# Spilled milk: valuing six centuries of unpaid breastfeeding in England

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**Breastfeeding is vital and valuable labour, contributing to the physical and cognitive health of children throughout their lives, yet it is rarely compensated in formal labour markets. Its economic importance may therefore go unrecognised. We impute upper and lower bounds for the value of unpaid breastfeeding over six centuries in England to better understand its economic role over the course of economic development. Along the way, we contribute a novel 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 GDP, reaching a possible peak of 5% 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 accounts | 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 unpaid caregiving and paid residential care for dementia patients are negatively correlated across US states, reflecting policymakers' focus on Medicaid costs while overlooking the burden on unpaid carers, often women.

Care work has shifted historically across the exchange frontier, sometimes commodified and sometimes unpaid. Historians have linked such changes to the decline of subsistence agriculture (2, 3), rising conspicuous consumption, and demographic change (4). Yet the feminization of paid domestic work has been stubbornly persistent (5), and unpaid tasks were never trivial. Humphries (6) estimates that cooking and cleaning produced the equivalent of 17- 25% of national income between 1300 and 1870.

This study focusses on a major task on the wider care docket: breastfeeding. Like other care work, breastfeeding is both gendered and demanding, taking 18.2 hours per week in contemporary estimates (7), and equally arduous in the past (8). Breastfeeding, like other care work, crosses the exchange frontier. Mothers once hired wetnurses; today, they purchase formula (9).

Breastfeeding is closely related to human welfare. It improves infant survival in unsanitary environments (10), supports long-term health and cognitive development (11–13), and suppresses fertility via lactational amenorrhea (14). Through these channels, breastfeeding affects labour supply and the productivity of future generations.

Yet the economic determinants of breastfeeding remain unclear. Cross-sectional data suggest that in low-income settings, breastfeeding declines with higher income (15), while in high-income settings, it rises (16). This implies 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 Malthusian 'positive checks'. We are aware of only one other study, of Norway, that documents this inversion occurring over time (17).

We estimate and value unpaid breastfeeding in England from 1400 to 2000, accounting for changes to fertility, inequality, infant mortality, and breastfeeding duration. We develop a method combining documentary and archaeological evidence

## Significance Statement

We produce the first numerical estimate of the value of unpaid breastfeeding relative to national income spanning six centuries and integrating historical and bioarchaeological data. The relative economic contribution of maternal nursing was greater in the distant past than in recent history, rivalling regionally significant industries such as pottery, glassmaking, and even the entire 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 likely fell as incomes rose, challenging the Malthusian assumption that higher income correlates with lower mortality.

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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 0.41% and 4.9% of GDP. Further, we identify a possible reversal of its income elasticity from negative to positive in the nineteenth century.

## 1. Accounting for breastfeeding

Given the scarcity of historical data on breastfeeding duration and its perceived value, we have relied on the pioneering work of other scholars to synthesize all available evidence on the subject.

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 months) (18). 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' (19). In this case, for example, we treat 10-12 months as a contemporary estimate and 18-24 months as a recommendation. We combine published data of this kind (20, 21) with 33 additional primary sources.

Breastfeeding data was 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 (22–24) . 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 1825-1852.[*]

We also use published isotopic analysis of skeletal remains. High concentrations of N-15 in infant rib collagen indicates breastfeeding, while long-bone lengths or tooth development indicate age at death (25). Bioarchaeologists typically estimate the age at which population-level N-15 returns to normal concentrations after infancy, but we propose a method to preserve individual differences in weaning age. That is, we assume that an infant who dies with elevated N-15 ($2\sigma$ above the adult mean) would have been weaned later had they survived, capping at 36 months. Infant remains without elevated N-15 were likely weaned before death.

Four such studies fit within the scope of our analysis: two from medieval York (rural and urban, midpoint 1450) (26, 27), one from Lukin Street Catholic cemetery (1843-54) (28), and one from Spitalfields (1760-1844), with remains linked to parish records (25).

Finally, towards 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. We identify 29 such studies (29, 30).

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 (31).

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

Cow's milk, a longstanding market substitute for breast-milk in England, provides a lower-bound imputed value. We use Clark's agricultural price series (32) through 1914 and Office of National Statistics (ONS) data thereafter, assuming hand-fed infants required one gallon of milk per week—a generous portion allowing for spoilage in the absence of refrigeration.

