Numeracy and the Impact of High Food Prices in Industrializing Britain, 1780-1850*

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Abstract: Using census-based data on the ability to recall one's age, we show that low levels of nutrition impaired numeracy in industrializing England, 1780-1850: Cognitive ability declined among those born during the Napoleonic wars. The effect was stronger in areas where grain was dear and poor relief – and early form

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of welfare support – was limited. Nutritional shortages had a non-linear effect on numeracy: Severe shortages impaired numeracy more. Nutrition during childhood also mattered for labor market outcomes -- individuals born in periods or countries with low numeracy typically worked in occupations with lower earnings.

Keywords: nutrition, cognitive development, age heaping, numeracy, occupational choice, Industrial Revolution, social spending, poverty traps, effects of war.

JEL: O11, O15, N33, I28

I. Introduction

In both developing countries and the developed world, there is substantial evidence that poor nutrition in early childhood has a negative effect on physical and mental health later in life, on educational attainment, and on labor market success. Medical research using controlled experiments and twin studies suggests that sudden shocks to nutrient availability have marked effects (Richards et al. 2002, Lucas 1998). Randomized control experiments in the developing world and quasi-random variations in nutrition amongst Muslims in developed countries point in the same direction (Vermeersch and Kremer 2004, Almond and Mazumder 2011, Currie 2009).

At the same time, evidence in favor of aggregate shocks having a major effect is surprisingly rare. While disease outbreaks can have strongly adverse consequences (Almond 2006), economic dislocation has rarely been shown to affect cognitive and health outcomes in a consistent fashion. Not even the "dust bowl" seems to have affected heights, chronic disease, or body mass (Cutler, Miller, and Norton 2007). Stein and Susser (1976) examined the Dutch hunger winter in 1944-45. Retreating German forces left part of the population starving for 5-6 months. Those affected in utero or just born showed no systematic reduction of cognitive ability later in life, perhaps because the insult could be compensated shortly thereafter.[1] In contrast, studies of Zimbabwe and China have found some negative consequences of civil war and famine (Alderman et al. 2006, Chen and Zhou 2007). The disconnect between micro-studies and examinations in the aggregate is an important puzzle.

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[1] This is despite reductions in birth weight (Stein and Susser 1976). At the same time, there is evidence that the cohorts affected suffered from greater incidence of heart disease and personality disorders (Neugebauer, Hoek and Susser 1999).

In this paper, we examine the decline in cognitive ability during a nation-wide quasi-experiment: The Napoleonic wars led to a nutritional crisis in England. A combination of a stop to imports from the Continent and poor harvests led to markedly higher grain prices in some years. Amongst Englishmen born after 1790, numeracy declined sharply. We derive a measure of cognitive ability by constructing a new dataset on misreported ages in England, 1780-1850, based on census data, and analyze differences-in-differences. As grain prices rose by up to 100% after 1790, the number of wrongly reported ages doubled. The decline in numeracy also differed by region. England had an early and generous form of poor relief (Mokyr 1993). Some parishes were more supportive than others. We show that income support for the poor helps to explain cross-sectional variation in cognitive skill– counties with generous payments saw the smallest declines in numeracy when prices were high. Price spikes had adverse effects that increased exponentially; they were also greater in areas of economic vulnerability.

We use data on age heaping – the number of people who wrongly report their age as a multiple of five in the census – to construct a simple measure of cognitive ability in the past. Self-reported ages often show a tendency for people to 'round off' to the nearest multiple of 5 or 10 (Mokyr 1983, Myers 1976). Age heaping can serve as a good proxy of numerical skill.[2] Today,

[2] Roman tombstones, for example, show high rates of age heaping (Duncan-Jones 1990). Gradual changes in heaping over longer periods can reflect a number of factors, such as schooling, the importance of administrative procedures relying on age, and evolving cultural norms. These factors are unlikely to explain abrupt changes over short periods. Short, sharp shocks to numeracy are more likely to reflect environmental factors.

numeracy predicts both wages and employment.[3] We show that numeracy is correlated with stature in many historical samples, and argue that this reflects the adverse effects of malnutrition on cognitive development. We also show that cognitive ability and age misreporting are positively associated amongst the elderly today.

Nutrition in the past was often poor. Average heights were low. Adult males born before 1850 often measured less than 170 cm, below the 10th percentile of the US population today.[4] Stature is a good indicator of cumulative net nutrient intake during the growing years (Steckel 1995, Komlos 1989). While short-term nutritional deficits can be compensated through so-called catch-up growth, sustained shortfalls affect terminal heights.[5]

The consequences of wide-spread stunting are less clear. Waaler (1984) demonstrated that heights and weight were good predictors of individual mortality risk. Fogel (1994) argued that low calorie intake drastically curtailed output per capita in the past. What has remained unexplored are the consequences of massive malnutrition in the past for cognitive development and educational attainment. Lack of data has so far stood in the way of such research. Standard measures of cognitive ability, such as IQ or math test scores are not available for the more distant past.

To substantiate the link with nutrition, we connect age heaping with evidence on stature. Numeracy – as captured by age-heaping – in part reflects the influence of nutrition; it fell the most in those counties that witnessed the biggest declines in height. Finally, we show that those affected

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[3] Rivera-Batiz (1992).

[4] This is the average height of 18th century Dutchmen and Norwegians, who today are amongst the tallest populations on earth (Fogel 1994).

[5] Because Europeans' genetic composition has changed little in the last two centuries, historic heights must reflect severe chronic malnutrition in the more distant past

by the food crisis of the Napoleonic years – and especially those born in counties with limited poor relief – were more likely to sort into occupations with lower wages. Thus, malnutrition in the past directly led to limited cognitive development, resulting in poor labor market outcomes.

Related literature includes work on nutrition and cognitive development, which suggests that nutrient intake in utero and in childhood affects intelligence directly. Our conclusions are in line with research showing that nutritional status is correlated with cognitive ability and labor market success. Persico, Postlewaite and Silverman (2004) showed that heights have considerable explanatory power for wages, and attribute the effect to differential socialization (through more active participation in school sports teams, etc.). Case and Paxson (2008) instead argue that the effect largely reflects the superior cognitive scores of the taller and better-nourished.[6] We discuss this literature in more detail in Section II.

Compared to earlier studies, this paper makes a number of contributions. We are the first to document a strong negative effect of an aggregate economic shock on numeracy. We also show that, in 18th century Britain already, early welfare systems could mitigate the impact of 'hard times'. Finally, we demonstrate that wartime shocks to nutritional status in childhood had negative consequences for labor market outcomes many decades later.

Our results build on recent anthropometric research that has sought to measure nutrition in the past, mainly based on heights (Steckel 1995, Fogel 1994). Other related research includes work on human capital formation in industrializing Britain (Mitch 1998, Schofield 1973). Finally, our findings have an indirect bearing on research into the origins of accelerating growth after 1850.

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[6] Komlos (1989) argued that nutrition mattered at the opposite end of the skill spectrum as well. He observed that many innovators of the Industrial Revolution in the UK were born during the good times of the 1730s, when food prices were low.

One class of unified growth models (Galor and Weil 2000) has aimed to join human-capital based interpretations with models of fertility choice. In this class of models, more investment in the skill of the workforce was crucial for the transition to self-sustaining growth. While we do not examine these arguments directly, we document how nutrition constrained a key dimension of pre-modern human capital – numeracy.

Section II reviews the literature on the link between IQ, malnutrition, and labor market performance. Section III describes our preferred measure of numeracy based on age heaping, and Section IV discusses the data we use. Our results are presented in Section V. In Section VI, we discuss our results in context, and Section VII concludes.

