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Agricultural Output, Calories and Living Standards in England before and during The Industrial Revolution

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AGRICULTURAL OUTPUT, CALORIES AND LIVING STANDARDS

IN ENGLAND BEFORE AND DURING THE INDUSTRIAL REVOLUTION[1]

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[1] The very helpful comments of Bruce Campbell, Hamish Maxwell-Stewart, Deborah Oxley, Peter Solar, David Stead, and Michael Turner on an earlier draft

ABSTRACT

This paper surveys the results of four recent, separate attempts at estimating agricultural output and food availability in England and Wales at points between the Middle Ages and the Industrial Revolution. It highlights their contrasting implications for trends in economic growth and nutritional status over time. It also offers some suggestions aimed at narrowing gaps between the evidence and how it has been interpreted.

KEYWORDS: agriculture, nutrition, economic growth

JEL CODES: N1, N5

AGRICULTURAL OUTPUT

Movements in living standards in England between the middle ages and the eve of the Industrial Revolution are the subject of an ongoing debate between optimists and pessimists (e.g. Clark 2007, 2010; de Vries 2008; Allen 2009; McCloskey 2010; Persson 2009a, 2009b; Hatcher 2011; Broadberry *et al*. 2011). Understandably, the debate has focused mainly on trends in real wages and GDP per capita, but the implications of other evidence such as trends in literacy, life expectancy, adult heights, hours worked, and the availability of new goods, have also featured in the discussion. The jury is still out.

The trend in English agricultural output and food availability between the medieval and industrial eras and of nutritional status before and during the Industrial Revolution has an important bearing on this debate. Food matters for material wellbeing not only as a consumption good but also as a contributor to human capital. More food today may mean yet more food tomorrow. For economic growth to occur, agriculture must generate the calorie surpluses needed to sustain an increasing and adequately fed non-agricultural labour force. When did progress in primary food production allow this to happen? How well fed were English workers on the eve of the Industrial Revolution? Estimates of agricultural output inform and influence interpretations of trends in nutrition and living standards both over the centuries and during the period of the Industrial Revolution.

1. *Four Conflicting Estimates*:

Unfortunately consensus is lacking on calorie consumption per capita in medieval and pre-industrial England. This is inevitable: calculating past agricultural output is an inexact science, and the precision of point estimates to the nearest unit of net output or their calorific equivalents is misleading. The challenge of producing reliable or plausible estimates of agricultural output in an era when key components such as crop acreages, crop and milk yields, seed ratios, carcass weights, and losses from processing and wastage are disputed is clear. Even the most careful estimates are subject to an unknown but non-negligible margin of error.

Table 1 reports four recent estimates of food supply—net agricultural value added plus net imports—measured in calories per head of population in England and Wales. The estimates by Robert Allen (2005) and Stephen Broadberry *et al*. (2011) cover the entire period under consideration since 1300, while those by Roderick Floud et *al*. (2011) and Craig Muldrew (2011) concentrate on the post-1600 period.[2] All build on a rich primary source-driven literature on English agronomics that extends all the way from the work of Arthur Young in the 1760s to that of Bruce Campbell and Mark Overton in the 1990s and of Michael Turner, John Beckett, and Bethanie Afton in the 2000s. The first two estimates remain unpublished in the traditional sense, but Allen (2005) informs important publications by the same author (e.g. Allen 2009), while Broadberry *et al*. (2011) is supported by an online database and is already being cited by other scholars. All four provide

[2]Note that while the estimates of Muldrew and Broadberry et *al*. refer to England only, those by Floud et *al*. and Allen refer to England and Wales. In 1801 0.54 million of England

estimates of calories per head for a range of dates, as well as of the shares of animal and vegetable sources in the total.

[Table 1 and Figure 1 about here]

The four estimates differ strikingly in their assessments of nutritional status (see Figure 1 and Table 1). Thus Allen (2005) reckons that calorie consumption per head was significantly higher in 1750 than in 1270, but that it decreased sharply during the Industrial Revolution, and that as a result calorie consumption was no higher in the mid-nineteenth century than in 1500AD, though not in 1300. Broadberry *et al*. (2011) tell quite a different story. They find that there was remarkably little variation and no significant sustained increase in per capita consumption over the entire period between 1300 and 1850. The gap between these two estimates is very wide except at the outset; c. 1750's Allen's estimate of calories per diem is nearly two-thirds higher than that of Broadberry *et al*. Floud *et al*. (2011) come closest to Broadberry et *al*. but their estimates, unlike the rest, envisage a rise in calorie consumption after 1800, in which the increasing contribution of imports plays a dominant role. Muldrew's estimate (2011) is by far the most optimistic of the four. His generous 'global estimates of food production' are consistent with an 'industrious' labour force that both worked hard and played hard (2011: 161). On the contrary, following Fogel (2004), Floud *et al*. (2011: 168) interpret their results as implying that a considerable percentage of the labour force was too poorly fed in the era of the Industrial Revolution to work effectively on a regular basis. They reach this conclusion by applying a plausible distribution of calories across the entire population to their estimate of mean consumption per head. It bears noting, however, that the estimates of Floud *et al*. are more generous than those reported in Fogel (2004). The former report 2,237 calories for 1750 and 2,439 calories for 1800, whereas the latter reports 2,168 and 2,237 calories, respectively (Floud *et al*. 2011: 161; Fogel 2004: 9).[3]

The four estimates also offer contrasting perspectives on the eighteenth century. While Broadberry *et al*. and Floud *et al*. envisage essentially no change in calorie consumption over the century, both Allen and Muldrew see a big increase to mid-century, followed by a big decline to 1800. But while Allen reckons that consumption declined over the century as a whole, Muldrew reckons that it rose. Finally, while Broadberry et *al*. and Floud et *al*., and to a lesser degree Allen, envisage an increase in the share of animal products in total calorie consumption during the eighteenth century, Muldrew implies that the opposite was the case. The estimates also disagree on conditions after 1800, with Floud *et al*. implying improvement in nutritional status and Allen sharp deterioration.

These remarkable differences are rather worrying since, as George Grantham (1995: 74) noted in a similar context nearly two decades ago, ‘the debate about the level of per caput consumption is… about the more fundamental issue of the long-run dynamics of agricultural supply’. Yet the four estimates do share some common ground. All agree that English consumers obtained the bulk of their calories throughout from vegetable rather than animal sources. Furthermore, the estimates generally do not differ radically in their assumptions about crop acreages and yields (Tables 2 and 3). Muldrew’s acreages in 1800 are on the high side, but his crop yield estimates tend to be lower

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[3]We use Floud et *al*.’s ‘B’ estimates, which rely in part on data derived by Turner *et al.* (2001) from farm accounts.

than the others. This suggests that most of the differences between the estimates probably stem from contrasting assumptions about the share of production devoted to value added and ending up as calories for human consumption. While it may not be possible to always determine whose assumptions are most plausible, it is still worth discovering which assumptions explain most of the differences.

[Tables 2 and 3 about here]

In what follows the main reasons for the divergent estimates are discussed first. Some historiographical implications of the estimates are then raised, and some suggestions offered as to how the estimates might be amended to fit our understanding on nutritional status and living standards before and during the Industrial Revolution.

