



Valuing five centuries of unpaid breastfeeding in England

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Breastfeeding is vital and valuable labor, contributing to the physical and cognitive health of children throughout their lives, yet it is rarely compensated in formal labor markets. Its economic importance may therefore go unrecognized. We impute upper and lower bounds for the value of unpaid breastfeeding over five centuries in England to better understand its economic role over the course of economic development. We also contribute an estimate of changes in breastfeeding duration over this period from historical and bioarchaeological sources using interval regression. At minimum, unpaid breastfeeding consistently exceeded 0.1% of gross domestic product (GDP), reaching a possible peak of 6.58% in the sixteenth century while the wider economy stagnated. This quantity exceeds expenditures on school and apprenticeship, making breastfeeding possibly the largest source of human capital investment in early modern England. Yet the relative value of unpaid breastfeeding gradually declined as the wider economy grew. Indeed, for much of English history the income elasticity of breastfeeding appears to have been negative, only becoming positive at some point in the nineteenth century. Because breastfeeding was strongly negatively correlated with infant mortality, this challenges longstanding assumptions about the relationship between income and mortality. In sum, breastfeeding was not a biologically determined constant but a dynamic, if neglected, part of economic life.

breastfeeding | unpaid care | human capital | national accounting | demography

Unpaid care for family and friends has long been excluded from national accounts, even when identical services are counted when exchanged for money. This omission distorts economic data and policy. For example, Lastuka et al. (1) find that costs of unpaid caregiving and paid residential care for dementia patients are negatively correlated across US states, reflecting policymakers' focus on lowering Medicaid costs while overlooking the burden on unpaid carers, often women.

Care work has shifted historically across the exchange frontier—sometimes commodified and exchanged, sometimes not. Historians have linked such changes to the decline of subsistence agriculture (2, 3), changes in the structure of consumption (4), and urbanization (5). Yet the feminization of paid domestic work has been stubbornly persistent (6), and unpaid tasks were never trivial. Humphries (7) estimates that cooking and cleaning produced the equivalent of 17 to 25% of national income between 1300 and 1870.

This study focuses on a major task on the wider care docket: breastfeeding. Like other care work, breastfeeding is both gendered and demanding, taking 18.2 h per week in contemporary estimates (8), and equally arduous in the past (9). Breastfeeding, like other care work, crosses the exchange frontier. Mothers once hired wetnurses; today, they purchase formula (10).

Breastfeeding is closely related to human welfare. It improves infant survival in unsanitary environments (11), supports long-term health and cognitive development (12–15), and suppresses fertility via lactational amenorrhea (16). Through these channels, breastfeeding affects labor supply and the productivity of future generations.

Yet the economic determinants of breastfeeding remain unclear. Breastfeeding incidence is higher in low-income economies but declines with income in the cross-section, while in high-income economies, incidence is low but rises with income in the cross-section (17–20). This suggests that the income elasticity of breastfeeding may change from negative to positive as economies develop. Because early weaning increases infant mortality, such a pattern would work against the Malthusian assumption that lower incomes must increase mortality via famine and disease in preindustrial economies (21). We are aware of only one study to document this change occurring in a repeated cross-sectional analysis (22) and of no other study to document how the relationship between average incomes and breastfeeding changes in the process of economic development.

Significance

We produce a numerical estimate of the value of unpaid breastfeeding relative to national income spanning five centuries and integrating historical and bioarchaeological data. The relative economic contribution of maternal nursing was greater in the distant past than in recent history, rivaling regionally significant industries such as pottery, glassmaking, and even the historical public sector. It was likely the largest source of human capital investment in early modern England, supporting the physical and cognitive development of the workforce. Finally, we show that breastfeeding rates probably fell as incomes rose, challenging the Malthusian assumption that higher income correlates with lower mortality.

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We estimate and value unpaid breastfeeding in England from 1540 to 2000, accounting for changes to fertility, inequality, infant mortality, and breastfeeding duration. We develop a method combining documentary and archaeological evidence to estimate breastfeeding duration and produce a bounded estimate of its value relative to long-run GDP.

At its peak, unpaid breastfeeding was worth between 0.55% and 6.58 % of GDP. Further, we identify a possible reversal of its income elasticity from negative to positive in the nineteenth century.