Breastfeeding, however, is also labour. 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 (31, 33), such data are rare in our setting. Fildes (34) identifies only 22 wage observations between 1500 and 1800, and these often recompensed duties beyond suckling. In a few cases where the same employer paid wet- and dry-nurses separately, Fildes reports a wage premium of approximately 100% for wet-nursing. We apply this premium to a long-run series of women's unskilled day wages to impute an upper-bound value.

These bounds have convenient properties. Opportunity cost imputations would fall below the upper bound—100% of women's casual day wages—as breastfeeding did not occupy a full working day. Conversely, novel market substitutes should exceed the value of milk alone, which was their primary input. Our bounds should therefore be robust to technological change and alternative imputation strategies.

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 (35).



## 2. Results

Although nominal GDP and real GDP per capita hardly changed in the fifteenth century, this period saw dramatic change in unpaid breastfeeding. Mean duration rose from 6.60 to 9.98 months, driving the largest share of growth (table S1) in its estimated economic value—from 0.13-2.62% of GDP in 1400 to 0.22-3.48% by 1500.

Nominal GDP began to rise during the sixteenth-century price revolution but stagnated on a real, per-capita basis. Breastfeeding duration continued its rise, peaking at 13.44 months in 1560 before falling again, making a small net contribution to change across the whole century (table S1). When valued using maternal wages as an upper bound, unpaid breastfeeding declined relative to GDP, as wage growth lagged rising nominal output. On the other hand, our lower-bound estimate rose, reflecting sharp increases in milk prices. Rapid population growth also contributed to a higher incidence of unpaid infant feeding. Taken together, these dynamics put the economic value of unpaid breastfeeding at 0.27-2.14 per cent of GDP in 1600.

The seventeenth century marked the onset of real per-capita GDP growth amid relatively modest population growth, yet this was accompanied by a decline in breast-feeding. 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 (table S1). Additionally, mean duration fell from 11.28 to 7.02 months. As a result, unpaid breastfeeding was equivalent to 0.15-1.01 per cent of GDP by 1700.

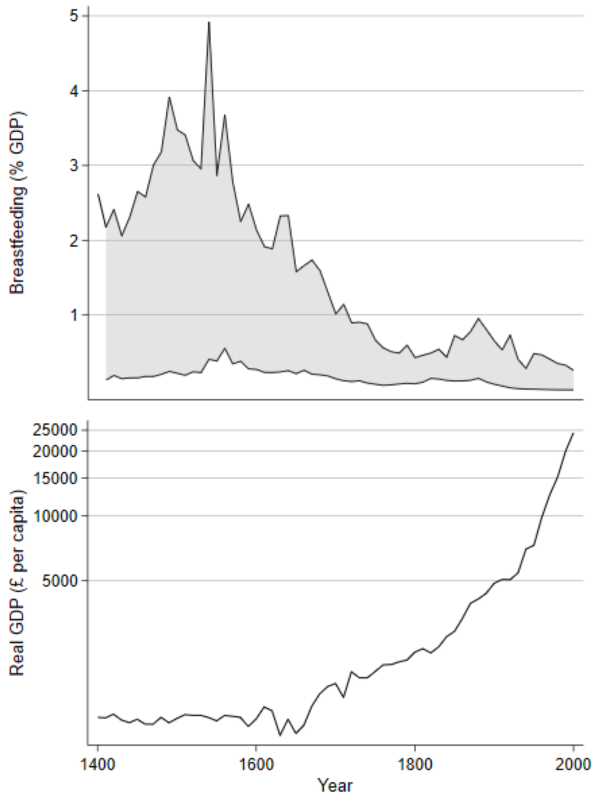


**Fig. 1.** The value of unpaid breastfeeding and living standards, 1400-2000

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 (table S1). Breastfeeding duration declined further, reaching a low of 3.56 months in 1770. By 1800, the economic value of unpaid breastfeeding had fallen to 0.08-0.43 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 (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, which occurred around 7.71 months in 1890—a second peak. Unpaid breastfeeding stood at 0.08-0.66 per cent of GDP in 1900.