2. *Deconstructing Agricultural Output*:

The details of how historical agricultural output estimates are constructed make dull reading, and so are usually confined to appendices and rarely consulted further. The details are also relegated to an appendix here, unfairly perhaps, because their role in underpinning competing interpretations of economic growth and living standards is fundamental. The main points are highlighted in the following paragraphs.

Tillage crops accounted for the bulk of output and calories throughout. In calculating the output of any crop requires information on acreage cultivated, net yield, and the proportion of production after seed destined for domestic human consumption. Three of the estimates agree broadly on the acreage under crops in 1750 and 1850; Muldrew's estimates are outliers in this respect (see Table 2). All four estimates exceed those generated by Michael Turner (1981) from official crop returns for 1801. The crop returns, which were gathered by the parish clergy, offer a useful cross-check on other estimates, but as Turner *et al*. (2001: 151) state, they 'may not be particularly dependable when used to assess the main parameters of agricultural production', since farmers feared that the acreages they reported might be used as the basis of extra taxation. Clearly, then, the crop returns must be regarded as lower-bound estimates of the true acreages (Hoskins 1949: 129-130; Henderson 1952: 341; Thomas 1958-60; Grigg 1967: 81).[4]

It seems appropriate to focus in particular on the estimates of output and calorie supplies in 1750 and 1800 by Muldrew and Broadberry et *al*., since these authors provide the most generous and the most conservative of the four estimates. Our examination of individual components has convinced us that significant reductions in Muldrew's suggested crop outputs in 1770 and 1800 are called for. Table 4 summarizes what we believe are highly approximate but plausible reductions to Muldrew's proposed crop totals. They entail haircuts of 500/800 calories in 1770 and 1,100 calories in 1800 to Muldrew's totals. While significant, such reductions would still leave his case for a reasonably well-fed workforce on the eve of the Industrial Revolution largely intact.

[Table 4 about here]

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[4]For example, the rector of Addle in Yorkshire noted that his return 'must, by no means, be considered as correct—as the farmers, in general, were shy and suspicious of giving any account of their crops'. Thus his statement was 'much under, and not above the real

On the other hand, we argue that some upward revisions of Broadberry *et al*.'s numbers might enhance the internal consistency of their interpretation of the growth of English productivity in the very long run. In the appendix we suggest a number of possible amendments that would revise Broadberry *et al.*'s estimates upwards. Thus, we argue that they have underestimated the contribution of rye—admittedly then a crop of rapidly diminishing importance—in mid-century; allowing it its due share would add about 300 calories to their estimate for c. 1750. Broadberry *et al*.'s estimates of meat and milk consumption also seem on the low side. There is a good case for adding about 100-150 calories to their meat numbers for both 1750 and 1800, while accepting Holderness's estimates of milk supplies rather than theirs would allow another 120 calories in 1750 and 100 calories in 1800. Adding imports of sugar and wine would add about 90 calories c. 1750 and 110 calories c. 1800. Incorporating imports of Irish meat and butter and of Scottish cattle and allowing for a higher acreage under beans and peas would mean a further 70-80 calories in 1800 and half that in 1750. Adding Floud *et al*.'s estimate of the contribution of the lard obtained from the fatty tissue of pigs would entail an extra 50 calories to Broadberry *et al.*'s total. Broadberry *et al*.'s total for potatoes in 1800, by which time 'untold acres of potatoes [were] grown in small plots or private gardens' (Turner 1801: 293-4), is also arguably on the low side. Other produce from garden plots and orchards could have been worth another 20-50 calories. Added together, such adjustments could have meant an additional 600/650 calories in mid-century and 450/500 calories c. 1800. The outcome is summarized in Table 4.

3. *Theory and History:*

Which of the estimates in Table 1 is most compatible with the empirical findings of development economics and demand theory? We follow the precedent set by Nick Crafts, who in a series of important studies on output and productivity growth before and during the Industrial Revolution (Crafts 1983, 1985) invoked modern estimates of the income and expenditure elasticities of demand for food to infer the growth of the agricultural sector relative to that of the economy as a whole. Jan De Vries (2008: 117-120) applies the same logic in his critique of Robert Fogel's 2004 estimates of calorie consumption in the eighteenth century, which he considers much too low. And Floud et *al*.'s resolution of the 'British food puzzle' identified by Gregory Clark, Michael Huberman, and Peter Lindert (1995) is in the same tradition.

What are the implications of a plausible expenditure elasticity of demand for food energy measured in calories for the competing estimates in Table 1? The answer is not straightforward as there is no consensus. Crafts (1985) and Clark *et al*. (1995: 224) based their choice of an elasticity of 0.449 on cross-section evidence on the late-eighteenth century expenditure patterns of poor households, but Floud et *al*. (2011: 97-105) generate a much lower estimate of 0.26 from the same evidence. Using modern Indian data, Shanker Subramanian and Angus Deaton (1996) reckon that the income elasticity of demand for calories at low levels of income is low but positive—about 0.45. Several subsequent case studies have also reported positive, albeit usually lower elasticities (e.g. Behrman *et al*. 1997; Thomas and Strauss 1997; Skoufias *et al*. 2011; Floud et *al*. 2011: 105; but see too Skoufias *et al*. 2009). Logan (2009), however, using historical data from nineteenth century England and the United States, reports estimates considerably higher than those reported in studies based on modern data. Logan attributes his results to living standards being much lower in the nineteenth century than they are today.

According to Broadberry *et al*. English GDP per capita trebled between c. 1260 and the mid-eighteenth century.[5] What they dub this ‘modest but positive trend growth’ is troubling for their estimates of agricultural output and average calorific intake, since even very low income elasticities are not easily reconciled with zero sustained improvement in calorie supplies over the same period (see Figure 2). Even an elasticity of, say, 0.2 would indicate a rise of three-fifths in calorie consumption per capita between the thirteenth and eighteenth centuries. This points to a potential tension between Broadberry *et al*.’s ‘optimistic’ interpretation of income growth in the very long run and their very bleak assessment of the course of calorific consumption over time. It is scarcely conceivable that energy consumption in the medieval era was much lower than the two thousand calories they assume; but a more generous estimate of agricultural output in the late eighteenth century, along the lines indicated here, would help solve the dilemma posed by their estimates as they stand.

[Figure 2 about here]

While Broadberry *et al*. describe an agricultural sector incapable, by implication, of feeding a significant proportion of the population adequately c. 1800, their data also describe a sector that was far from static in the very long run. Their calculations imply that an agricultural labour force that doubled at best

[5] The data are available at:

between 1381 and 1800 produced an increase of 270 per cent in output. And in a period often depicted as Malthusian, that increase in agricultural output comfortably outpaced the rise of 169 per cent in population over the same period. Why the significant increase in agricultural output per head was not accompanied by a rise in calories per head, given the extremely low level of calories consumed at the outset, is not clear. On the contrary, by Broadberry *et al*.'s reckoning supplies per diem in 1381 exceeded those in 1800 by nearly 300 calories.

Increased incomes should mean not only more calories, but also more meat and other animal products. An added puzzle, then, is how the rise of two-fifths in food availability per head between 1270 and 1381 (when real wages more than doubled) was linked an increase in per capita calories from 2,188 calories to 2,447 calories but a reduction in the pastoral share of the total from 19 to 16 per cent, while the 28 per cent rise food availability between 1381 and 1801 (when real wages fell by about a quarter) was linked to significant fall in per capita supplies from 2,447 calories to 2,165 calories, but in a rise in the pastoral share from 16 to 27 per cent (see Table 1).