1. Accounting for Breastfeeding

Breastfeeding refers to the provision of human milk to infants. Although breastfeeding norms in the past differed across Europe (23), the available evidence suggests breastfeeding at birth was—with few exceptions detailed below—nearly universal in England, and infants would be fed on breast-milk exclusively or in combination with other foods until weaning. In our historical sources, weaning refers to the introduction of supplementary foods followed by the complete cessation of breastfeeding. Although these stages are conceptually distinct, in the past weaning often occurred rapidly, sometimes within a week or two, making it difficult to distinguish periods of exclusive breastfeeding from those of mixed feeding (24). We generally define breastfeeding duration as the period of exclusive breastfeeding, following usage in our historical sources.

Direct reports of breastfeeding in the past are often made in passing in diaries and memoirs. For instance, John Evelyn's (b. 1620) memoir notes "It appears, by a note of my father's, that I sucked till 17th of January, 1622" (i.e., aged 14.5 mo) (25). Other evidence comes from medical texts, which may contain both prescriptive recommendations and estimates of weaning age, such as physician John Pechey's (b. 1655) remark that "some are weaned in the tenth month, and some in the twelfth, and yet it is most convenient that the Child suck a year and a half or two years" (26). In this case, we treat 10 to 12 mo as a contemporary estimate and 18 to 24 mo as a recommendation. We combine published data of this kind (27, 28) with 33 additional primary sources (*SI Appendix*).

Breastfeeding data were also produced by the state. For instance, local governments in the past hired wetnurses to feed poor infants whose mothers may have been unavailable to feed and generated data in the process (29–31). We add to published evidence of this kind data collected from medical reports on 25 nursing mothers who were sentenced to transportation to Australia between 1825 and 1852.*

We also use published isotopic analysis of skeletal remains. High concentrations of N-15 in infant rib collagen indicate breastfeeding, while long-bone lengths or tooth development indicate age at death (32). Bioarchaeologists typically interpret the age after infancy at which average N-15 reaches adult concentrations as an indicator of population-level breastfeeding norms. However, a recent critique points out that this method ignores individual variation (33). By analogy with the survival curve, we add that such population-level estimates are likely to reflect the right tail of the weaning age distribution rather than the central tendency.

We propose a method to estimate mean weaning age that preserves individual-level variation and integrates well with our other sources. Specifically, we assume that an individual infant who dies with elevated N-15 (2σ above the adult mean) would

have been weaned later had they survived, up to a maximum of 36 mo. Infant remains without elevated N-15 were likely weaned before death. Together, these observations bracket the age at which weaning likely occurred for each individual (see *SI Appendix, section D* for details).

We identify two such studies that fit within the temporal scope of our study and have published their underlying osteological dataset in full to enable replication: one from Lukin Street Catholic cemetery (1843–54) (34), and one from Spitalfields (1760–1844), with remains linked to parish records (32).

Finally, toward the end of the nineteenth century and with increasing frequency throughout the twentieth century, medical and public health professionals published surveys on the extent and duration of maternal nursing. However, these surveys increasingly count mixed feeding in breastfeeding duration after the mid-twentieth century. This shift may reflect the growing availability of cheaper, safer alternative infant foods, which encouraged mothers to combine nursing with supplementary foods for longer. Consequently, estimates of breastfeeding duration after about 1950 may overstate the duration of exclusive breastfeeding. We identify 30 such studies (35, 36).

These same developments also increased the prevalence of formula feeding at birth in the twentieth century (37). Indirect evidence from the age-specific incidence of infant mortality and direct evidence from the earliest surveys suggests breastfeeding at birth was nearly universal before the twentieth century in England (see *SI Appendix, section C* for details). In the twentieth century, we adjust for declining breastfeeding initiation rates using a subset of surveys that adopted nationally representative sampling designs. A summary of all the sources used in the paper is produced in *SI Appendix, Table S2*.

These sources help identify the extent of breastfeeding in the past, but they do not provide means to value it. Researchers propose three methods to impute a value to unpaid breastfeeding: the cost of market substitutes, e.g., infant formula or purchased human milk; the opportunity costs of nursing mothers' time; and the wage necessary to purchase this service, e.g., wet-nurses' wages (38).

Cow's milk, a longstanding market substitute for breastmilk in England, provides a lower-bound imputed value. We use Clark's agricultural price series (39) through 1914 and Office of National Statistics (ONS) data thereafter, assuming hand-fed infants required one gallon of milk per week—a generous portion that allows for spoilage in the absence of refrigeration.

Breastfeeding, however, is also labor. Commodity prices do not capture the time, effort, and skill involved in infant feeding. While wetnurses' wages have been used elsewhere to impute this value (38, 40), such data are rare in our setting. Fildes (24) identifies only 22 wage observations between 1500 and 1800, and these often recompensed duties beyond suckling.