Finally, the economic value of unpaid breastfeeding collapsed to 0.001-0.26 per cent of GDP over the course of the twentieth century. Declining fertility, falling breastfeeding duration (around 4 months by 2000), and sharply rising GDP all contributed, while maternal wages and the price of market substitutes failed to keep pace (table S1).

Over six centuries, therefore, the value of unpaid breastfeeding rose and fell, with peaks in the mid-sixteenth century and the late nineteenth century. No single factor drove change at all times, but breastfeeding's value often failed to keep pace with economic growth.

## 3. Discussion

We highlight three implications of our 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, small but regionally important industries, represented together about 0.8 per cent of GDP (36).

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 pre-modern economy (37). Total expenditure on education in 1833 did not exceed 1 per cent of GDP, and was probably much less in earlier years (38). Larger sums were expended on apprenticeship fees (39), 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 sixteenth century, trends in breastfeeding's value suggest a wave of modest growth until roughly 1540 followed by modest shrinking. Further, sustained growth in real GDP per capita after 1600 was accompanied by a long decline in the value of breastfeeding.

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.

Indeed, third, we find that the income elasticity of breastfeeding possibly changed over time. Figure 3 plots the log of our decadal estimate of breastfeeding duration against the log of 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 (40).

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 (23) finds that poor households exhibited longer birth intervals, a pattern also found in early nineteenth-century London (41). A survey of breastfeeding practices in Derbyshire circa 1910 found a slight negative relationship between nursing duration and wealth (42) 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 (43).

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 labour-force participation and enable the purchase of market substitutes for breastmilk, with the former effect encouraging and the

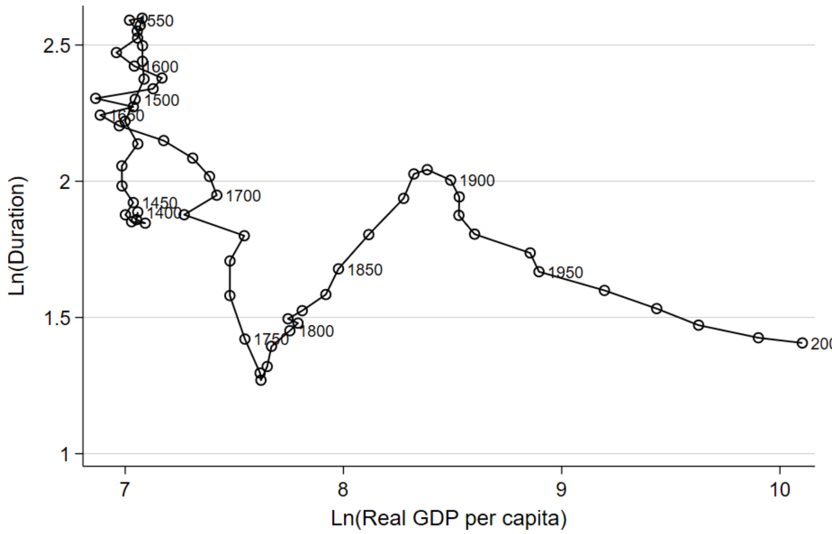


**Fig. 2.** Income elasticity of breastfeeding over time



latter discouraging maternal nursing (44). 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 (figure S1). This may be one more reason that the pre-industrial demographic regime was not as harsh as Malthus imagined. Our findings highlight the need to better understand this relationship and its role in demographic outcomes.

Taken together, 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.

## Materials and Methods

Our estimate uses two basic identities. The first,

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

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

$$p = id \qquad [2]$$

where i is incidence and d is mean duration (45).

**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 (46), but earlier measures of fertility are rare (47). However, churchwardens accounts from Walden in Essex (1439-1488) recorded the number of women 'churched' or purified after childbirth, from which Poos estimates a relatively static birth rate of 30 per 1000 (47, p.123ff). We combine this with national population totals (CITE) to estimate medieval births. Post-1871 data are from Mitchell (48).

We adjust $i$ for two 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 6). After roughly 1850, when norms around wet nursing shifted and the practice fell into decline (49), we drop this adjustment.

Second, we adjust for the endogenous infant mortality rate, $m$, assuming such infants are unlikely to appear in our data. Endogenous infant mortality is conceptually related to birth complications and maternal health as distinct from mortality due to post-natal environmental exposure. The method relates the cumulative mortality rate to the following function of age in days after the first month of life

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

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.