A further complication is that Broadberry *et al*.'s current estimates imply that calorie consumption per head in England c. 1800 was roughly equivalent to that in contemporary France. Jean-Claude Toutain, a 'pessimist' insofar as agricultural productivity during the *ancien régime* is concerned, has proposed a national average of two thousand calories per head at the end of the eighteenth century. Grantham would prefer a somewhat higher total (Toutain 1995: 772; Grantham 1995: 774; see too Grantham 1993; Fogel 2004: 9). It must be said that estimates of English agricultural output in this period rest on firmer foundations than those of French output.

Broadberry *et al*.'s estimates do not tally either with contemporary English popular opinion, as represented in the cartoons of William Hogarth, James Gillray, and others, that John Bull was much better fed than Louis Baboon. More rigorously, the finding does not readily square with the common understanding that real wages in mid- and late eighteenth-century England were roughly double those in France (Allen 2001). Broadberry *et al*.'s low estimate is also not easily reconciled with the apparent considerable productivity advantage of English workers over French workers. That advantage is corroborated by the longer life expectancy of the English and their significant height advantage on the eve of the Industrial Revolution (Kelly, Mokyr, and Ó Gráda 2012). An adjustment along the lines suggested by Table 4 would go some way towards resolving the issues posed by Broadberry *et al*.'s estimates as they stand.

4. *Crises*:

The energy accounting exercises of Fogel and, to a lesser extent, Floud *et al*. imply that a significant proportion of England's population may have been malnourished until the nineteenth century. The implications of Broadberry *et al*.'s estimates are gloomier still. Table 5 imposes Floud *et al*.'s hypothetical calorie distribution per male adult equivalent on Broadberry *et al*.'s estimates of calories per head for the 1750s and the 1800s. If, as this suggests, the bottom decile of the English population subsisted on the equivalent of 1,700 calories per adult male in mid-century and on 1,650 calories in the 1800s, the implications for living standards during the Industrial Revolution are very bleak indeed.

[Table 5 about here]

It does not end there. Note that Table 5 is based on average yields and harvests in a normal year. Year-to-year fluctuations in agricultural output before c. 1800 can only have exacerbated the problem initially highlighted by Fogel (1994). How big were such fluctuations? Hitherto analysis of short-term variations in farm output and food supplies has relied on proxy measures such as fluctuations in tithe payments or in grain prices and grain crop yields (Campbell and Ó Gráda 2011). Now, the estimate of annual agricultural production since 1270 produced by Broadberry *et al*. allows us for the first time to measure the size of agricultural fluctuations directly.

In order to de-trend the series we split it in two (approximately) and estimated separate Hodrick-Prescott filters for 1270-1549 and 1550-1800. This exercise identified the main harvest deficit years highlighted in the literature although their implied ranking in terms of proportional shortfall is not quite what might have been expected (Figures 3A and 3B). While all the well-known harvest shortfalls are identified, it emerges that the crises of the sixteenth and seventeenth centuries were more serious—purely in terms of the size of deviations from trend—than those of the 1310s and 1430s.

[Figures 3A and 3B and Table 6 about here]

Table 6 reports averages of the absolute values of proportional deviations from trend by sub-period between the 1270s and the 1800s. Again, the implication that aggregate output fluctuated much more between 1500 and 1650 than either before or after is striking. Perhaps this is a reflection of the lower quality of post-1500 data: yield estimates for this period are calculated from probate inventories using price data, and may exaggerate fluctuations, whereas those for the pre-1475 period are based on yield data directly recorded in manorial accounts.[6]

Here we are more interested in the finding that implies that output fell by twenty per cent or more below trend in fourteen years between 1550 and 1800. These years were 1556, 1577, 1586, 1594, 1596, 1597, 1629, 1630, 1631, 1650, 1659, 1709, 1710, and 1713. Most serious would have been the repeated failures in 1594-97, 1629-31, and 1709-10, when the cumulative shortfall reached 50 per cent or more. If average calorie intake in non-crisis years was really as low as Broadberry et *al*. estimate, then it is difficult to imagine how tens of thousands of those eking out calories near the bottom of the socio-economic pyramid did not succumb to mass starvation in those years. Yet only in 1594-97 was there a nation-wide famine—England's last truly major famine. Neither poor relief nor grain imports would have been capable of mitigating the output losses inflicted on the calorie-poor population implicit in Broadberry *et al*.'s estimates. Perhaps Broadberry *et al*. did not intend such a literal interpretation of short-term fluctuations in their data. Be that as it may, allowing for a secular increase in calorie supplies per head would help explain why a cumulative output shortfall of one-third in 1315-6 led to a catastrophe, while larger cumulative shortfalls in output in 1629-31 and 1709-10 did not. It would also be easier to reconcile with evidence that while the positive check, in the sense of the short-run response of mortality to price and real wage shocks, was powerful in the middle ages, but had virtually disappeared by the late eighteenth century (Kelly and Ó Gráda 2011).

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[6] On changes in the variability of crop yields over time see Campbell and Ó Gráda (2011).

Table 7 reports the estimated response of mortality to three measures of real income for fifty-year intervals from 1546 to 1800. The death rates are those of Wrigley and Schofield (1981); the income proxies are Clark's real wage series and Broadberry *et al*.'s estimates of agricultural output and GDP per head. Since the variables are transformed to differences of log values, the reported coefficients may be interpreted as elasticities. We ran the death rate on its own lagged values and on current and lagged income; only the income coefficients are reported in Table 7. The outcomes using real wages are broadly as found in Kelly and Ó Gráda (2011). Thus, there is evidence of a strong positive check before 1650 but no significant response in the following half-century, and of a renewed response in 1700-49 but no adverse impact thereafter. Broadberry *et al*.'s output estimates corroborate this outcome in some respects; in particular, they capture the impact of adverse shocks on mortality in the first half of the eighteenth century. However, two features of the results using their data are puzzling. First, before 1600 the response of mortality to variations in GDP per head is much stronger than that to variations in agricultural output per head. Second, the lack of a statistically significant response in the seventeenth century is also surprising.

[Table 7 about here]

5. *Concluding Remarks:*

Broadberry *et al*. (2011), like Allen (2009), Clark (2008), and Muldrew (2011), have embarked on a very ambitious project of uniting newly minted data that straddle the centuries with an interpretation of the beginnings of modern economic growth. Keeping all the empirical and theoretical balls in the air at once is not easy. Critics have already questioned key aspects of the data underpinning rival approaches (e.g. Hatcher 2011; Clark 2010; Persson 2009, 2010; Broadberry, Campbell, and van Leeuwen 2011a).

In evaluating the nutritional status of the English two potential mitigating factors deserve mention.[7] First, it is possible that as the share of the total labour force in agriculture fell, the number of calories required for effective work also declined. In the mid-eighteenth century England's labour force was no longer mainly agricultural. Following Leigh Shaw-Taylor *et al*. (2010), Broadberry, Campbell, and van Leeuwen (2011b) claim that the share of male labour force in farming fell from 68 per cent c. 1522 to 43.4 per cent c. 1700 and 35.7 per cent c. 1800.[8] More or less simultaneously, urban areas gained relative to the countryside, with the share of the population of England and Wales living in towns and cities of 10,000 or more increasing from 3.1 per cent in 1500 to over one-fifth in 1800 (de Vries 1984: 39). While not discounting the physical demands placed on the likes of porters, dockers, and construction workers in the towns and cities, the shift away from agricultural occupations and towards urbanization may have reduced the daily energy requirements of the average worker relative to earlier centuries.