The challenge is to separate the value of breastfeeding from the bundle of other tasks wet-nurses performed. We consider wages paid to wet- and dry-nurses separately by the same employer. In such cases, the nature of the labor contract and bundle of other duties should be comparable, allowing us to isolate the value of breastfeeding.[†] Fildes reports evidence of the same sixteenth-century employer paying his wet nurse twice what he paid to

[†]Wet-nurses typically cared for children in their own homes, unlike other domestic servants whose pay often included room and board. Although wet-nurses also received nonwage compensation, these perquisites were unlikely to exceed the value of room and board provided to other servants. Differences in nonpecuniary compensation will thus tend to compress earnings premia between wet- and dry-nurses. Therefore, even after accounting for such extras, the imputed value of breastfeeding should not surpass our upper bound. The within-employer comparison may further minimize such differences if employers offered similar contracts to all their servants.

*The National Archives of the UK (TNA): ADM 101.

his dry nurses and suggests this premium is common across her sources (24).

To extend this within-employer comparison into a long-run series, we need a proxy for dry-nurses' wages, which are not systematically recorded. Evidence from Christ's Hospital supports using married women's day wages. Live-in wet nurses received total daily compensation (including board) worth 3.61 pence in the 1550s and 7.95 pence per day in the 1650s, and married women's daily wages were 2.0 pence and 4.32 pence in the same respective decades (41, 42). Wet nurses again earned roughly twice as much as comparable unskilled women, which implies dry-nurses' pay was close to unskilled married women's earnings. Moreover, because wet-nurses were usually married, this is the natural labor market to follow.[‡] We therefore assume that married women's unskilled earnings capture the value of other care tasks performed by wet-nurses and that the additional 100% premium captures the value of breastfeeding over our period. Limited data make this strong assumption necessary; in Spain, where data on historical wetnurses' wages are more numerous, the nursing premium fluctuates over time but remains approximately anchored around 66.7% (43). Our assumption of a constant 100% premium allows us to use a long-run series of married women's unskilled day wages (42) as a proxy to impute an upper-bound value on the labor of breastfeeding.

As an upper bound, this approach has convenient properties. It captures the direct market value of the task on the labor market at a point in time. The actual premium likely varied with supply and demand conditions, but the evidence shows it could be at least as high as 100%, particularly during the critical sixteenth and seventeenth centuries when our estimates of value are highest. The opportunity-cost approach to imputation, by contrast, argues that women who breastfed (or their households) must have valued breastfeeding at least as much as their foregone earnings. As breastfeeding occupied about a third of the historical working week (8, 44), these opportunity costs would not exceed our wage-replacement imputation.

As a lower bound, milk prices exhibit similarly convenient properties. Because milk was the primary input cost of market substitutes, such as infant formula, the value of these substitutes should not fall below the price of milk alone. Our bounds should therefore be robust to alternative imputation strategies and technological change affecting infant food.

We assess our imputed value for breastfeeding against long-run national accounts reconstructed by summing the value-added output of all major sectors of England's economy since the medieval period (45).

2. Results

Although real GDP per capita hardly changed in the sixteenth century, this period saw a dramatic fall in unpaid breastfeeding. Mean duration fell from 17.5 mo in 1540 to 12.7 mo by 1600. However, this was overwhelmed in significance by the rise in nominal GDP during the sixteenth-century price revolution, which grew faster than the nominal value of breastfeeding and drove the largest share of decline (*SI Appendix, Table S1*) from 0.55–6.58% of GDP in 1540, the highest value we observe in our window, to 0.29 to 2.26% by 1600 (*Fig. 1*).

The seventeenth century marked the onset of real per-capita GDP growth amid relatively modest population growth, yet this