II. Nutrition, cognitive ability and occupational outcomes

In this section, we briefly review the literature linking nutrition, cognition, educational attainment, and labor market outcomes. There is strong evidence that childhood health and nutrition matter for cognitive ability, education, and success in the labor market later in life. Experiments suggest that nutrition in childhood influences intellectual ability. Low birth weight in humans predicts lower cognitive scores (Richards et al. 2002).[7] Malnutrition between ages of 1 to 16 months is a strong predictor of poor cognitive outcomes (Lloyd-Still 1976). In one study of preterm infants, the protein content of the diet was varied on a random basis (Lucas 1998). Children receiving poorer diets showed markedly lower mental development scores and psychomotor scores at the 18 month follow up than the control group. These effects could still be detected as late as at age 7.5, when

[7] Currie and Hyson (1999) demonstrate that low birth weight is associated in British post-WW II data with lower employment probability, lower IQ scores, and lower income. Case, Fertig, and Paxson (2005) show that this effect is still visible for subjects at age 42.

IQ scores were significantly lower. Vermeersch and Kremer (2004) show that a protein enriched diet given to pre-school children in Kenya improved both participation in educational activities as well as cognitive scores in schools with experienced teachers. In addition, poor in utero conditions, as reflected by low birth weight, are systematically associated with a greater risk of mental disease (Linnet et al. 2006).

The positive correlation of heights and cognitive scores also suggests that malnutrition can adversely affect intellectual development. Just like heights, intelligence of individuals is in part determined by parental genes and partly by environmental factors. Paxson and Schady (2007) find that, in a large sample from Ecuador, test scores for shorter children are significantly lower than for taller ones. Richards et al. (2002) use data on IQ scores and height for a large British post-war sample, and find that the variables are strongly and positively correlated. In particular, maximum height gain during early childhood and the timing of the adolescent growth spurt predict cognitive ability. There is also some evidence that rising IQ scores in developed countries reflect improving nutrition (Lynn and Vanhanen 2002).[8] Genetic factors do not dominate: Twin studies suggest that genetic influences cannot explain the correlation between heights and cognitive ability (Magnusson, Rasmussen, and Gyllensten 2006).[9]

While sensitivity is great in utero and in early childhood (Heckman 2007), nutrition during the second decade of life also appears to have a major effect. Recent studies found a clear cumulative effect of persistent exposure to malnutrition and poverty. The longer a child's

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[8] A randomized experiment in Guatemala demonstrates that protein supplements can produce marked improvements in cognitive ability (Pollitt et al. 1993).

[9] Sunder et al. (2005) argue that height and intelligence may be jointly determined by parental genes, and argue that this accounts for approximately 30% of the observed comovement.

nutritional, emotional and educational needs are not satisfied, the greater his or her cognitive deficits (Paxson and Schady 2007). There also appears to be little ‘catch-up’ in cognitive scores: The effects of a disadvantageous early environment still appear into late middle age and beyond (Abbott et al. (1998), Richards et al. (2002), and Richards and Wadsworth (2004)).

Cognitive ability also has an effect on labor market outcomes. Zax and Rees (2002) show that intelligent members of the workforce earn substantially more. Heckman (1995) finds IQ to be one important predictor of wages. Using British post-WWII data, Case and Paxson (2008) show that the correlation between height and earnings disappears when one controls for cognitive scores. This suggests that much of the observed association of stature with earnings may simply reflect the effect of nutrition on intellectual development. [10]

A large literature demonstrates childhood nutrition matters for cognitive ability, education, and success in the labor market in later life. We now turn to documenting these links for the case of industrializing Britain.

III. Numeracy

Age heaping has been used as an indicator of numeracy in a number of studies. Bachi (1951) and Myers (1976) show that across countries and within them, richer, more educated populations are less prone to show age heaping. Historical applications include the work of Herlihy and Klapisch-Zuber (1978) on fourteenth century Florence, Mokyr (1983) on selectivity bias among Irish emigrants, and Duncan-Jones (1990) on the Roman Empire. Over the very long run, numeracy as

[10] An additional channel through which nutrition matters for labor market outcomes is schooling. Worm eradication in Kenya increased school attendance markedly while leaving test scores unaffected (Miguel and Kremer 2004).

proxied by age heaping varies strongly with income, and is highly correlated with literacy (Clark 2007, A'Hearn, Baten and Crayen 2009).

The most commonly used measure of age heaping is the Whipple index.[11] It calculates the number of self-reported ages that are multiples of 5, relative to the number expected with a uniform distribution of ages:

$$W = 100 \frac{\sum (n_{25} + n_{30} + n_{35} ... n_{60})}{\frac{1}{5} \sum_{i=23}^{62} n_i} \qquad (1)$$

The range of ages has to be chosen so as to include the same number of ages for each terminal digit (in this case, 23 to 62). The index ranges from 0 to 500. Accordingly, a Whipple Index of 0 (500) implies no (only) ages ending in multiples of 5. At 100, it would imply that exactly 20% of the population report ages ending in multiples of 5, the expected frequency in a population without heaping.

We use the age statements of the censuses of 1851 and 1881 and organize those by birth decade and birth county, because basic numeracy is mostly determined in the first decade of life (details in Appendix A). **Fehler! Verweisquelle konnte nicht gefunden werden.** illustrates the phenomenon by plotting the age distribution in two English counties, Somerset in the census year 1851 (lower panel), and Sussex in 1881 (upper panel). In Somerset, heaping was strong – the

[11] There is substantial evidence that the Whipple index dominates competing estimators like the Bachi measure, in particular in terms of accuracy at low levels of heaping. For an overview of different indicators, cf. A'Hearn, Baten, and Crayen (2009).

Whipple score is 125. In Sussex, age heaping was also present, but the ratio between the number of persons reporting a multiple of five and the expected number is considerably lower (Whipple of 109).

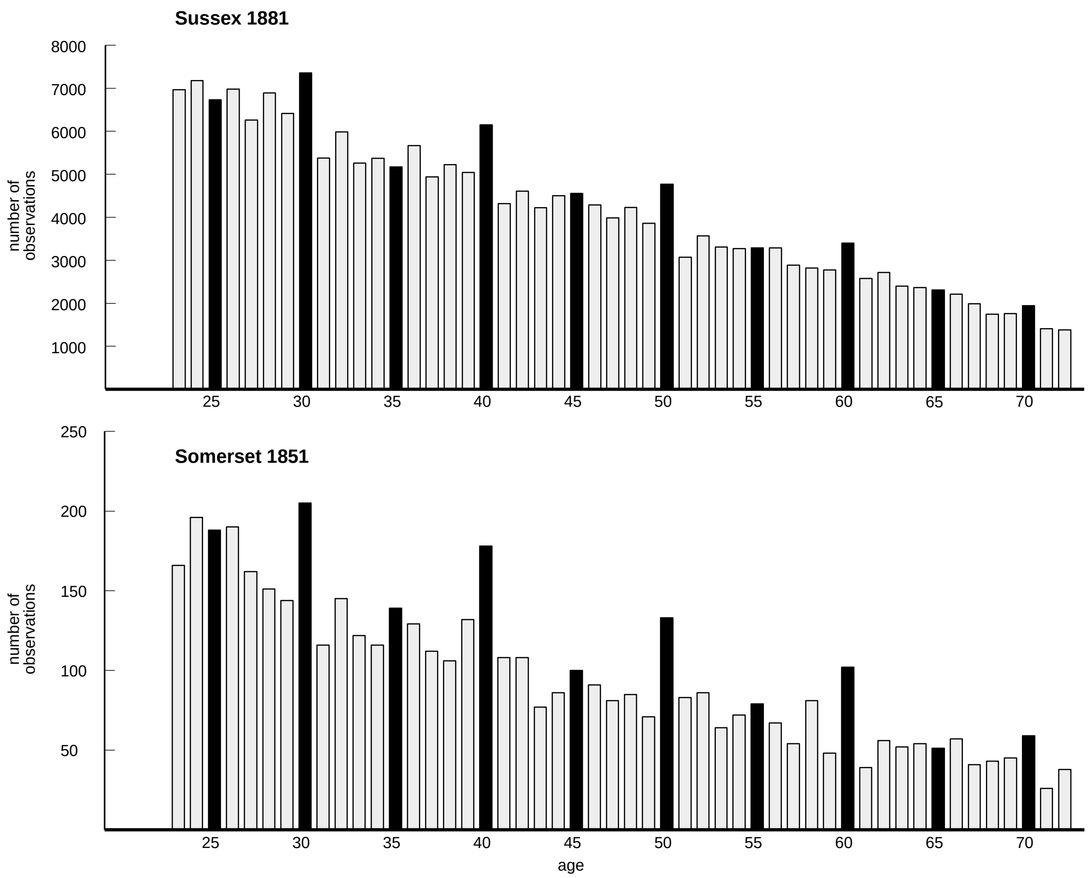

Figure 1

Age Distribution in Somerset 1851 (upper panel) and Sussex 1881 (lower panel)