Against this must be weighed a likely increase in the number of days worked per annum in the early modern era. Unfortunately, estimates of the number of days worked in England range widely, although if the estimates of Ian Blanchard

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[7] A third possibility is that calorie requirements were lower in earlier centuries because people were smaller. However, hard evidence for this is lacking (compare Koepke and Baten 2005). Even if it were the case, the reduction in calories required for survival would have been modest. The example in Floud *et al*. (2011: 43-44) is onsistent with a reduction in male adult height of one-tenth reducing the basal metabolic rate by one half that.

[8]Shaw-Taylor *et al*. (2010) reckon that between 1710 and 1817 the share of manufacturing in the male labour force rose from 38.7 to 42.7 per cent, while the share of services rose marginally from 18.0 to 18.9 per cent.

(1978) for the fifteenth century, Hans-Joachim Voth (1998) for the eighteenth, and Gregory Clark and Ysbrand van der Werf (1998) for c. 1550-1850 are at all indicative, some increase in labour intensity is implied, perhaps enough to overturn any gain from urbanization and occupational shifts.

A second consideration possibly mitigating the need for calories may have been the gradually increasing availability of fuel and more fuel-efficient housing. By reducing the Basal Metabolic Rate (BMR)—the number of calories required just to sustain life—increased supplies of coal and better insulation improved the quality of life in the pre-industrial era. While important for comfort, however, the resultant energy savings cannot have counted for too much in proportionate terms. Suppose that as a result Englishmen and Englishwomen c. 1800 enjoyed temperatures on average a generous two degrees centigrade warmer than their medieval ancestors. A recent Dutch study (Westerterp-Plantenga *et al*. 2002) reckoned that an extra twenty calories or so daily in foodstuffs are needed for every degree below 22C^0 spent at rest.[9] That would mean that average energy requirements were forty calories fewer in the latter than in the former period.

Estimates of agricultural output in the past must be treated with caution, as must interpretations of economic growth and wellbeing that lean heavily on such estimates. Yet in a discipline in which the creation of newly minted data earns fewer credits than new interpretations of the past based on such data, the temptation to combine data construction and interpretation is almost irresistible. In the case of English agriculture, four recent attempts at estimating output before

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[9]Compare Shils and Shike (2005: 143), who report that 'studies consistently suggest that low-normal temperatures of 20 to 22°C and high temperatures of 28 to 30°C are associated with an increase in sedentary EE of 2 to 5% compared with temperatures of 24 to 27°C'. See too Johnson *et al*. 2011.

and during the Industrial Revolution have been accompanied by four competing interpretations. It has seemed appropriate, then, to compare the estimates and to suggest ways in which they might err in one direction or the other.

Our review of the estimates of food availability has focused on the 1750-1800 period. We argue that while precision is impossible, the best guess at calorie supplies per head in these decades is closer to that of Broadberry *et al*. (2011), Allen (2005), and Floud *et al*. (2011) than to the overgenerous estimate of Muldrew (2011). Nevertheless, the estimates of Broadberry *et al*. for this period require upward revision. Revising them along the lines suggested here would have four important implications for our understanding of nutritional status and productivity on the eve of the Industrial Revolution. First, it would make room for a rise in English calorie supplies over time, in line with—though not the same as—the posited rise in both GDP and agricultural output per head. Second, it would help explain why although output fluctuations did not lessen over time, crisis mortality did. Third, it would restore England's calorific advantage over France. And fourth, in the spirit of Muldrew (2011), it would allow for a more 'industrious' English labour force, the productivity of which was not constrained by the lack of food before the Industrial Revolution. Finally, if this paper prompts producers and consumers of the output and calorie supply estimates currently on offer to work towards a consensus figure or range, it will have achieved its purpose.

TABLE 1. FOUR RECENT ESTIMATES OF ENGLISH CALORIE CONSUMPTION PER CAPITA, C. 1300-1800				
A. Muldrew (2011)				
Year	*[1] kcals*	*[2] vegetal*	*[3] animal*	*[3]/[1] (%)*
1600	3,062	1,968	1,094	35.73
1700	3,579	2,682	897	25.06
1770	5,047	3,985	1,062	21.04
1800	3,977	3,189	788	19.81
B. Allen (2005)				
Year	*[1] kcals*	*[2] vegetal*	*[3] animal*	*[3]/[1] (%)*
1300	1,791	1,502	289	16.14
1500	3,397	2,733	664	19.55
1700	3,255	2,601	654	20.09
1750	3,803	2,962	841	22.11
1800	2,938	2,248	690	23.49
1850	2,525	2,019	506	20.04
C. Broadberry et *al*. (2011)				
Year	*[1] kcals*	*[2] vegetal*	*[3] animal*	*[3]/[1] (%)*
1275	2,188	1,771	417	19.06
1305	2,041	1,610	431	21.12
1315	1,983	1,561	422	21.28
1385	2,447	2,056	391	15.98
1425	2,132	1,702	430	20.17
1455	2,162	1,698	464	21.46
1605	2,082	1,676	406	19.50
1655	1,909	1,540	369	19.33
1705	2,162	1,752	410	18.96
1755	2,248	1,729	519	23.09
1805	2,165	1,580	585	27.02
1835	1,947	1,436	511	26.25
1845	2,160	1,652	508	23.52
1855	2,104	1,576	528	25.10
1865	2,471	1,951	520	21.04
D. Floud et *al*. (2011)				
year	*[1] kcals*	*[2] vegetal*	*[3] animal*	*[3]/[1] (%)*
1700	2,229	1,667	562	25.21
1750	2,237	1,427	810	36.21
1800	2,439	1,707	732	30.01
1850	2,544	1,921	623	24.49
Source: Muldrew (2011: 156); Allen (2005: 39, table 12); Broadberry et *al.* (2011, personal communication);Floud et *al.* (2011: 167, Table 4.13: Variant 11B)				

TABLE 2: CROP ACREAGES, ENGLAND 1600-1800 (million acres)					
	Wheat	Rye/Maslin	Barley	Oats	Pulses
1800					
Broadberry et *al.*	2.51	0.06	1.46	1.97	0.83
Allen	2.5	0.3	1.3	2.0	1.3
Muldrew	3.104	0.097	1.843	2.522	1.067
Floud et *al.*	2.5	0.3	1.3	2.0	1.2
Turner	2.32-2.57	---	1.38-1.53	1.91-2.13	0.71-0.78
1750					
Broadberry et *al.*	1.95	0.06	1.50	1.82	0.98
Allen	2.1	0.5	1.7	1.4	1.3
Muldrew (1770)	2.957	0.635	1.892	1.295	1.198
Floud et *al.*	1.8	0.5	1.4	2.0	1.0
1700					
Broadberry et *al.*	1.99	0.42	1.82	1.15	0.98
Allen	1.4	0.9	1.9	1.2	1.2
Muldrew	1.6	0.52	2.04	1.06	0.98
Floud et *al.*	1.361	0.89	1.901	1.223	1.3
1600					
Broadberry et *al.*	1.85	0.77	1.44	1.32	0.61
Allen (1500)	1.8	0.2	1.5	1.3	1.2
Muldrew	1.53	0.47	1.78	0.89	0.83
Sources: Allen 2005; Muldrew 2011: 142-3; Broadberry et *al.* 2011; Floud et *al.* 2011: 208; Turner 1981: 301; Turner et *al*. 2001: 218. *Note*: Allen's and Turner's data refer to England and Wales, while the others refer to England only. Turner's wheat data includes rye and maslin.					