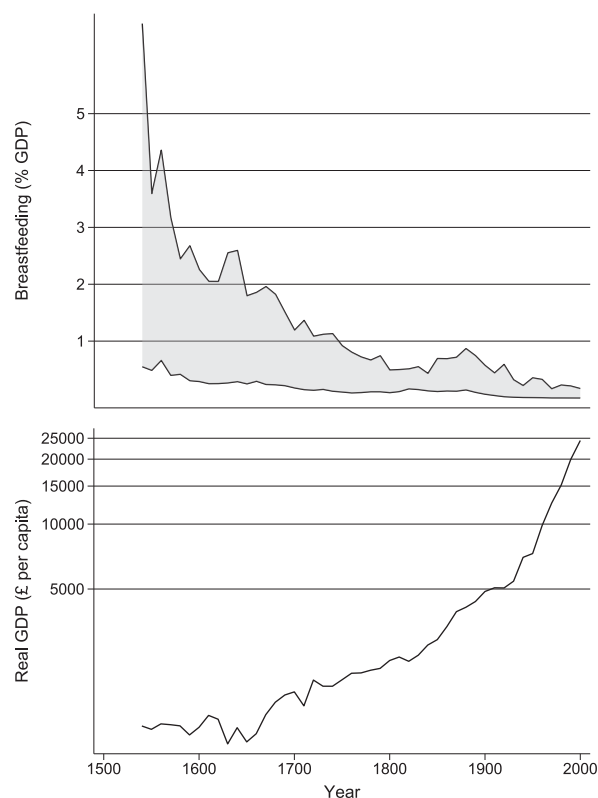


Fig. 1. The value of unpaid breastfeeding and living standards, 1540–2000.

was accompanied by a decline in breastfeeding. While real GDP rose from £ 1,143 per person in 1600 to £ 1,668 in 1700, and nominal output grew around 0.9 per cent per year, the unit value of unpaid breastfeeding did not keep pace (*SI Appendix, Table S1*). Additionally, mean duration fell to 8.52 mo. As a result, unpaid breastfeeding was equivalent to 0.18 to 1.19 per cent of GDP by 1700.

These trends largely persisted in the eighteenth century, except for an upward inflection in population growth toward the century's end. Nominal output rose faster than population, allowing improvements in per-capita real GDP, but both maternal wages and substitute prices lagged (*SI Appendix, Table S1*). Breastfeeding duration declined further, reaching a low of 5.32 mo in 1770. By 1800, the economic value of unpaid breastfeeding had fallen to 0.09 to 0.49 per cent of GDP.

In the nineteenth century, maternal wages rose and milk prices fell, leading to divergence in the upper- and lower-bound value estimates (*SI Appendix, Table S1*). Nominal and real GDP per capita continued to rise, and population growth remained rapid. However, unlike previous centuries, economic expansion was now accompanied by later weaning in the second half of the century, rising to a second peak of 7.54 mo in 1890. Unpaid breastfeeding stood at 0.07 to 0.57 per cent of GDP in 1900.

Finally, the economic value of unpaid breastfeeding collapsed to 0.00081–0.17 per cent of GDP over the course of the twentieth century. Declining fertility, falling breastfeeding duration (around 4 mo by 2000), and sharply rising GDP all contributed, while maternal wages and the price of market substitutes failed to keep pace (*SI Appendix, Table S1*).

Demographic indicators provide corroborating evidence. Earlier weaning should be associated with shorter birth intervals due to reduced lactational amenorrhea. Indeed, evidence from

[‡]The literature has argued that female labor markets were segmented by marriage (42); in that case, the series representing married women's daily earnings would capture wet-nurses' outside option.

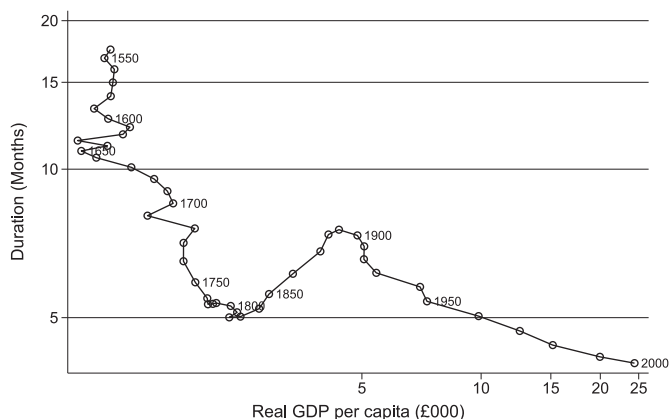


Fig. 2. Income elasticity of breastfeeding over time (log scale).

church records suggests birth intervals trended shorter from 1550 to a nadir in 1810–9, with a potential reversal between 1820 and 1837 when the series stops (46). Birth intervals likely lengthened further over the nineteenth-century demographic transition (47, 48).

Patterns in infant mortality provide a further check. Lower breastfeeding prevalence, due to its immunological benefits, should predict higher levels of infant mortality seasonally concentrated in warmer summer months when environmental hazards associated with weaning were most acute, such as food spoilage and flies (49). Indeed, infant mortality rose between ca. 1580–1750, and a summer peak occurred during the second year of life over this period (46). Although drawn from a different source, these findings are remarkably consistent with our evidence of initially high but declining breastfeeding duration between ca. 1560–1775 (Fig. 2).