The endogenous mortality rate is reported throughout the historical demographic literature. For the period 1580-1837, we use data from Wrigley et al. (50), while for 1840-1920 we apply linear interpolation to data reported in Eckstein (51). After 1920, we apply the endogenous mortality calculation to Office of National Statistics data on infant mortality. For the medieval period, a demographic model developed by La Poutré and Janssen (52) implies the medieval infant mortality rate was 170 per 1,000. Lewis and Gowland (53) evaluate the medieval Wharram Percy site as representing a nearly complete record of all infant deaths and find 61 per cent died pre-term. Applied to the model, this proxy suggests a medieval endogenous mortality rate of around 103.7 per 1,000.

After these adjustments, equation 2 becomes

$$p = i(1-w)(1-m)d. \qquad [3]$$

**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

$$T = \mathbf{S}\gamma + \varepsilon \qquad [4]$$


**Fig. 3.** Changes in breastfeeding duration, 1400-2000



**Table 1. Time invariant source bias relative to health surveys**

| | (1)<br>OLS: Weaning age |
|---|---|
| Bone | 3.78*** |
| | (0.53) |
| Diaries, etc. | 6.86*** |
| | (0.64) |
| Medical advice | 5.63*** |
| | (0.62) |
| Contemporary estimate | 4.97*** |
| | (1.30) |
| Institutional | 3.69*** |
| | (1.01) |
| Constant | 6.47*** |
| | (0.02) |
| ln($\sigma$) | 1.50*** |
| | (0.00) |
| Observations | 138183 |
| Log-likelihood | -192674.8 |

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 $\epsilon$ 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 bias, $\gamma$, introduced by each data-generating process relative to public health surveys (omitted category), our most complete and representative data source. Note that our earliest public health survey dates to 1857, creating temporal overlap across all source categories in the late nineteenth century. This overlap allows us to identify source-specific bias in weaning age, $\gamma$, independently of temporal variation in data availability, provided the bias is itself time invariant.

We use maximum likelihood estimation to address interval censoring. For example, weaning age is only known relative to age at death for skeletal remains, while surveys and contemporary estimates sometimes report weaning in age intervals.

The likelihood function is:

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

where $C$ are interval-censored observations, $D$ are point observations, and $\Phi$ and $\phi$ are the CDF and PDF, respectively, of the normal distribution with standard deviation $\sigma$.

All our sources exhibit positive bias relative to public health surveys, probably reflecting underreporting of early weaning and social selection (see table 1). The largest biases are in diaries (+6.86 months) and medical opinion (+5.82 months), possibly because of self-selection in these sources.

Figure 3 plots residuals from equation (3) over time. Following Topp and Gómez (? ), 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 estimated time trend to the constant estimated in table 1 to estimate the expected duration of breastfeeding, $d$.

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 U.S. 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 the SI.

**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 (32) 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 (54). They interpret women's casual day wages as a proxy for married women's earnings in a segmented labour market because family constraints restricted labour 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 labour 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 (55). For 1900-2000, we convert real wages from Horrell (56) to nominal wages using the RPI. We again apply the rate of nominal wage growth to our wage series to preserve the married women's earnings penalty reported in Humphries and Weisdorf.

**Decomposition.** After having calculated incidence, prevalence, and duration by decade from 1400-2000, we apply a logarithmic decomposition to measure the relative contribution of each component to change over time, which is described in more detail in the SI.

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## Supporting Information Text

## Methods

**Factor decomposition.** We decompose the per-century change in the value of unpaid breastfeeding into its component factors to simplify our discussion of results. The value of unpaid breastfeeding relative to GDP is

$$\frac{v}{g} = \frac{idu}{g} \qquad [1]$$

where $i$ is incidence, $d$ is duration, $u$ is unit value, and $g$ is nominal GDP. Taking the log gives

$$\ln\left(\frac{v}{g}\right) = \ln(i) + \ln(d) + \ln(u) - \ln(g) \qquad [2]$$

and applying the difference operator,

$$\Delta\ln\left(\frac{v}{g}\right) = \Delta\ln(i) + \Delta\ln(d) + \Delta\ln(u) - \Delta\ln(g) \qquad [3]$$

The proportional contribution of each factor $x \in \{i, d, u, g\}$ to change is

$$\frac{\Delta\ln(x)}{\Delta\ln\left(\frac{v}{g}\right)} \qquad [4]$$

which is negative if $x = g$. Finally, change $\Delta$ is estimated as the coefficient from regressing each factor separately on time using OLS for each century.