TABLE 3: CROP YIELD ESTIMATES, 1800					
Study	Wheat	Rye/Maslin	Barley	Oats	Pulses
Broadberry et *al.* (net)	18.7	21.81	28.58	25.19	18.65
Muldrew (gross)	18	23	24	32	19.5
Allen (gross)	20	28	35	38	20
Floud et *al*. (gross)	21.1	23.4	29.2	37.4	22.0
Turner *et al*. (gross)	19.2	22.3	26.7	36.5	20.0

TABLE 4. SUGGESTED AMENDMENTS TO THE ESTIMATES OF MULDREW AND BROADBERRY et al.				
Item	Muldrew		Broadberry *et al.*	
	1770	1800	1750	1800
Wheat	-500	-250		
Rye	-100		+300	
Oats	-300	-350/-650		
Barley	-400	-250		
Milk			+100	+100
Meat			+100/+150	+100/+150
Sugar/wine	+90	+110	+90	+110
Peas/ Beans/Irish Imports			+25/+30	+50/+60
Potatoes	+100	230		+50
Garden plots and orchards			+20/+50	+20/+50
Total	-1100	-500/-800	+600/+650	+450/+500

TABLE 5. HYPOTHETICAL DISTRIBUTION OF CALORIES PER MALE ADULT EQUIVALENT BY DECILE			
Decile	England 1800 [Floud *et al.*]	England 1750s [Broadberry *et al.*]	England 1800s [Broadberry *et al.*]
Highest	5,244	4,765	4,624
9th	4,258	3,869	3,754
8th	3,822	3,473	3,370
7th	3,509	3,188	3,094
6th	3,251	2,954	2,866
5th	3,019	2,743	2,662
4th	2,797	2,541	2,466
3rd	2,568	2,333	2,264
2nd	2,305	2,094	2,032
1st	1,872	1,701	1,651
Derived from Floud et *al*. (2011: Tables 2.4 and 4.13)			

TABLE 6. VARIABILITY OF AGRICULTURAL OUTPUT, 1270-1800	
Period	Average Deviation [%]
1270-1349	7.7
1350-1399	6.8
1400-1449	7.6
1450-1499	4.9
1500-1549	10.1
1550-1599	11.3
1600-1649	12.6
1700-1749	9.2
1750-1800	5.2
Source: Broadberry *et al*. 'Final data'	

TABLE 7. SHORT-TUN RESPONSE OF THE DEATH RATE TO ANNUAL VARIATIONS IN REAL INCOME			
Period and Lags	Wage	Agricultural Output per head	GDP per head
1546-99			
0	-0.131	0.054	0.267
1	-0.273	-0.266 *	-0.518 *
2	-0.572 **	-0.383 *	-0.868 **
3	-0.197	-0.400 **	-0.999 **
4	-0.331 *	0.136	-0.132
1600-49			
0	0.223	0.063	0.155
1	-0.518 **	0.065	0.165
2	-0.049	-0.189	-0.371
3	-0.085	-0.049	-0.119
4	-0.112	0.070	0.101
1650-99			
0	-0.024	-0.020	0.038
1	-0.000	0.040	0.069
2	-0.110	0.087	0.194
3	0.206	0.045	0.123
4	0.194	0.041	0.202
1700-49			
0	-0.017	0.176	-0.077
1	-0.522 **	-0.076	-0.196
2	-0.180	-0.305 **	-0.660 **
3	-0.199	-0.139	0.087
4	0.036	0.261	0.405
1750-99			
0	0.151	0.145	0.468
1	0.214	-0.048	-0.004
2	0.187	0.289 **	0.619 *
3	0.351 **	0.198 **	0.259
4	0.534 **	0.110	0.130
Note: estimated using robust regressions * = significant at 10%; ** = significant at 5%			