Infant mortality declined gradually after 1750, although mostly driven by falling neonatal mortality (50). Neonatal mortality is closely associated with maternal, not infant health so is unlikely to have been a causal consequence of greater breastfeeding. However, better maternal health, either via improved nutrition or a reduction in injuries during birth (51), would likely also contribute to greater breastfeeding, consistent with our series. Given that our estimate of mean breastfeeding duration over this period is very low and that poor infant health is associated with weaning before six months (12), improvements from this low level may not have been reflected in infant health. Seasonal patterns in infant mortality provide more corroborating evidence. Huck (49) finds that a summer peak in under-one mortality emerged in the second half of the nineteenth century, implying a later nadir for breastfeeding than we suggest. On the other hand, a detailed study of a London population reports that summer-peak mortality disappeared after ca. 1800, consistent with the rising trend in breastfeeding duration we identify, although this change was restricted to the one-to-five-month age group (52).

Although the data are limited, we also find evidence of change within places consistent with national trends. In Manchester, for example, a survey conducted in 1857 reported that 26.0% of infants were exclusively breastfed beyond six months (53). Two later surveys taken in 1895 found exclusive breastfeeding rates of 32.9% and 58.0% at six months (54). While the medical officer of health for Manchester did not survey breastfeeding, the medical officer for neighboring Salford in 1908–13 reported that 77.5% of infants were exclusively breastfed at six months (36).

In Norwich, exclusive breastfeeding rates in the first few weeks of life rose from 67.6% in 1905 to more than 90% in the 1910s (36). Both cases are consistent with rapidly rising breastfeeding rates at the turn of the twentieth century. A survey of Newbiggin-on-Sea over the years 1940–45 found that between 25 to 30% of infants continued to be breastfed at six months, while earlier generations reported having breastfed for around twelve months on average, consistent with our estimate of rapid decline in the middle of the twentieth century (55).

These complementary strands of evidence point to long-run change. Over five centuries, the value of unpaid breastfeeding fell from a high point in the mid-sixteenth century to a nadir in the early nineteenth century and reached a second peak at the turn of the twentieth century. No single factor drove change at all times, but the imputed unit value of breastfeeding often failed to keep pace with economic growth.

3. Discussion

Our estimates of the value of unpaid breastfeeding make use of all, to our knowledge, directly reported data on breastfeeding's duration, its value, and corroborating demographic evidence over five centuries. Still, the scarcity of data remains the major limitation of our study.

Where gaps in knowledge exist, we have relied on assumptions to fill them, erring toward assumptions more likely to understate breastfeeding's value. Our approach differs from previous studies that infer the extent of breastfeeding from birth intervals, which generally conclude that breastfeeding suppressed fertility for much longer than we estimate (46, 52). Both methodologies involve assumptions and require overcoming biases in the underlying data. By providing a fresh lens, we hope to stimulate further interest in this important topic. A fuller methodological discussion is left to *SI Appendix, section G*, but we note that these data are drawn from a rural and geographically immobile population, while our data are likely drawn from a more urban population. It is possible that rural populations breastfed for longer, leading us to underestimate the duration of breastfeeding before rapid urbanization in the nineteenth century. In general, the shortage of individual-level covariates in our underlying data limit our ability to adjust for compositional change in the population over time and make it necessary to assume constant source bias to identify trends in breastfeeding duration. Archaeological studies using dental remains may yet produce more direct evidence on urban/rural differences, although such data are currently scarce, limited by high costs (33). Due to data limitations, we have also assumed that the market value of breastfeeding was a constant proportion of married women's wages. While the available evidence for the earlier period broadly supports this assumption, for the twentieth century, this is probably too conservative. As institutional restrictions on married women's work relaxed, the opportunity costs of breastfeeding likely rose beyond our reconstructed wetnurses' pay (56), and as the health externalities of breastfeeding were better recognized, our value estimates likely fell increasingly short (37). Notwithstanding, we highlight three implications of our present findings.

First, unpaid breastfeeding was economically significant relative to measured economic activity. In 1841, for example, all public administration and defense accounted for roughly 1 per cent of GDP. Potteries, glassmaking, and brickmaking, all regionally important industries, represented together about 0.8 per cent of GDP (57).