That age reporting in the UK censuses was not fully accurate has been known for some time.[12] The General Report for the 1891 census argued that 'a very large proportion of persons, not improbably the greater number of adults, do not know their precise ages and only report it approximately'.[13] Various other studies have examined age recording between two or several 19th century British censuses. They found that 2 to 11 percent were 'off' by more than two years (Higgs 1989, Tillot 1972). Adjustments were as likely to be up as down, suggesting genuine mistakes.[14]

In addition, we use a measure of misreporting of ages in the spirit of the Myers index. For each county, we fit a linear trend to the distribution of reported ages. Then, for each birth year, we obtain a measure of inaccurate age-reporting as the absolute value of the residual of the regression. Both over- and underreporting age frequencies will influence the estimate of inaccuracy. While the decade-based measure of the Myers index is generally less robust as an indicator of numeracy than the decade-specific Whipple index (A'Hearn, Baten, Crayen 2009), we will use this indicator to exploit short-term variations in age misreporting.

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[12] Apart from the heading of the appropriate column in the household schedule which said 'Age [last birthday]', no general instruction was given to households how to report their age.

[13] Census 1891, p. 27. Thomson (1980) traced individuals' self-reported ages across the 1861, 1871, and 1881 censuses. He found that for both men and women, the correct age (found by adding 10 or 20 to the earlier reported age) was only given by 38 to 64 percent of respondents aged 60 and over. Up to 30 percent gave answers that were wrong by more than two years.

[14] As late as 1951, only 94 percent of men and 64 percent of women reported their ages correctly (Census 1958, p. 36).

It could be argued that the ability to recall one's age correctly is indicative of schooling, the bureaucratization of life, and changing cultural norms rather than of cognitive development. However, where it varies considerably over short periods, it is less likely to reflect cultural norms and administrative procedures. Since the use of age and birth date to identify individuals and the prevalence of schooling has generally been on the rise over the last three centuries, there is an asymmetry in how we should interpret short-term fluctuations. Increases could be driven by, say, the introduction of compulsory schooling (in the later 19th century in most European countries). Where numeracy declined sharply, on the other hand, additional factors are likely to be at work.[15]

IV. Historical Background and Data

Britain's population increased from 5.9 million in 1760 to 16.7 million in 1850, turning the country into a net importer of food. Consequently, 'food… [became] the weakest link in Britain's chain of defense' (Olson 1963). After poor harvests, grain had to be imported from the Baltic and from France (Jacks 2011). The French Revolutionary and Napoleonic wars made the flow of grain more difficult. As both sides sought to destroy the merchant fleet of their adversary, insurance rates for shipping surged (Jacks 2011; Mokyr and Savin 1976). The "Continental System" constituted a ban on all trade with Britain from French-controlled Europe (Davis and Engerman 2006). The system was at its peak in the years 1807-12. While France supplied Britain with grain in 1810, it charged export fees that more than quadrupled the price (Jacks 2007).[16]

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[15] To validate our method, in Appendix A.1, we show that in modern data from the US Health and Retirement Survey (HRS), greater heaping is strongly associated with lower cognitive scores.

[16] According to some estimates, the UK imported around 15% of its total food in 1810 (Jacks 2007).

The difficulty of importing food came at a bad time for Britain. Harvests were poor in 1795/96, 1800/1801 and in the late 1810s. At their peak, prices were more than twice as high as they had been in the 1780s. While some imports continued to flow into Britain, high transaction costs limited the extent to which domestic weather shocks could be arbitraged away. **Fehler! Verweisquelle konnte nicht gefunden werden.** plots the wheat price over time; it will serve as our main indicator of a nutritional crisis. The most vulnerable parts of society often did not earn wages, and depended on the informal sector or on charity. The household surveys by Sir Frederick Morton Eden (1797) and Reverend David Davies (1795) were motivated by wide-spread misery: Bread riots in 1795, 1800, and 1812 reflect how precarious Britain's food situation had become.

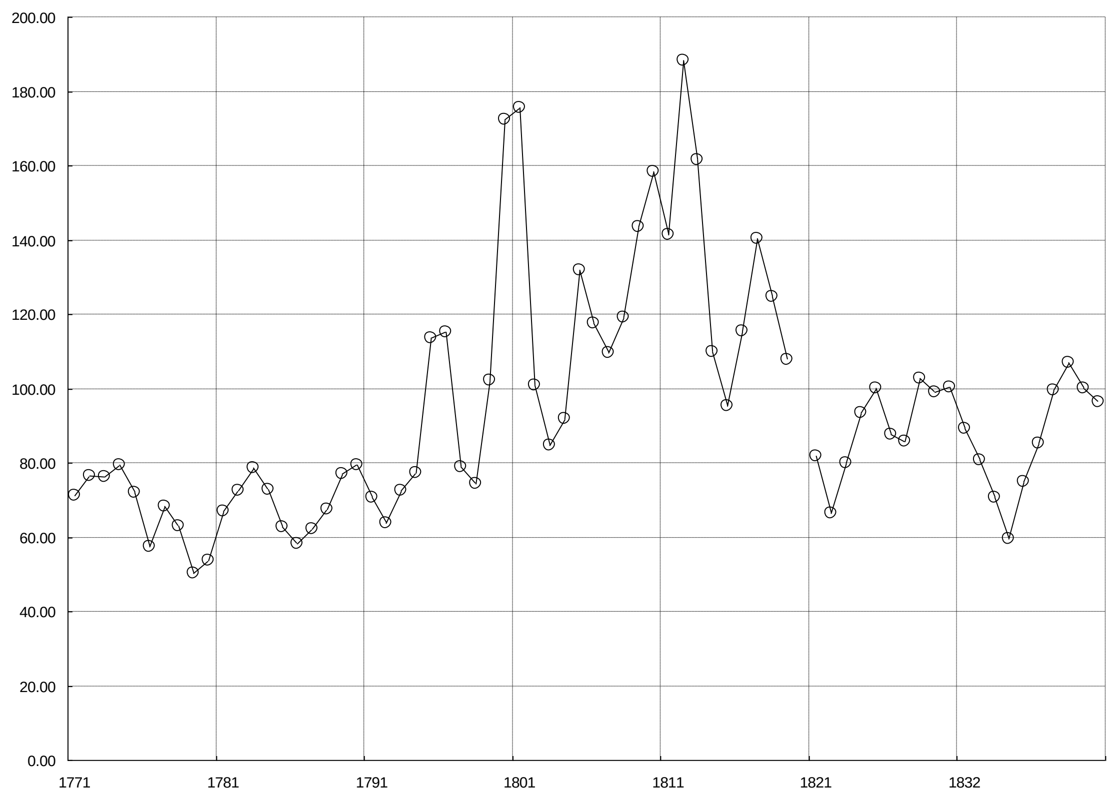

Figure 2

Grain Prices in England (1800=100)