The results of the decomposition are presented in table S1. For each century, the change in upper- and lower-bound estimates are decomposed separately, recalling that maternal wages and the cost of milk are used to bound the value of $u$. We highlight the factor contributing the most to observed change in the value of unpaid breastfeeding in bold.

**Exogenous infant mortality.** Infant death will also stop breastfeeding, and there is a need to account for this given the strong relationship between early weaning and infant mortality. But the direction of causality matters. As Knodel and Kintner (1977) demonstrate (replicated in figure S1), the rate of infant mortality rose sharply after weaning in an historical sample of U.S. cities. This suggests weaning raised the likelihood of infant death, as this exposed infants to novel pathogens and reduced the protection offered by mothers' antigens. For many infants, death was caused by weaning and did not "interrupt" breastfeeding.

We therefore consider two events, weaning and infant death, occurring at time W and D, respectively, where the first to occur terminates breastfeeding. At any moment, t, there are three mutually exclusive possibilities: neither event has occurred, weaning has occurred before death, or death has occurred before weaning, with corresponding probabilities,

$$P(W > t, D > t) + P(W \leq t, W < D) + P(D \leq t, D < W) = 1 \qquad [5]$$

The probability that neither event has yet occurred, i.e., the survival curve, is of primary importance to estimating the expected duration of breastfeeding:

$$\mathbb{E}[\min(W, D)] = \int_0^\infty P(W > t, D > t)dt = \int_0^\infty S(t)dt = \int_0^\infty 1 - F_W(t) - F_D(t)dt \qquad [6]$$

where the joint probabilities are represented by $F_W(t) = P(W \leq t, W < D)$ and $F_D(t) = P(D \leq t, D < W)$.

However, we do not observe the joint probability of weaning because virtually every child whose weaning age is observed in our dataset must not have died first.* Our weaning data is therefore conditional on $W < D$. The conditional probability of weaning is related to the joint probability as

$$P(W \leq t \,|\, W < D) = \frac{F_w(t)}{\theta} \qquad [7]$$

where $\theta = P(W < D)$. Substituting Eq. (7) into Eq. (6) yields

$$\int_0^\infty S(t)dt = \int_0^\infty 1 - \theta P(W \leq t \,|\, W < D) - F_D(t)dt$$

or equivalently

$$\int_0^\infty S(t)dt = \int_0^\infty 1 - \theta P(W \leq t \,|\, W < D) - F_D(t) + \theta - \theta dt \qquad [8]$$

$$= \theta \int_0^\infty 1 - P(W \leq t \,|\, W < D)dt + \int_0^\infty 1 - \theta - F_D(t)dt. \qquad [9]$$

*Except for the skeletal remains, for which we only know that weaning would have occurred after death. We think this difference would be captured by our bias term.

Because the survival curve is the complement of the cumulative density curve, the first integral on the RHS in (8) is understood as the mean duration of weaning, conditional on weaning before death. This is arguably what our regression framework above estimates so we substitute this term with those values, weighted by $\theta$. The second integral is the infant mortality "correction", which converges because

$$\lim_{t \to \infty} F_D(t) = 1 - \theta.$$

Estimating $F_D(t)$ requires detailed data on the mortality of unweaned infants. As far as we know, such data does not exist for England in our period, and we must rely on analogous data taken from a sample of U.S. cities at the turn of the 20th century (Woodbury 1925). The U.S. was then in the very early stages of the epidemiological transition, and we expect the pattern of unweaned infant mortality here to be more representative of historical European populations than any other data we have been able to identify.

Weaning status and mortality are reported in this source in monthly intervals up to 12 months of age. We adjust the raw data to remove endogenous mortality, as our method already accounts for these deaths. After 12 months of age, we use the average mortality rate of all English children up to age 4 from Wrigley et al. (1997). The relationship between mortality and early weaning fades after about 9 months, suggesting mortality and breastfeeding are largely independent in later childhood.