Relative to other forms of human capital investment, breastfeeding's value was also large. This is a particularly salient comparison due to the importance of physical competence and applied skills to the premodern economy (58). Total expenditure on education in 1833 did not exceed 1 per cent of GDP, and was probably much less in earlier years (59). Larger sums were expended on apprenticeship fees (60), but these too represented a fraction of a percent of GDP. At the upper bound, therefore, unpaid breastfeeding arguably represented the largest human capital investment in early modern England. At the lower bound, it was nonetheless of inescapable economic significance.

Second, accounting for breastfeeding's imputed value modifies the macroeconomic history of Britain. For instance, although real GDP per capita stagnated until the seventeenth century, the value of breastfeeding declined rapidly from 1540, and this continued after the onset of sustained growth after 1600. Further, modest increases in the value of breastfeeding over the nineteenth century are missing from measured growth in this period.

While these revisions are modest, they represent only one task in a larger bundle of unpaid work. This example suggests unpaid care may not simply move in tandem with economic growth (61).

Indeed, third, we find that the income elasticity of breastfeeding possibly changed over time. Fig. 2 plots our decadal estimate of breastfeeding duration against real GDP per capita, with points connected across time. Until roughly 1800, falling breastfeeding duration accompanied rising GDP per capita, but the relationship reversed over the nineteenth century. A second reversal after 1900 likely reflects the spread of commercial formula and a reduction of the cost of market substitutes operating at all income levels rather than income effects per se (37).

Limited cross-sectional evidence from birth intervals, which increase with breastfeeding duration, broadly support this interpretation. For instance, in a case study of a rural village in seventeenth-century Devonshire, Sharpe (30) finds that poor households exhibited longer birth intervals, a pattern also found in the wider population (62). A survey of breastfeeding practices in Derbyshire circa 1910 found a slight negative relationship between nursing duration and wealth (63) which is later than the timing implied by our time series. However, by the time of the first national infant feeding survey in 1946, the cross-sectional relationship had turned positive (64).

Economic theory suggests income affects maternal nursing in a number of conflicting ways. On the one hand, higher maternal wages reduce breastfeeding by raising its opportunity costs. On the other, greater overall household income would both reduce the marginal value of maternal labor-force participation and enable the purchase of market substitutes for breastmilk, with the former effect encouraging and the latter discouraging maternal nursing (65). It is possible that relative differences in men's and women's earnings at different levels of the income distribution, or differences in other factors, such as social norms, account for the lagged impact of changing income elasticity in the cross-section relative to the time series.

Nonetheless, this shift has implications for long-run economic dynamics. Specifically, it is at odds with the Malthusian assumption that income and mortality were negatively correlated before the demographic transition, given the close connection between early weaning and infant mortality (SI Appendix, Fig. S1). This may be one more reason that the preindustrial demographic regime was not as harsh as Malthus imagined (66). Our findings highlight the need to better understand this relationship and its role in demographic outcomes.

These three implications suggest that breastfeeding was a significant and variable component of economic life. Its exclusion from historical accounts of GDP has distorted our understanding of both growth and welfare in the long run.

4. Materials and Methods

Our estimate uses two basic identities. The first,

$$v = pu \quad [1]$$

defines breastfeeding's total value, v , as the product of its prevalence, p , and unit value, u . Prevalence is

$$p = id, \quad [2]$$

where i is incidence and d is mean duration (67).

4.1. Incidence. Incidence refers to new cases of unpaid breastfeeding. We approximate i using annual births, averaged over five years to smooth fluctuations. Parochial baptism records enable reconstruction of fertility for the period 1540–1871 (68), while post-1871 data are from Mitchell (69).

We adjust i for four factors. First, to impute a monetary value to unpaid breastfeeding, we remove the share of children likely nursed by a paid wetnurse, w , proxied by the share of families employing domestic servants. Social tables for benchmark years 1290, 1688, 1759, 1801, and 1846 provide data on income and household size, from which we infer the share of families employing domestic servants and use linear interpolation between benchmarks (details in ref. 7). After 1850, roughly when wet-nursing norms shifted and the practice declined (70), we set $w = 0$.

Second, we adjust for the endogenous infant mortality rate, m . Endogenous infant mortality is a measure of excess neonatal mortality beyond what would be expected from postnatal environmental exposure. Conceptually, it is often related to birth complications and maternal health; we argue that it should also capture deaths due to noninitiation. Insufficient milk and maternal illness were the most commonly cited reasons for noninitiation of breastfeeding in the past (24, 49), and prior to technological improvements in the quality of alternative infant foods noninitiation was often fatal. For example, in Brighton in 1905, while 1.8% of breastfed children aged 0 to 3 mo died, the rate was 65.4% for children who received no breast milk; 11 out of 12 children who received only cow's milk aged 0 to 3 mo died (71). Endogenous infant mortality thus likely captures the consequences of residual noninitiation before the twentieth century.