We use the average price of wheat in each county and year as the main explanatory variable. Acts of Parliament ordered the compilation of grain price data during the period 1770 to 1863.[17] Liam Brunt and Edmund Cannon hand-collected this data from historical prize gazettes.[18] Wheat was the main staple of eighteenth and nineteenth century British diets. Wheat flour alone accounted for 27% of working class expenditure on food (Figure A1 in Appendix B).[19] Bread – mostly wheat-based – took up another 20% of the food budget. Together with oatmeal, grain-based food accounted for 60% of the food budget, or 40% of the consumer basket overall.[20]

English grain markets were highly integrated – abstracting from transport cost, the no-arbitrage condition held.[21] While market integration in general was high, price differences at the county level could still be substantial. For example, in 1794, the dearest counties had prices that

[17] 10 George III, 31 George III, 1 and 2 George IV, 9 George IV, and 5 Victoria

[18] The authors kindly made their data available to us as county-year averages. The source is described in more detail in Brunt and Cannon (2013). The data can be accessed at the ESRC data archive (http://dx.doi.org/10.5255/UKDA-SN-4383-1).

[19] The figure is from Voth (2003).

[20] To gauge the importance of wheat in particular, and grain more generally, we also have to add part of the 10% spent on drink. The largest share of this would have been consumed in the form of beer, derived in large part from wheat and barley.

[21] The Brunt-Cannon data has already been used in recent studies of market integration (Jacks 2011), which show how during the Napoleonic wars, regional price differences increased (as a result of attacks on coastal shipping etc.).

were 27% higher than in the cheapest ones; in 1800, the gap was 40%. This reflects the decline in market integration during the Napoleonic Wars (Jacks 2011). As maps of grain prices in England (Figure 3) show, the relative position of individual counties could also reverse quickly, with some of the cheaper areas in 1794 experiencing much higher prices in both relative and absolute terms in 1800. Coastal areas in particular – such as the one around Bristol – experienced much higher prices because transport had become so much more difficult (Jacks 2011).[22]

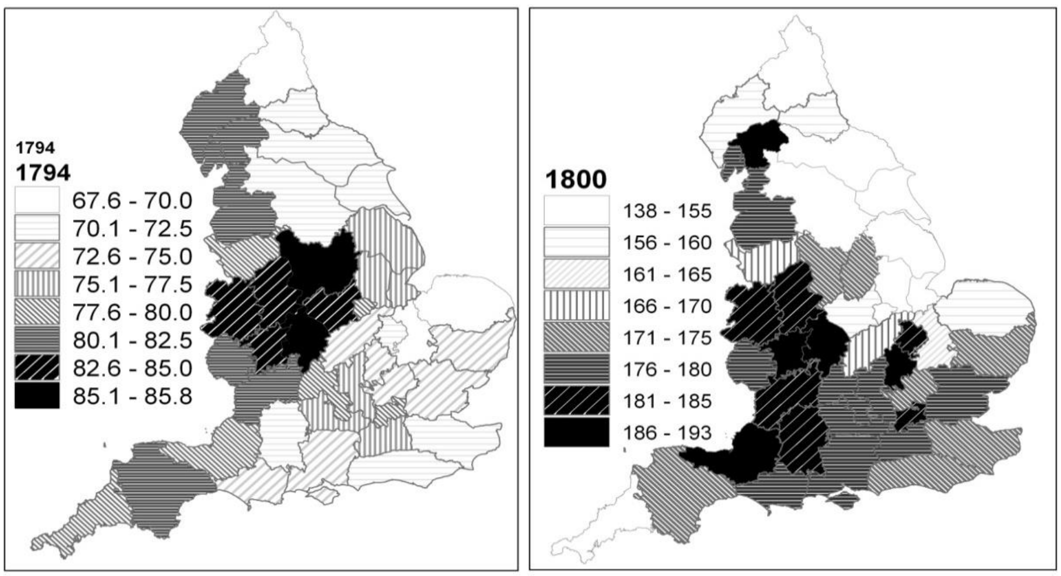

Figure 3

Wheat Price Variation in England, By County, 1794 and 1800

[22] Otherwise, the map displays typical regional price patterns: prices were higher near manufacturing centres (for example, Lancashire), which could not be as easily served by cheap water transport. In contrast, the London market in 1794 benefited from cheap coastal transport. Grain prices were also higher in regions specializing on dairy farming (i.e., the English West)..

(in pence per bushel)

Figure 4 shows the distribution of county grain prices by year, using a box-and-whiskers plot. The lower and upper parts of the box indicate the 25th and 75th percentiles, respectively; the "whiskers" show the rest of the distribution, i.e. the 0th and 100th percentile. In most years, the range of prices is relatively small. The pairwise correlation coefficients of wheat prices are very high – typically 0.97 or above (cf Appendix E). However, in some years – especially in years of high grain prices – the range is dramatically wider. This is important for our study – it shows that years of nutritional crisis also coincided with lower market integration, and greater region-specific shocks.

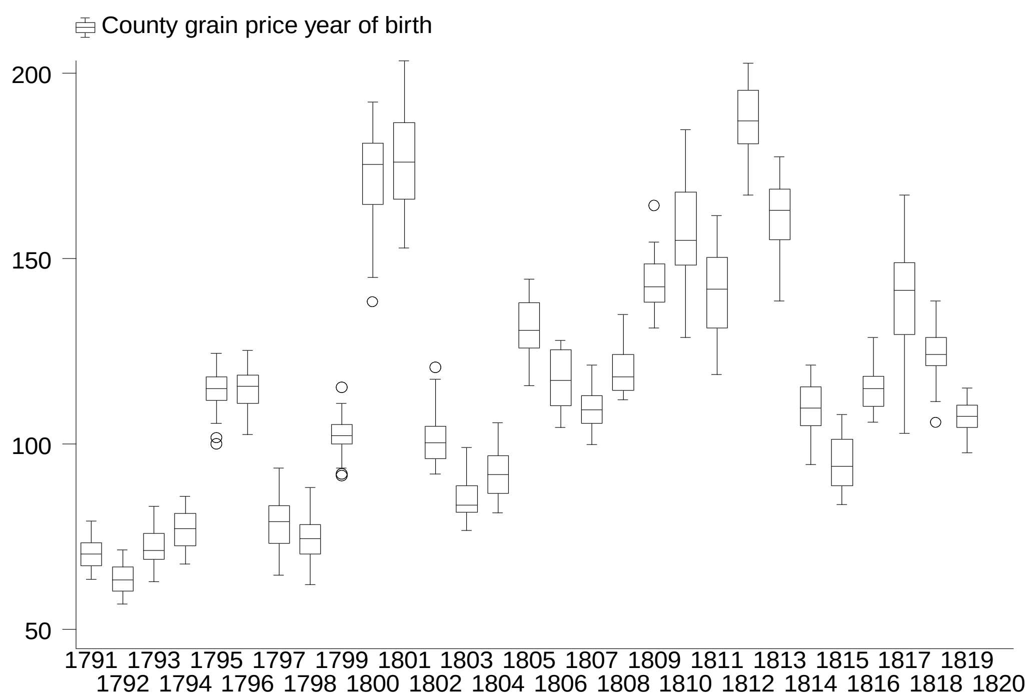

Figure 4

Range of Wheat Prices, Across Counties, by Year of Birth

(in pence per bushel)

We merge our new dataset on numeracy with information on the generosity of poor relief under the so-called "Old Poor Law", and on heights.[23] Britain was one of the first countries to make support payments for able-bodied adults (outside a workhouse). The system was generous: An agricultural laborer could expect to earn 22-35 shillings a year; relief expenditures per recipient ranged from 7 to 19 shillings (Boyer 1990). Overall, the system cost as much as two percent of GDP (Mokyr 1993). Generosity was determined at the parish level, and funding was raised locally.[24] We use Boyer's (1990) data on relief under Old Poor Law, supplemented by additional data from his original source.[25]

V. Empirical Results

In this section, we first demonstrate that across a wide range of samples, from different time periods, countries, and social groups, the tall are also more numerate. We then document that numeracy fell precipitously among cohorts born in industrializing England when grain prices surged as a result of the Napoleonic Wars. We do so using the Whipple index for our baseline estimation. Declines in numeracy were particularly pronounced in counties where (i) grain prices were particularly high (ii) income support for the poor was less generous.