Figure 1. Four Estimates of Calories per Head

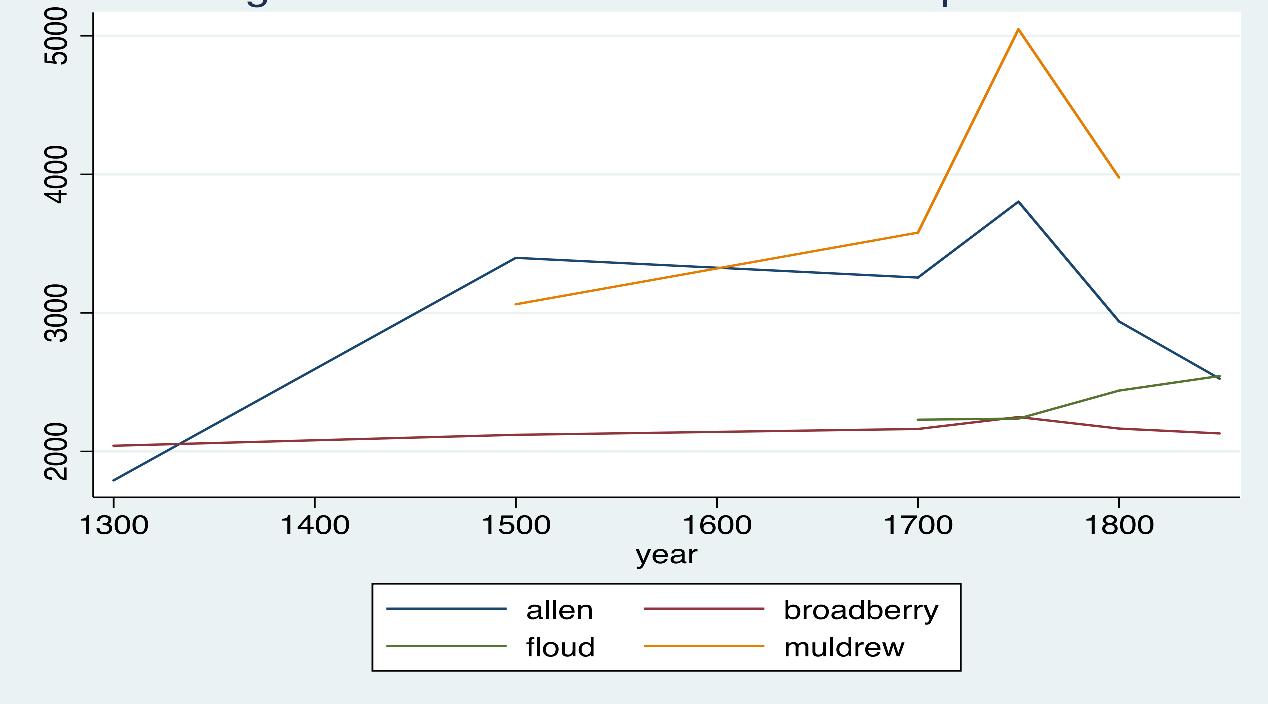


Fig. 2. Agricultural Output and GDP per Head, 1300-1800

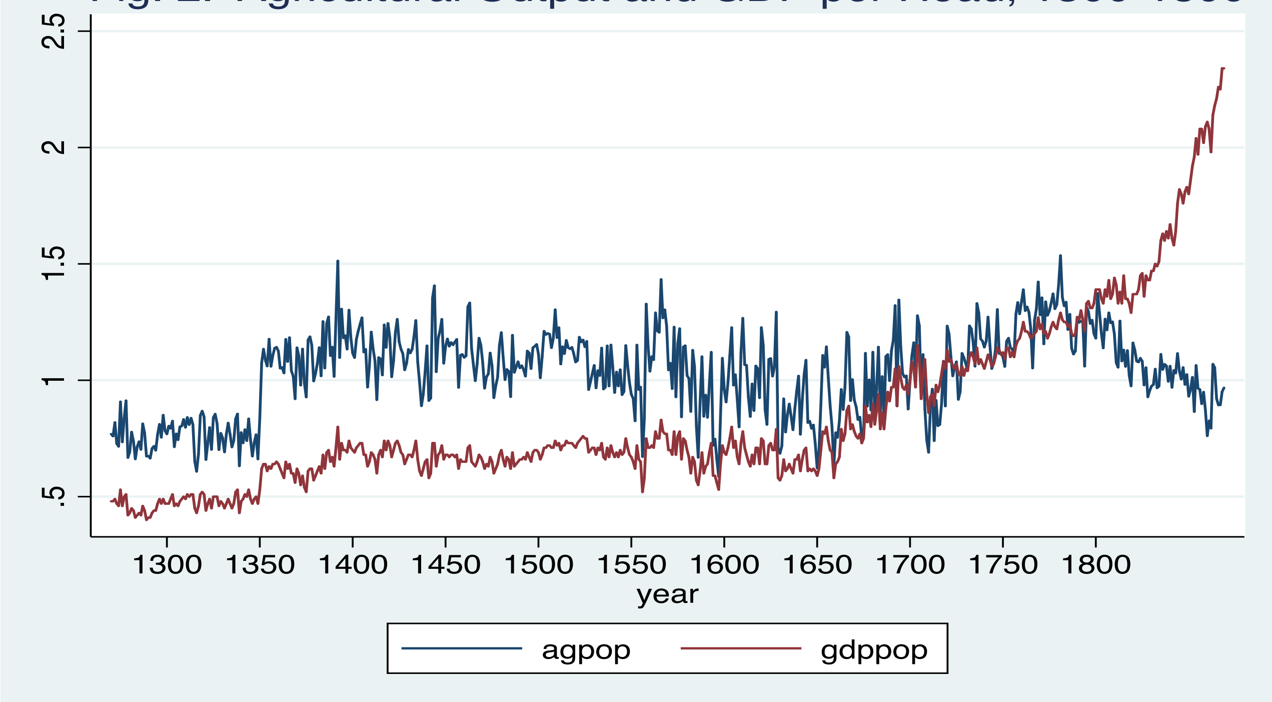
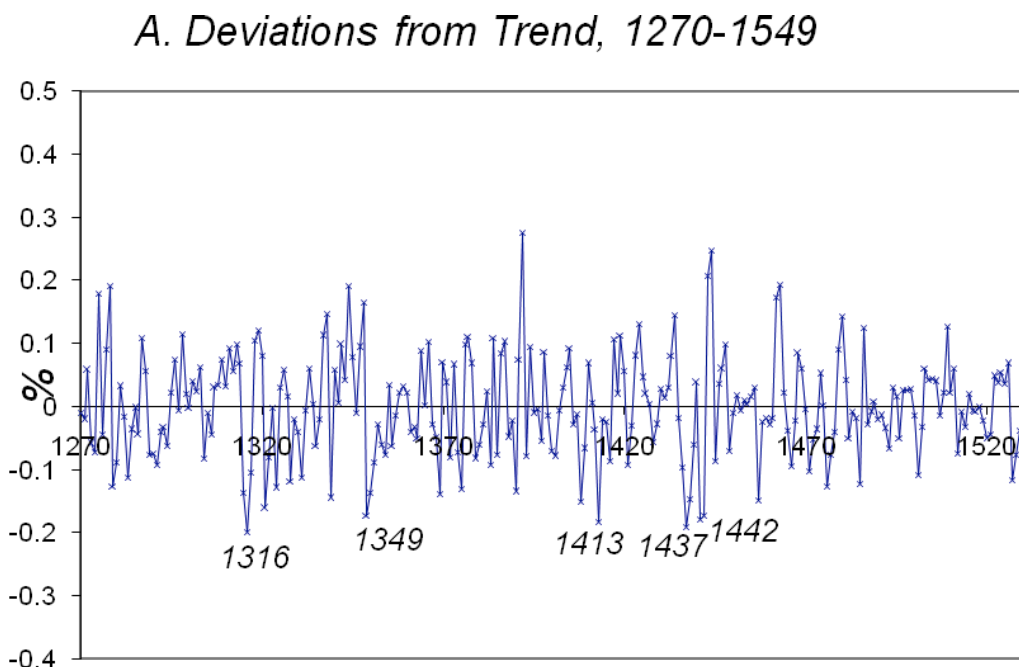
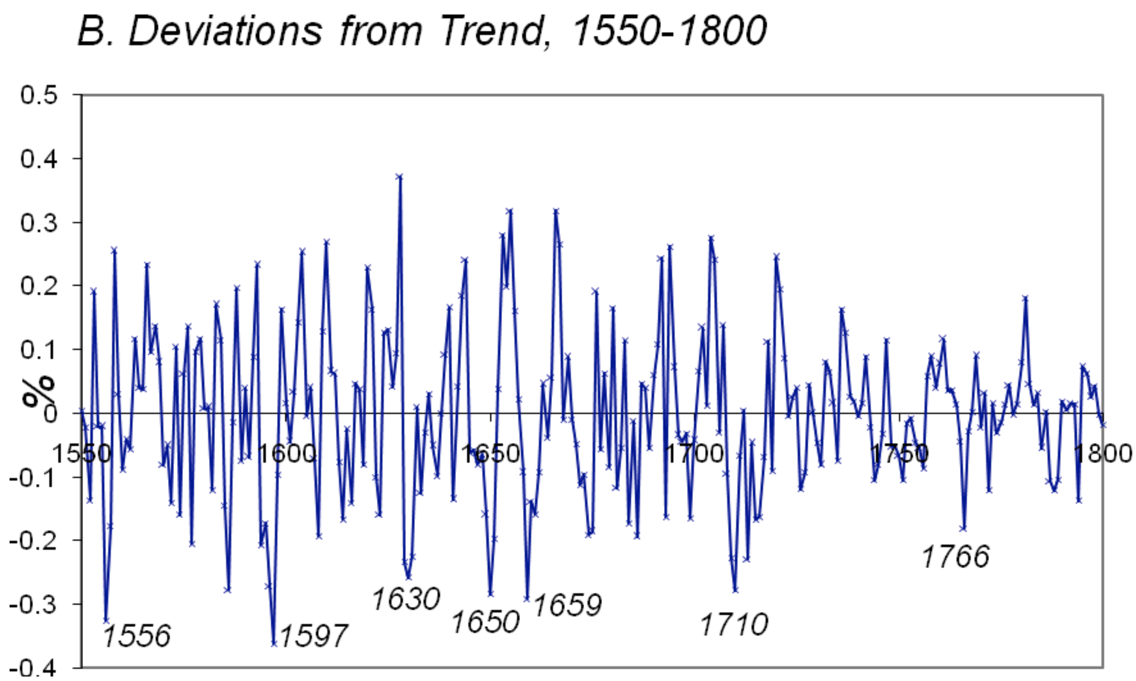


Figure 3. Agricultural Output, 1270-1800





APPENDIX: THE COMPONENTS OF AGRICULTURAL OUTPUT

Here we compare the main individual items that constituted agricultural output, the details of some of the most important calculations are accordingly elevated briefly to the main text. For the sake of clarity and brevity, we focus particularly on crop outputs in the most pessimistic and optimistic estimates, those of Broadberry *et al*. and Muldrew.