Methodologically, m relates the cumulative mortality rate to the following function of age in days after the first month of life

$$f(x) = [\ln(x + 1)]^3.$$

The relationship is approximately linear, indicating continuous exposure to environmental hazard. The linear trend is then extrapolated back to the first month of life to estimate the share of neonatal mortality attributable to environmental causes. The remainder is endogenous infant mortality (11).

The endogenous mortality rate is reported throughout the historical demographic literature. For the period 1580–1837, we use data from Wrigley et al. (46), while for 1840–1920 we apply linear interpolation to data reported in Eckstein (48). After 1920, we apply the endogenous mortality calculation to Office of National Statistics data on infant mortality. For the years between 1540–1580, we assume the 1580 rate applies.[§]

Third, to reflect the increasingly common practice of feeding artificial foods at birth over the twentieth century, we adjust incidence by the noninitiation rate, n , estimated from nationally representative survey data (SI Appendix, section C). We assume that $n = 0$ before 1900.

Fourth, we consider foundlings and out-of-wedlock births, two groups whose breastfeeding patterns were distinctive. Foundlings were infants abandoned by

[§]This gap exists because crude birth rates are available from 1540 (68), but age-specific mortality is only available from 1580 (46).

their parents to local welfare or charity institutions so did not receive maternal breast-milk. The practice was concentrated in London, which offered urban anonymity to parents, and it probably represented no more than 0.5% of annual births (29). Roughly 30 to 80% of foundlings died in infancy, with variation explained by differences in the quality of institutional care (72). We therefore expect some foundlings to be captured by our endogenous infant mortality correction. Data are not available to estimate and subtract surviving foundlings from our measure of annual births, but the available evidence suggests their influence should be relatively small.

On the other hand, data on the share of out-of-wedlock births, o , are available for our study period, which ranged from roughly 3 to 8% of births before the twentieth century. So-called “illegitimate” children often lived with their unmarried mothers, on whose sole income the household relied. Consequently, these mothers had less time available for intensive breastfeeding and were less likely to initiate (63). Because detailed historical data on breastfeeding practices of unmarried mothers are scarce, we assume all unmarried mothers did not breastfeed prior to the twentieth century. This is very likely an overestimate. One study from Derbyshire circa 1920, for example, indicates noninitiation rates among “illegitimate” children were roughly 20% (63). The absence of commercial infant food products in earlier centuries probably made noninitiation even less common (37). Nonetheless, unmarried mothers also weaned sooner so that this conservatively underestimates the lower prevalence of breastfeeding among this group. After 1900, we set $o = 0$ because the survey data capture unmarried mothers in their broader noninitiation rates, n (see *SI Appendix, section C* for details).

After these adjustments, Eq. 2 becomes

$$\rho = i(1 - w)(1 - m)(1 - n)(1 - o)d. \tag{3}$$

4.2. Duration. We develop a flexible methodology to account for bias in each data-generating process represented by our diverse sources on breastfeeding duration.

First, we estimate

$$T = \mathbf{S}\gamma + \epsilon, \tag{4}$$

where T is the age (months) at weaning, $\mathbf{S}$ is a vector of source indicators (including diaries, medical advice, contemporary estimates, skeletal remains, health surveys, and state/welfare sources) and ϵ is a normally distributed error.

Though covariates with which to assess the representativeness of our data are absent from most of our sources, this model captures time-invariant

Table 1. Time invariant source bias relative to health surveys

	(1) MLE: Weaning age
Bone	5.82* (0.94)
Diaries, etc.	5.76** (2.55)
Medical advice	2.66** (1.10)
Contemporary estimate	6.93 (4.51)
Welfare	3.56*** (1.00)
Constant	6.57*** (0.10)
log(σ)	1.49*** (0.02)
Observations	2,081
Log-likelihood	−4,509.8

Standard errors in parentheses * ($P < 0.10$), ** ($P < 0.05$), *** ($P < 0.01$)



Fig. 3. Estimate of trends in breastfeeding duration, 1540–2000.

source bias, γ , introduced by each data-generating process relative to public health surveys (omitted category), our most complete and representative data source. We assume that differences across sources at a moment in time reflect bias associated with each source. We therefore use a sample restricted to the nineteenth century, a period where we have temporal overlap across all source categories, to estimate the parameters in Eq. 4.