Next, we exploit short-term variation, using a variation of the Myers index of age heaping.

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[23] Appendix A details the data sources for Poor Law relief and British heights.

[24] Economic factors partly explain differences in generosity. Some regions had much greater incentives than others to retain a large number of able-bodied poor to help with the harvest. In the empirical analysis, we will control for these factors separately (Boyer 1986).

[25] Table A2 in the Appendix contains the data descriptives for our key variables.

We show that there are important non-linearities in the effect of high grain prices on numeracy. In addition, we demonstrate that nutritional status, as proxied by English height, is correlated with numeracy. The part of the variation in heights in our sample driven by grain price shocks predicts age heaping to a significant extent. This strengthens the case for nutritional shortages harming cognitive development. Did any of these effects matter for labor market outcomes? This is the question we address in the final section, where we demonstrate that the malnourished sorted into occupations with lower earnings.[26]

First, we turn to the basic link with nutrition, and examine heights. These capture cumulative nutritional status since childhood (Floud, Wachter, and Gregory 1990). Well-nourished individuals stand a better chance to reach their genetic potential in terms of height. In Table 1, we present data from the US, France, Ireland, and the UK (Wandsworth prison), from the 1660s to the 1840s. The samples are divided into 'tall' and 'short', according to whether individuals' heights are above or below the median. We then calculate Whipple indices for both groups. Throughout, the tall are less likely to misreport their age. In some cases – such as the data from Wandsworth prison– the difference is small. In other cases, such as the Irish prisoners sent to Australia, and French Army recruits from Paris, the differences are marked, with Whipple indices that are 20-40 percent higher for the shorter group than for the taller one.[27] Since the samples are drawn from relatively homogenous backgrounds, this strengthens the *prima facie* case in favor of a link

[26] A large number of factors unrelated to cognitive ability – such as schooling, changing cultural norms, and bureaucratization – has the potential to influence age-awareness.

[27] In a logit regression (with the dependent variable equal to unity if no rounded age is reported) on a dummy variable "taller than average", we obtain a significant coefficient (Table 1, Col. 7).

between nutrition and our indicator of cognitive ability, age heaping.[28]

Table 1: Stature and Whipple Ratios

Country/Region	Birth Decade	Average Height		Whipple Index		P-value Logit
		Short	Tall	Short	Tall	
England (Wandsworth Prison)	1800-1840	62.65	67.11	133	129	0.764
Ireland (deportees)	1790-1810	63.65	67.71	160	131	0.004
US (recruits)	1800-1830	65.76	69.81	126	114	0.021
France –Paris (recruits)	1660-1760	61.50	64.06	145	102	0.000
France –northeast (recruits)	1660-1760	61.97	64.60	126	121	0.212
France –southwest (recruits)	1660-1760	61.39	63.94	142	123	0.000
France-total	1660-1760	61.51	64.08	135	123	0.000

Source: Various sources as cited in Crayen and Baten (2010). ‘P-value Logit’ is the test of significance from logit regressions with the dependent binary variable ‘does not provide a round age’ on the dummy variable ‘taller than average’.

[28] In his analysis of nineteenth century Bavaria conscripts, Schuster (2005) finds that individuals with exceptionally low intelligence were heavily concentrated amongst the shortest recruits.

Baseline results

Did years of high prices affect numeracy? **Fehler! Verweisquelle konnte nicht gefunden werden.** 5 plots the median Whipple indices over time. After the outbreak of the Napoleonic wars, Whipple indices rose sharply. Starting from very low levels in the 1780s, median scores reach their highs for the sample in the 1790s and 1800s – 125 to 130. The rise in Whipple scores is apparent in counties with both above and below-average levels of poor relief, but counties with limited relief show a greater and more sustained rise. There, Whipple scores stayed elevated in the 1800s, while they were already declining in the more generous counties. While not conclusive proof that the poor in parishes with low income support suffered worse declines in nutritional status, harming children's cognitive development, the pattern in the cross-section and over time is consistent with such an interpretation.

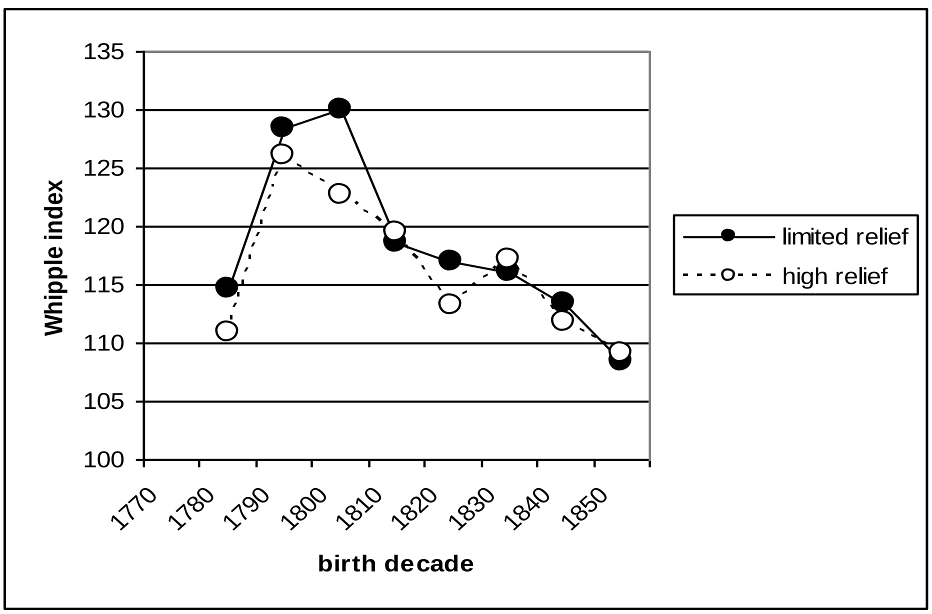

Figure 5

Median Whipple Indices over Time, by Generosity of Poor Relief

Next, we examine these patterns econometrically. We estimate

$$W_{i,t} = a + \phi S_{i,t} + \beta G_{i,t} + \gamma X'_{i,t} + \varepsilon \qquad (2)$$

where $W_{i,t}$ is the Whipple index for county i at time t, *a* is the intercept (which is county-specific in some of our specifications), S is an indicator variable for the gender of the individuals in each group, $G_{i,t}$ is the grain price in county i at time t, and X' is a vector of controls (including for a dummy variable for the census year from which the age information is drawn.