WHEAT: As seen from TableA1, Muldrew's totals for both wheat and the coarser grains c. 1750-1800 are significant outliers. Wheat in the form of white bread has long been the staple food of England. Wheat's pre-eminent role as a cereal crop is reflected in all four estimates, but Muldrew's estimate (2011: 143) of the area under wheat in the mid- and late eighteenth century is the highest by far. Adjusting his estimates to reflect acreages of 2 million in 1770 and 2.5 million in 1800 (instead of his 2.957 and 3.104 million) would reduce his daily calorie supply from wheat from 1,646 to 1,113 calories in 1770 and from 1,322 to 1,065 in 1800.

[Table A1 about here]

RYE: Coarse grains were still a significant item in the English diet in the eighteenth century. According to E. J. T. Collins, nearly one-third of the population consumed barley, oats, or rye rather than wheat as late as c. 1800. Rye was by far the least important of the coarse grains: Collins rates the relative importance of wheat, barley, oats, and rye c. 1800 at 67:17:15:2 (Collins 1975: 105; on rye see also Ashley 1921; Turner *et al*. 2001: 68-69). These proportions are not readily reconciled with Muldrew's claim (2011: 143) that coarse grains accounted for 56.3 and 56.1 per cent of all calories supplied by cereals in 1770 and 1800, respectively.

Muldrew's figure for rye output in 1770—enough to account for 415 calories of the 3,985 calories supplied daily by all crops (Muldrew 2011: Table 3.14)—is a particularly notable outlier, although his figure for 1800 (generating 56 calories) is consistent with Collins' reckoning that rye accounted for only 2 per cent of cereal consumption c. 1800. The unimportance of rye is confirmed by the 1801 crop returns (Turner 1981). Yet if Muldrew's estimate of a total of 635,440 acres under rye in 1770—declining very sharply to 97,000 acres by 1800—seems on the high side, the 60,000 acres adopted by Broadberry et *al.* for the entire 1750-1871 period (2011: Table 1) is almost certainly too low for the pre-1800 period. Our standard here is Holderness's finding that 'the maximum acreage under rye in our period (i.e. 1750-1850) was about 500,000, which in proportion to the land under wheat may be an exaggeration' (Holderness 1989; 130). That is also the figure adopted by Allen. By this reckoning, Muldrew's estimate of 12.4 million bushels of rye (and therefore 415 calories per day) consumed c. 1770 may be closer to the mark than Broadberry et *al*.'s 1.5 million bushels.

OATS: The contrasting estimates of the contribution of oats require some elaboration. Muldrew (2011: 142-3) assumes that a gross production of 80.7 million bushels (i.e. gross yield of 32 bushels per acre on 2,522,000 acres) in 1800 left 67.1 million bushels for human consumption. This generous total stems from choosing a high crop acreage (2.5 million acres, compared to the 2 million acres adopted by Allen and Broadberry *et al*.), and from two key assumptions regarding oats consumed by horses and the calorie loss from converting oats to oatmeal.

Let us consider the horses first. Allowing an estimated horse population of 0.9 million c. 1800 an annual ration of 6.5 quarters of oats each (Holderness 1989: 132), and assuming quarters of 320lbs and bushels of 38lbs, would account for 49.3 million bushels in total. By that reckoning horses and seed requirements (8 million bushels at a minimum) would have consumed 58 million of the 80.7 million at the very least, leaving a maximum of approximately 23 million bushels for human consumption. The more conservative estimate of consumption per horse suggested by Alexander Apostolides *et al*. (2008) for 1800—26 bushels per mature horse—would entail a total of 23.4 million bushels, leaving 49 million bushels for human consumption.[10] These totals are almost five times and ten times, respectively, the 4.8 million bushels adopted by Broadberry *et al*. (Table 2). Reducing the area under oats to two million acres would narrow these multiples to less than two (7.3 million) and seven (33.2 million). Some of the remaining gap is accounted for by Muldrew's conservative assumption regarding the processing loss from converting oats to oatmeal. He uses 7.5 per cent, while Broadberry et *al*.

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[10] 6.5 quarters of oats is equivalent to about 0.9 tons each. Peter Solar (1989: 133) assumes levels of 0.5cwt per farm horse and 1.4cwt per non-farm horse in mid-nineteenth century Ireland.

use 30 per cent. Even the latter ratio may be conservative (compare Bourke 1976).

Muldrew's estimate of a daily 816 calories for oats in 1800 is therefore almost certainly too generous. Substituting Broadberry *et al*.'s 14.06 million bushels for Muldrew's 67.14 million bushels would reduce the latter's calorie estimates for 1800 by 645 calories; the more conservative option of applying the lower acreage of two million and a processing loss of 30 per cent to Muldrew's total would reduce oats' contribution in 1800 from 816 to 453 calories.

Thus, insofar as rye and oats are concerned, we believe that while Broadberry et *al*. underestimate the role of the former before 1800, Muldrew exaggerates that of the latter, particularly in 1800, by a similar or wider margin.

BARLEY: Another key difference between Broadberry et *al*. and Muldrew is the food conversion loss assumed when barley was converted into beer. The former allow a 70 per cent loss, while the latter allows only 27 per cent. Here the evidence of one abstemious economist--Adam Smith (*Wealth of Nations*, Book 5, Chapter 2[2])—seems apposite:

> In London a quarter of malt is commonly brewed into two and a half and sometimes into three barrels of porter; and in the country brewery for common sale the like quantity is seldom made into less than two barrels of strong, and one of small beer, and frequently into two barrels and a half of strong beer.

Using rates of 1 quarter = 80 bushels and 1 barrel = 36 gallons, and assuming that a pint of beer or porter contained 250 calories and a pound of barley 1,650 calories, then the 8x48 lbs of barley (=384x1,650 calories) would have converted into 3x36x8x250 calories in the form of beer. That implies a processing loss of 66 per cent.

However, as Collins (1975) reminds us, by no means all barley was consumed as beer. Applying a 50 per cent loss to Muldrew's estimates of barley output as a rather arbitrary compromise would reduce his daily energy supply (2011: 156) from 5,047 to 4,661 calories in 1770 and from 3,977 to 3,719 calories in 1800.