Finally, we must know the weight $\theta$, i.e., the probability that weaning occurs before death. In the U.S. sample, approximately 20 per cent of infants who died before their first birthdays had not yet begun weaning. The infant mortality rate was 102.6 per 1,000. A crude estimate of the proportion who died before weaning in this population would therefore be 2.5 per cent, for example, which implies $\theta = 0.975$

Although this method does not wholly account for changes in infant mortality or its relationship to early weaning, it nonetheless makes clear that early mortality will have only a small impact on the measurement of breastfeeding duration (i.e. $\theta$ will be large). This is because early weaning so often led to premature death so came first in the order of events.

**Table S1. Decomposition of change in value of breastfeeding by factor**

| | | Contribution (%) to change of... | | | |
|---|---|---|---|---|---|
| | **Change (%)** | **Value** | **Incidence** | **Duration** | **GDP** |
| **1400s** | | | | | |
| Upper bound | 63.9 | -21.4 | 11.4 | **81.7** | 28.3 |
| Lower bound | 52.0 | -49.2 | 14.0 | **100.5** | 34.8 |
| **1500s** | | | | | |
| Upper bound | -51.6 | -99.4 | -167.1 | -10.2 | **376.3** |
| Lower bound | 38.9 | **364.3** | 221.8 | 13.5 | -459.6 |
| **1600s** | | | | | |
| Upper bound | -66.8 | -83.0 | -18.1 | 6.3 | **131.9** |
| Lower bound | -41.6 | -294.0 | -29.1 | 11.3 | **111.9** |
| **1700s** | | | | | |
| Upper bound | -99.9 | -1023.4 | 12.9 | **58.7** | **231.9** |
| Lower bound | -51.8 | -136.6 | 13.8 | 13.2 | **262.0** |
| **1800s** | | | | | |
| Upper bound | 66.0 | 81.0 | **166.0** | 110.9 | -527.9 |
| Lower bound | -30.8 | 141.3 | -360.7 | -241.1 | 56.5 |
| **1900s** | | | | | |
| Upper bound | -70.7 | -1023.4 | 34.1 | 88.5 | **1000.8** |
| Lower bound | -386.1 | -105.8 | 6.3 | 16.2 | **183.3** |

Note: factor contributing most to observed change in value to GDP highlighted in bold

## References

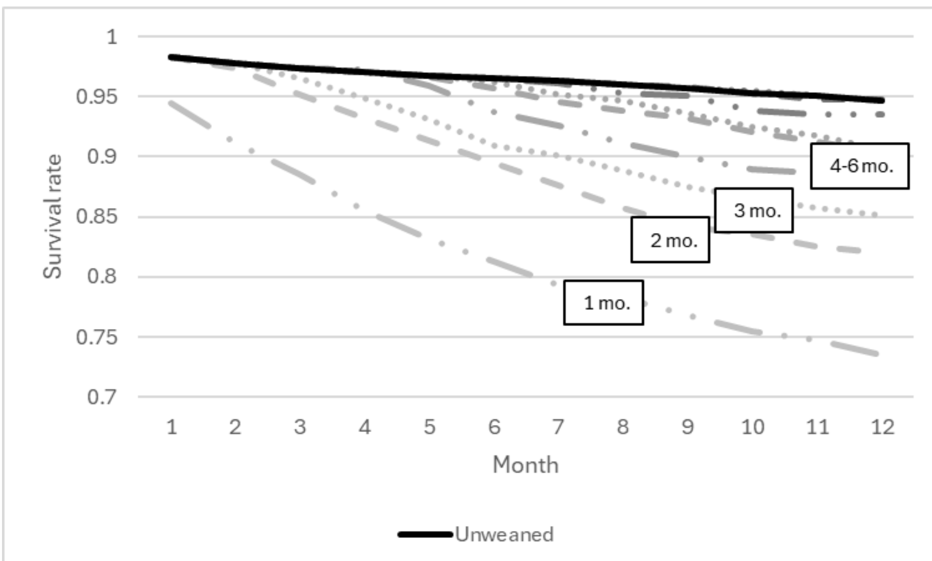


**Fig. S1.** Survival rate of infants by weaning age, c. 1910