Table 2: Pooled Regression Analysis: Whipple Scores and Grain Prices (Whipple index as dependent variable)

regression	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
estimation method	OLS	OLS	OLS	OLS	Quantile	OLS	OLS	Quantile	Quantile
county grain price	0.107***	0.115***	0.127***		0.120***	0.067***	0.078***	0.082***	0.096**
	(4.98)	(4.86)	(5.59)		(4.28)	(3.35)	(4.14)	(3.66)	(2.92)
female	-1.333	-1.309	-1.300	-1.402	0.100	-0.630	-0.604	-0.503	0.062
	(-1.63)	(-1.59)	(-1.55)	(-1.70)	(0.09)	(-0.87)	(-0.81)	(-0.54)	(0.05)
reliefhigh		-2.517**				-1.963*			
		(-2.15)				(-1.96)			
relieflack			5.118***	4.549***	3.551*		4.732**	3.834**	7.550**
			(3.25)	(2.79)	(1.86)		(3.40)	(2.55)	(2.67)
national grain price				0.106***					
				(4.20)					

Interaction country grain									0.058***
price x vulnerability									(2.62)
Vulnerability									-16.55
									(-1.54)
Constant	108.4***	108.7***	99.68***	102.6***	99.63***	115.4***	107.3***	103.3***	103.0***
	(52.02)	(47.44)	(32.19)	(28.97)	(23.03)	(59.59)	(38.98)	(30.20)	(12.16)
Census fixed effects	N	N	N	N	N	Y	Y	Y	N
N	309	309	302	310	302	372	365	365	302
Adjusted R^2	0.065	0.084	0.098	0.069		0.177	0.197		

t-statistics based on standard errors clustered at the country level, in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Definitions: the dependent variable is the Whipple score by birth county, gender and birth decade (running from 1779-88, 1789-1808 etc. to 1849-58). We use the national two per cent sample of the 1851 British census, created by Michael Anderson (1987). The data are available at http://www.data-archive.ac.uk/, and more recently, and in standardized form, from North Atlantic Population Project and Minnesota Population Center. NAPP: Complete Count Microdata. NAPP Version 2.0 [computer files]. Minneapolis, MN: Minnesota Population Center [distributor], 2013. Download March 11th, 2013 [http://www.nappdata.org]. Kevin Schurer and Matthew Woollard (2002) produced the five per cent national sample of the 1881 British Census. Main explanatory

variables (sources in text and appendix) are the grain price by county and year for the same years; 'Female' is a dummy that equals 1 if the observation refers to the females in a county and birth decade. Relief (another dummy) = 1, if relief payments in a county and decade are above average. Relieflack is [R_{max} – R_i], where R_{max} is the maximum relief payment per capita and R_i is the relief payment in county i. National grain price is the average of all county grain prices by decade.

Table 2 shows OLS and quantile regressions, with the Whipple index by birth decade, gender and county as the dependent variable. Wheat prices by the same decades and counties, and relief generosity serve as explanatory variables. Higher grain prices are consistently and strongly associated with greater age heaping in our sample. On average, a one standard deviation increase in county wheat prices is associated with a Whipple index that was higher by 2 – 2.5 points (regressions 1 - 3).[29] Counties with generous relief (above the median of payments per capita) had Whipple scores that were lower by 2.5 points (reg. 2). Instead of the simple dichotomous variable that codes counties as generous or not, in regressions 3-5, we use a continuous transformation of the poor relief variable. This allows us to test if numeracy was consistently lower in those parishes where relief payments were smaller. We define relieflack as [R_{max}-R_i], where R_{max} is the highest relief payment per capita recorded in any county, and R_i is the relief payment in county *i*. It therefore captures the difference in relief payments in any one county relative to the most generous one (Sussex in 1810) in our sample. We find that lack of poor relief consistently and strongly predicts higher Whipple scores. The continuous measure of poor relief generosity does not undermine the size and significance of the grain price variable. The effect was big. According to our results, the average county in our sample – with a relieflack measure of 1.34 – had Whipple scores that were 6-7 points higher than the most generous ones.

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[29] Because our data is highly aggregated, the true effects must be substantially larger. Below, we show that even for these point estimates, the income and labor market effects of the grain price on cognitive ability relationship are substantial.

In reg. (4), we also use the national grain price index instead of the county one, which yields very similar results.[30]

Regression (5) uses a quantile regression, which minimizes the mean absolute deviations instead of the square of deviations. The influence of outliers is thus reduced. We still find similar effects for county grain prices and relieflack, evaluated at the median. We also explore responses across the range of the dependent variable. Figure A3 in Appendix B plots the coefficients for relieflack and county grain price, for different points in the distribution of the dependent variable (Whipple score). In both cases, as we examine higher and higher conditional percentiles, the effect of the explanatory variables rises. At the 80th percentile, for example, a one standard deviation increase in relieflack goes hand-in-hand with a Whipple that is 3 points higher (vs. 1 at the median). Similarly, at the 80th percentile, a one standard deviation rise in the grain prices pushes up the Whipple by 3.5 (which accounts for about 40 percent of the standard deviation of the Whipple Index, see Table A1 in Appendix A); at the median, the effect is 2.4. In regressions 6-8, we disaggregate not only by country, birth decade and gender, but also by census year. This allows us to include a census fixed effect. The number of observations is slightly larger than in regressions 1-5, whereas the number of underlying age reports that could be employed to calculate Whipple scores was smaller; this increases

[30] All standard errors are clustered at the county level. One strategy applied here to reduce potential problems of endogeneity is to use the national grain price, as the national price is less likely to be endogenously influenced by county-specific developments. However, as the impact of price shocks is pre-determined at the time age-heaping is observed, endogeneity is probably not an important issue here. The working paper version contains IV-evidence which reinforces this conclusion.

measurement error. Including the census fixed effect does not affect the results, compared with regressions 2, 3, 5: The grain price coefficient is only slightly smaller.

The evidence in Table 2 suffers from one important drawback – possible bias from unobserved heterogeneity and the effects of year-specific, unobserved economic shocks. Panel estimation at the county level and time fixed-effects can help to overcome the pitfalls of cross-sectional analysis (Table A3 in Appendix B). Several of our exogenous variables do not vary over time, and cannot be used at the same time as fixed effects. Results for panel fixed effects estimation are presented in Table A3 in Appendix B. The $\hat{\beta}$'s in the fixed effects regressions are broadly similar to the OLS results, and suggest a rise of 7.5 Whipple points for every standard deviation increase of county grain prices. Without decade fixed effects, the grain price coefficients is smaller (final column). Panel models with time fixed effects are preferable because they capture unobserved decade-specific effects. Results are unaffected if we use county-specific controls (5), such as population density, whether an area is grain-growing, and the presence of cottage shop manufacturing. These additional variables are only available for the Southern counties in our dataset; the number of observations declines when we use them. Additional labor market opportunities (cottage shop industry) had no clear-cut effect on numeracy. The same is true of living in a grain-growing area. "Wealth" is the average value of real estate per capita (Boyer 1990). It is associated with higher Whipple scores.

Columns 3 - 5 show panel regression results, using poor relief as an additional explanatory variable. We find strongly positive results for the lack of poor relief if we use time dummies. If we use time and county dummies, we obtain a wrongly signed and insignificant result for relieflack. In estimating the effect of relieflack, all the important identifying variation is captured by the time and county dummies. In regression (5), we use additional controls for county characteristics. In this specification, the coefficient on relieflack is large, positive and significant. Importantly, the significance of the coefficient for grain prices is never affected.

High-frequency analysis and the effect of non-linearities

If our premise is right that nutritional shocks impede cognitive development and undermine the acquisition of numeracy, then this should matter most in years of extreme shortfalls. To examine this further, we first use an additional indicator designed to capture short-term changes in age misreporting. Second, we construct a measure of economic vulnerability from county characteristics, and show that in counties with more vulnerable individuals, nutritional shocks mattered a great deal more.

To conduct high-frequency analysis, we use an adaptation of the Myers index, which calculates deviations from an expected age distribution. Typically used on a decade basis, it can be applied to individual birth years: For each county, we fit a linear trend to the distribution of reported ages. Then, for each birth year, we use the absolute value of the residual as a measure of age-misreporting. Values range from 0 to 45, while the decade-based Whipple index varies from circa 100 to around 135. Next, we analyze how nutritional shocks influenced this measure of numeracy.

