the age distribution of the enslaved, for

19 Age distribution is important in the analysis of slavery since the concentration of captives in the young adult ages is precisely the factor which caused the slave trade to threaten the size of the African population. But since the variation of age distribution of captives is known within some limits because of the age distribution of the Atlantic slave population, it is the variations within those limits with which we are concerned, and they were not a significant determinant of the dependent variables. Thus, we are measuring the sensitivity of outcome variables to changes of input variables *within known or assumed limits*. For a life table for West Indian slaves, see Jeffrey P. Koplan, "Slave Mortality in Nineteenth-Century Grenada," *Social Science History*, VII (1983), 311–320.

instance—but variations in these factors did not affect the results so greatly.

Stage 4. Historical Projections Our initial application of this model to the conditions of the western coast of Africa has yielded projections suggesting that the Export slave trade reversed African population growth from 1730 to 1850, that the population fell by 3 to 7 million from a base of some 25 million in 1730, and that the population of adult women exceeded that of adult men by 15 to 20 percent throughout the region during that century.[20] These results present an apparent paradox: if the crude export rate of African slaves was roughly 3 per 1,000, how could that result in a decline of an African population whose crude rate of natural increase was 5 per 1,000? The resolution of the paradox lies in the impact of the slave trade on age distribution. For young adults ages 15 to 29, the losses to slave exports and to mortality in enslavement averaged 8 per 1,000 for females and 15 per 1,000 for males. The loss of females in their crucial reproductive years was sufficient to reduce the total African population.

The simulation model provides a structured, internally consistent way to increase the value of scarce African demographic data by linking them with demographic principles and the historical record. To date the model has been useful in generating hypotheses about the demography of African slavery. In future work, it should be useful in verifying or rejecting these and other hypotheses. More generally, simulation provides a tool for addressing that intractable demographic problem: migration.[21] Here migration is integrated into an approach which does not abandon the traditional heart of demographic analysis, fertility and mortality. That a daunting list of assumptions is necessary to any migration analysis is confirmed by the number of migration variables required for the simulation. But the sensitivity analysis offers the possibility that migration studies can be simplified, after appropriate analysis, to permit concentration on a small number of variables.

20 Manning, "Impact of Slave Trade Exports."

21 Andrei Rogers, *Introduction to Multiregional Mathematical Demography* (New York, 1975), 191–194.