We use maximum likelihood estimation to address interval censoring. This occurs where weaning is only known to fall between two points, such as surveys with age bins and writers who provide a range of contemporary estimates. Data from rib collagen are also interval censored as they only identify where weaning age falls relative to age at death.

The likelihood function is

$$\mathcal{L} = \prod_{i \in C} [\Phi(R_i, \mathbf{S}, \sigma) - \Phi(L_i, \mathbf{S}, \sigma)] \prod_{i \in D} [\phi(T_i, \mathbf{S}, \sigma)], \tag{5}$$

where C are interval-censored observations, D are point observations, and Φ and ϕ are the CDF and PDF, respectively, of the normal distribution with SD σ .

All our sources exhibit positive bias relative to public health surveys (Table 1). Large biases in diaries (+5.76 mo) and contemporary estimates (+6.93 mo) are likely related to left-truncation in these sources. For example, due to death or abandonment, roughly a quarter of children grew up without fathers in the past (73). Mothers in such families may have given up breastfeeding to replace lost income, and their experiences would not likely be reflected among diarists or in the recommendations and contemporary estimates of medical writers (see *SI Appendix, section E* for details).

Skeletal remains are also positively biased (+5.82 mo). This possibly reflects lags in the biophysical deposition of nitrogen in bone collagen, errors in estimating age, or sample selection (32, 33). Our methodology, however, points to rising weaning ages over time, after adjusting for this difference in levels, which agrees with the analysis of one source study (32).

We further assume that the source bias estimated in Eq. 4 is time invariant so that change over time in residuals across different sources reflects unbiased change in population breastfeeding patterns. Fig. 3 plots residuals from Eq. 3 over time. Following Topp and Gómez (74), residuals for interval-censored data are defined as the expected value of the outcome conditional on falling within the known interval, minus the predicted value. A local linear trend (bandwidth = 30, Gaussian kernel) captures temporal change in mean residual duration, $\hat{d}$, after controlling for time-invariant source bias. We add the residual time trend to the constant estimated in Table 1 to estimate the expected duration of breastfeeding, d .

We perform a number of robustness checks in *SI Appendix*. Our core estimates in Eq. 4 are robust to estimating time-invariant source bias from the whole sample unrestricted in time and to assuming weaning age follows a log-normal distribution. We also relax the assumption of time-invariant bias in two ways. First, authorship and readership of diaries and medical texts likely became more general over time due to rising literacy rates. We demonstrate that our results could not be driven by rising literacy rates without being inconsistent with other

demographic evidence. Second, cultural differences across individual remains covered by our archaeological studies do not appear to drive change over time (*SI Appendix*). Overall, our results are qualitatively robust and err on the side of being too conservative.

Finally, we adjust our measure of duration to account for the competing risk of dying before weaning using high-quality proxy data on mortality and breastfeeding from the United States before its epidemiological transition was complete (c. 1910). This turns out to make little difference because early weaning was so often the cause of infant mortality and preceded it. Details of this adjustment are therefore left to *SI Appendix*.

4.3. Value. We use milk prices to impute a lower-bound value and women's casual wages to impute an upper-bound value to unpaid breastfeeding, following the logic described above.

Clark (39) reports agricultural prices, including milk, for the period 1209–1914. For later years, we use milk prices collected by the ONS to calculate the retail prices index (RPI).

Historical women's wages are estimated by Humphries and Weisdorf until 1850 (42). They interpret women's casual day wages as a proxy for married women's earnings in a segmented labor market because family constraints restricted labor market participation to more short-term forms of employment. As wet-nurses were likely married, we take this as the appropriate wage for imputing the labor value of breastfeeding. For 1850–1900, we assume women's casual

day wages grew at the rate of the women's wages index reported in Hutchins and Harrison (75). For 1900–2000, we convert real wages from Horrell (76) to nominal wages using the RPI. We again apply the rate of nominal wage growth to our wage series to preserve the original married women's earnings penalty.

4.4. Decomposition. After having calculated incidence, prevalence, and duration by decade from 1540–2000, we apply a logarithmic decomposition to measure the relative contribution of each component to change over time, which is described in more detail in *SI Appendix*.

Data, Materials, and Software Availability. Replication file data have been deposited in Zenodo (<https://doi.org/10.5281/zenodo.22117474>) (77).

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