Figure A4 in Appendix B gives an overview of the variable's short-term movements, and how they correlate with national grain prices. We plot the residual of the age-distribution regressions alongside the grain prices. The correlation is not perfect, but the large spikes largely coincide. The crisis year of 1800/1801, in particular, shows a high degree of co-movement, and the sequence of bad harvests from 1810-12 also coincides with a major jump in age misreporting. In figure A5 in Appendix B, we show how this effect unfolded in the cross-section, at the height of the crisis in 1800: Wherever grain prices were unusually high, the error rate implicit in our residual variable is markedly greater, too.

Next, we examine the extent to which this co-movement in the aggregate is statistically significant. To exploit the high-frequency variation in the new short-term dependent variable (also called 'residual variable' below), we now perform regression analysis along the lines of that conducted earlier with the Whipple index (Table 3). A naïve regression (without country fixed effects) of the residual variable on county-specific grain prices yields a large and significant coefficient. When we add a variable for unusually high grain prices (in the top quintile of prices, Col. 2), this is also associated with an additional increase in the error rate of age reporting amongst respondents. In column (3), we explore the potential for a non-linear relationship further, by introducing a quadratic term (country grain price – squared). As the predicted values (Figure A7 in Appendix D) show, the net effect of higher grain prices turns positive (i.e., detrimental) – and becomes large in exponential fashion – above grain prices of 100. In column (4), we estimate including county fixed effects, and again obtain a large and significant coefficient. When using county-specific characteristics (column 5), we again find the same effect. As a general consequence of high grain prices, areas with substantial grain production saw a bigger rise in the number of incorrectly reported ages.

Table 3: High Frequency Analysis: Grain Prices and Incorrect Age Reporting (dependent variable: Residual variable)

	(1)	(2)	(3)	(4)	(5)
county grain price	0.090***	0.050**	-0.599***	0.072***	0.094***
	(5.07)	(2.00)	(-6.80)	(4.27)	(4.06)
female	-0.009	-0.005	-0.005	-0.006	-0.001
	(-0.61)	(-0.35)	(-0.35)	(-0.42)	(-0.05)
relieflack	0.026*				
	(1.88)				
extremely high grain		0.041*			
price		(1.77)			

county grain price^2			0.694***		
			(7.48)		
grain					0.102***
					(4.62)
density					0.029
					(1.22)
cottage industry					0.100***
					(5.08)
county FE	N	N	N	Y	N
N	4180	4290	4290	4290	2317
Adjusted R^2	0.008	0.008	0.022	0.065	0.022

Standardized beta coefficients; *t* statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

To examine the issue of non-linearities further, we do two things. First, we run a quantile regression with county grain prices (at the year of birth), a dummy for female respondents, and relieflack as explanatory variables. We then plot the size of the coefficient on grain prices and relieflack for every percentile of the distribution of reporting errors. The results are summarized in Figure A6 in Appendix B. At the lower end of the misreporting distribution, the effect of both relieflack and of county grain prices is small and statistically insignificant. However, the bigger the reporting errors, the stronger is the influence of the two variables that capture “hard times” in our data.

Second, in Appendix D, we examine if high grain prices *during the years of most rapid physical growth* had a disproportionate impact on numeracy. Humans go through two major growth spurts in their life – early childhood, and the teenage years. We use a standard weighting scheme (YASSIS - Yearly Average Sex and Age Specific Increase in Stature, cf. Coll 1998). If it is indeed the case that cognitive development is also most sensitive during these periods, we expect an additional effect during the second decade of life which adds to the strong effect of the first life years (Lenroot and Giedd 2006, Paxson and Schady 2007). As table A6 in Appendix D shows, there is ample evidence that grain prices, weighted to account for the speed of human development by age, have greater predictive power than grain prices in the year of birth only. Based on beta-standardized coefficients, we find that the grain price variable (with YASSIS weighting) is about 50% larger than the unweighted county grain price. In combination, these findings show that there is not only a negative effect of nutritional shortages on numeracy; the effect also increases in a non-linear fashion in years of extreme distress, for shocks that hit the same individual multiple times, and for larger shocks than normal.

Vulnerability

We now define a socio-economic measure of vulnerability, based on an income threshold. We then examine if counties in the UK containing an unusually high number of economically vulnerable people were more affected by price increases. For each respondent, we impute earnings based on the reported occupation, using information from Long (2006) and Williamson (1980, 1982). We defined a person as 'vulnerable' if he/she had less than the median income (47 shillings per year). This covers the unskilled and semiskilled working class. Bakers, butchers, farmers with their own land, and those with higher incomes were less vulnerable.

We created a dummy variable for districts with a more than average number of vulnerable persons. In Column 9 of Table 2 the interaction term has an additional and significant effect of the expected direction. This suggests that more vulnerable counties suffered more from grain price shocks. Vulnerability per se, in contrast, is insignificant.

Heights

The previous section demonstrates that individuals born in periods of high prices were, on average, less likely to remember their age correctly. The same is true if they were born in parishes where poor relief payments were limited and vulnerability was higher. One crucial element in our analysis is missing so far: evidence that it is nutrition (or the lack thereof) that drove changes in numeracy. Height is known to be a good indicator of net nutritional status between conception and age 25. We use data at the county level derived from military heights. In this subsection, we show that numeracy was systematically lower in parishes where heights declined during the period 1790-1815.

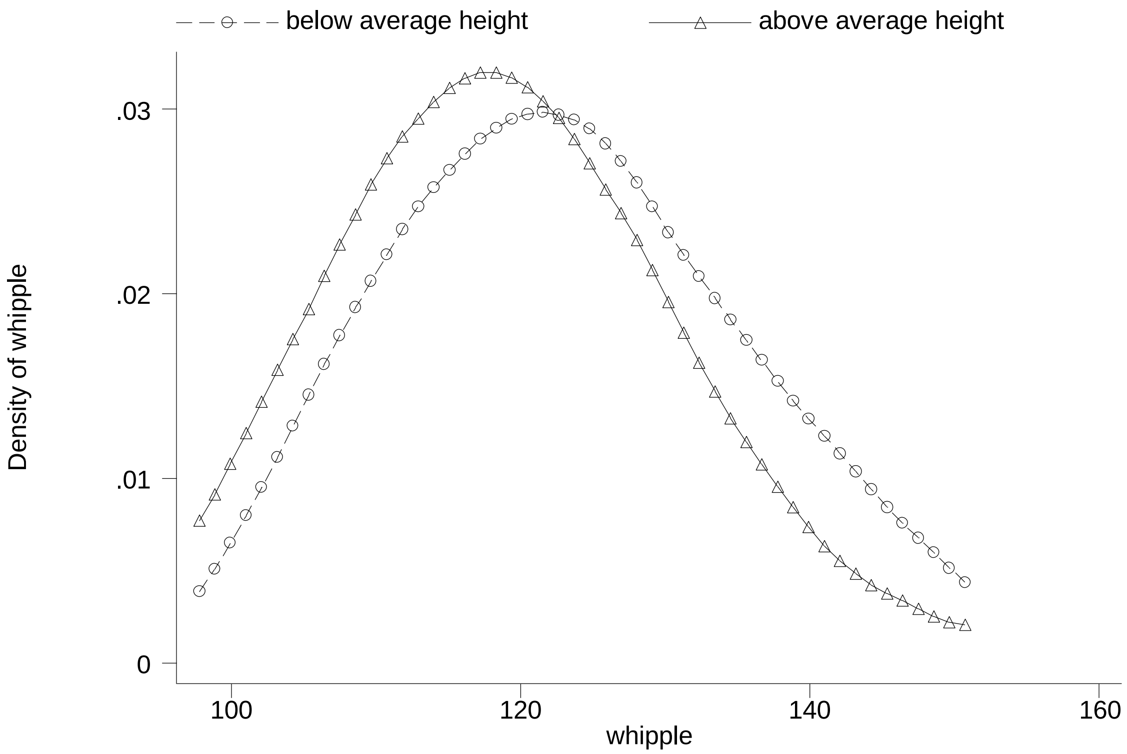

Figure 6

Kernel Density Estimates – Numeracy in Counties with Above/Below Median Heights

As a first pass, we examine the relationship graphically. Figure 6 plots the distribution of Whipple scores for two groups of counties – those with above and below average heights.

As we would expect if nutrition influenced both stature and numeracy, counties with above-average heights had lower Whipple scores. Next, we examine this relationship econometrically (Table 4). In regressions (1) – (3), greater height in county i at time t is associated with lower Whipple scores. In other words, Englishmen and –women from counties with low stature on average made more mistakes reporting their ages. The effect can be large – up to two Whipple points for a standard deviation change in heights. The effect is large and significant when we include time dummies; it falls below conventional significance levels once we include both time and county dummies.

Table 4: Heights and Numeracy (Panel Regressions; dependent variable: Whipple index)

	(1)	(2)	(3)
Height	-0.820*	-0.612*	0.025
	(-1.86)	(-1.83)	(0.07)
Constant	261.4***	220.1***	107.3
	(3.46)	(3.95)	(1.65)
Year FE	N	Y	Y
County FE	N	N	Y
N	134	134	134
Adjusted R^2	0.024	0.227	0.276

t -statistics in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

VI. Discussion

In this section, we examine the overall economic impact of war-induced lack of numeracy. We also discuss potential limitations of our argument.

Economic Impact

Did the nutritional shocks during the Revolutionary and Napoleonic Wars matter for economic outcomes? To answer this question, we examine if there were negative consequences for earnings. We use information on the occupation of each individual in the 1851 and 1881 census datafiles, and calculate imputed earnings for each birth cohort by county based on their reported occupation (Long 2006 and Williamson 1980, 1982). We regress earnings on the Whipple index, instrumented by the national and county grain prices. Table 5 shows the results. Regression 1 indicates that higher Whipple scores went hand-in-hand with lower earnings. A one standard deviation gain in the Whipple was associated with a 1.9% decline in earnings (relative to the median). Regressions 2 and 3 show that the effect is robust to including county and decade fixed effects. If we control for time and county fixed effects, a one standard deviation rise in numeracy increased earnings by 3.3%. If we use county grain prices as the instrument instead, the effect is weaker (except for regression 5); in regression 6, the coefficient becomes positive. Remarkably, the detrimental effects of the Napoleonic Wars remained visible in earnings for many decades. Overall, lower numeracy was partly responsible for translating the adverse shock of the wars into lower earnings.

Table 5: Earnings and Numeracy (IV-Panel Regressions; dependent variable: log earnings)

	(1)	(2)	(3)	(4)	(5)	(6)
Whipple	-0.0080***	-0.0073***	-0.0199***	-0.0016	-0.0065***	0.0029
	(-3.33)	(-2.72)	(-8.73)	(-0.46)	(-2.83)	(1.14)
Female	-0.461***	-0.459***	-0.463***	-0.459***	-0.459***	-0.454***
	(-17.55)	(-15.90)	(-15.75)	(-15.47)	(-15.30)	(-14.61)
Constant	5.273 ***	5.199***	6.599***	4.525***	5.107***	3.897***
	(19.24)	(17.22)	(26.66)	(11.86)	(19.90)	(12.87)
County	N	Y	Y	N	Y	Y
Year FE	N	N	Y	N	N	Y
Instrument	national gp	national gp	national gp	county gp	county gp	county gp
N	243	255	255	247	247	247

t -statistics in parentheses; standard errors clustered at the county level.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

sample restricted to counties with more than 500 observations on occupation (from which we derive earnings)

Potential Limitations

The decline in numeracy was concentrated during the Revolutionary and Napoleonic wars. We cannot completely rule out that other factors – to the extent that they are correlated with the generosity of poor relief – were responsible for our results in the cross section. Britain fought a war that required major military, fiscal, and economic mobilization. Theoretically, the absence of fathers or a decline in school attendance could also cause lower numeracy.[31] Neither is a likely explanation for this period: Few men of marriageable ages served, and the acquisition of basic skills took place outside day schools before the 1870s (Mitch 1992). Schofield (1973) found that illiteracy rates for men and women were broadly stable or gradually declining between 1750 and 1840; there is no evidence of a sudden fall in signature rates during the Napoleonic wars (Nicholas and Nicholas 1992).

VII. Conclusions

In this paper, we exploit a quasi-natural experiment: When industrializing Britain went to war with France in the 1790s, grain imports from the continent were sharply curtained for many years. Market integration within Britain declined as privateers preyed on coastal shipping. Prices for wheat and other staples surged, especially during years with poor harvests. We examine the impact of these exogenous shocks on food availability, and show that they lowered

[31] This would be in line with recent work by Miguel and Kremer (2004).

average numeracy. Our findings are amongst the first to demonstrate that large economic shocks can have deleterious effects on cognitive ability.[32]

We show that subjects born in the hungry decades of the 1790s and 1800s were much less likely to remember their age correctly, or to perform the calculation necessary to derive it without errors. The detrimental effect of high food prices (i) was particularly pronounced in those areas that did little to help the poor (ii) increased in exponential fashion (iii) was greatest in areas of economic vulnerability. We demonstrate that numeracy declined sharply where nutritional intake, as measured by average heights, declined the most. This strengthens the case for a link between nutrient availability and cognitive development, as reflected in age heaping. In addition, the food crisis of the war years also affected the careers of those in their infancy when high grain prices hit. They selected into occupations that were, on average, less demanding in terms of cognitive skills, earning less than their peers.

England operated an early and unusually comprehensive system of income support (Boyer 1990). Individuals from areas hit by particularly high prices, and without much income support, showed particularly low numeracy: The 'first welfare state' was effective in improving the lives of the poor.[33] While social disruptions during the Napoleonic Wars reduced schooling, it is more likely that lower cognitive ability, driven by poor nutrition, was the main factor behind lower numerical ability.

How relevant are our findings to other periods and countries? Englishmen and –women during the early modern period were unusually well-nourished (Fogel 1994); England is the

[32] The paper closest in spirit to ours is Alderman et al. (2006), where the effects of war are also apparent in educational outcomes and test scores.

[33] The importance of average incomes in general – and of England's income support in particular – is explored in Voigtländer and Voth (1996).

only European country where food fantasies play no role in popular fairy tales. This suggests that average nutrition was poorer elsewhere, and that shocks there would have had even more dramatic effects. It seems plausible that nutritional deficiencies constrained cognitive development for much of mankind's history.

Life in the past was not only 'nasty, brutish, and short' (in the words of Thomas Hobbes); people in the past may have been ignorant because they were often poor and hungry. Yet causation may also have flowed the other way – output may have been low because of low cognitive ability.[34] While we offer no direct proof, improved nutrition and higher cognitive ability after 1800 may well have fostered the transition to self-sustaining growth in industrializing Europe.[35]

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[34] In this way, our research complements the argument by (1994) who argued that better nutrition led to higher productivity over the last 200 years because it increased strength. Cognitive ability is a crucial factor not emphasized in his interpretation.

[35] There are also possible implications for the more recent past. Flynn (1984) showed that cognitive scores underlying IQ tests have been rising for several decades in the 20th century. Between 1930 and 1900, average cognitive ability scores rose by the equivalent of 0.6 IQ points per year (Hiscock 2007). The benefits of higher cognitive scores in the labor market today are well-known (Case and Paxson 2008). A strong link between nutrition, cognitive ability, and productivity would arguably offer an alternative explanation for the poverty of the past – one that does not have to put store in the slow rise to dominance of a population segment possessing a superior culture, as argued by Clark (2007).

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