BEANS AND PEAS: Broadberry et *al*.'s figure for the acreage under beans and peas in 1750 and 1800 is the most conservative of the four (Table 2). However, selecting acreages of 1.3 million for 1750 and 1800, rather than their 0.98 million and 0.83 million, respectively, would add only about 20 calories daily to their total for either date.

POTATOES: Potatoes were not a significant part of the English diet until the late eighteenth century, so the rather different accounts of its calorific contribution in the four estimates do not affect the overall outcome much. Floud et *al*. (2011: 221), following the lead of Redcliffe Salaman (1949), reckon calorie supplies from potatoes at a daily average of 53 calories in 1700, 79 calories in 1750, and 154 calories in 1800. Broadberry et *al*. assume that output net of seed rose from 1.27 million bushels in the 1700s to 13.56 million bushels in the 1750s, and 26.7 million bushels in the 1800s. Allen, following Holderness (1989: 145), assumes that gross production, before deducting for seed, rose from 30 million bushels in 1750 to 45 million bushels in 1800. Muldrew (2011: 142-3) makes no allowance for potatoes. Assuming bushels of 60lbs and 23 calories per ounce (Floud et *al*. 2011: 221), Broadberry et *al*.'s output totals would have yielded a paltry 14 calories per head in 1700, but 132 calories in 1750 and 175 calories in 1800. Allen's totals are more generous: deducting one-sixth of his crop estimates for seed would have left nearly 250 calories per diem in 1800, and one-third and two-thirds of that in 1700 and 1750, respectively. But that calculation seems to assume that potatoes were destined for human consumption only, which certainly was not the case (e.g. Moore-Colyer 1989: 358). The incomplete 1801 crop returns include nearly 76,679 acres under potatoes in England and Wales but, as Turner (1981: 294-5, 297) notes, this is an underestimate for the parishes it covers since the returns exclude potatoes grown in small garden plots. Assuming that this figure represented one-third of the national acreage (compare Turner 1981: 301) and a net yield of 5 tons per acre would yield a daily calorie supply of about 230 calories per head[11], or closer to Allen's estimate that those of Floud et *al*. and Broadberry et *al*.

ANIMAL PRODUCTS: Muldrew's estimates of calories supplied through animal output (meat, eggs, dairy products) are also generally the highest of the four (see Table 1). Part of the gap may be explained by his over-generous allowance of 400 gallons for milk yield per cow (see Table A2). Applying instead the 330 gallons adopted by Allen (who follows Holderness 1989: 161-4) would reduce the Muldrew's estimate of daily calorie consumption c. 1770 through milk from 483 to 398 calories. However, Broadberry et *al*.'s estimate of milk output—163 million gallons in 1750 and 280 million gallons in 1800—are distinctly lower than those implied by B.A. Holderness, who reckons that the rise in cow numbers from 0.75 million in 1750-75 to 1 million in 1800 was accompanied by a rise in yield per cow from 330 gallons to 380 gallons (1989: 162-3, 169). Assuming milk contained 20.35 kcal/oz (Floud et *al*. 2011: 211), Holderness's numbers would imply an extra 120 calories daily in mid-century and about 100 calories c. 1800.

Muldrew's estimates of carcass weights c. 1770 are also far higher than Allen's (see Table A2). However, his estimate for cattle carcasses is lower than the 713lbs yielded by the farm accounts-based sample of Turner *et al*. (2001: 186; compare Fussell 1929).

[Tables A2 and A3 about here]

Table A3 compares the competing estimates of meat available for human consumption. Allen and Floud et *al*. both closely mirror Holderness, so we report only Floud et *al*.'s estimates here. The latter suggest that meat from pigs, cattle, and sheep supplied 456 calories per head in 1750 and 409 calories per head in 1800. If we apply their estimate of kcal/oz to Broadberry et *al*.'s average of meat supplied in 1700-49 and 1750-99, this yields 324 calories per head; for the average of 1750-99 and 1800-49, it yields just 270 calories per head.

Turner's review of official inquiries into livestock numbers (Turner 1998) yields a 'best guess' of 12 to 14 million for the number of sheep c. 1800. This is not far from Broadberry *et al*.'s 16 million, but implies that Allen's estimate of sheep-meat based on a national flock of 20 million may be over-generous.

Only Floud et *al*. (2011: 210) allow for lard; they estimate that it generated 52.5 calories per head in 1750 and 45.7 calories in 1800.

FOREIGN TRADE: While Muldrew's estimates are generally on the high side, they are alone in not factoring in the contribution of foreign trade. By the late eighteenth century England was a net importer of cereals, and Broadberry et *al*. reckon that imports contributed 20 calories per capita daily in the 1750s and 166 calories in the 1800s. By the same token, one minor item omitted by both Muldrew and Broadberry et *al*. (2011) is imports of beef, pork, and butter from Ireland. From an Irish perspective these were not trivial in the late eighteenth century (see Cullen 1968: 69-70; Thomas 1982), although they would not have added much to calories per head in England—perhaps 40-50 calories c. 1800.

None of the estimates allows either for imports of live cattle from Scotland. Trow-Smith (1959: 226; see too Blackman 1975: 60) suggests that they numbered as many as 100,000 animals per year at the end of the eighteenth century. Assuming an average carcass weight of 600lbs. worth 82.4 calories per oz. (Allen 2005; Floud et al. 2011: 210) would add a further 20/25 calories or so per head c. 1800.

One significant imported item included only by Floud et *al*. (2011: 217) is sugar, worth 72 calories in 1750 and 95 calories in 1800. Wine and spirits imports account for an additional 11 calories in 1750 and 17 calories in 1800 (Floud et *al*. 2011: 218).

FISH, HUNTING, AND POULTRY: Allen (2005: 20) is content to exclude calories from poultry, hunting, and fishing, since 'it is hard to believe that those sources radically increased food availability'. Still, Broadberry et *al.* allow 200 calories for these items, while Floud et *al*. (2011: 167) allow 24 calories for fish. Muldrew's allowances under this heading are atypically conservative: nothing for fish, and about 40 calories for poultry in 1770 (Muldrew 2011: 154).

Holderness reminds us that 'the quantity of meat…from rabbits was not negligible, and should not be ignored simply because we have no statistics' (1989: 149). Yet on his reckoning that the annual output of rabbit warrens before 1800 was no higher than two or three million animals, and that the average rabbit yielded 1.5 lbs of meat, farmed rabbits would have added only about three calories daily per head at most in 1750-1800. Wild rabbits cannot have added contributed even less to aggregate calorie availability.

CONVERSION RATES: A feature of Floud *et al*.'s estimate is their use of coefficients generated by U.S. output estimates to calculate the proportions of English crop outputs not entering human consumption (2011: 154). They also employ U.S. conversion ratios to correct for milling losses and distributional losses. The relevant ratios are given in Table A4. Given that crop yield ratios were about 10:1 in England and Wales at this time, Floud *et al*.'s assumed proportions of wheat, barley, and rye entering gross production in column [1] seem to be on the low side. Similarly, comparing [2] and [3] suggests that the assumed losses from processing and distribution may be too high except, perhaps, in the case of barley.

Although in general Muldrew's estimates seem over-generous, Table A5 suggests that his calorie conversion rates are conservative (except in the case of beans and peas, where he uses 74.6 calories per oz. compared to Floud *et al*. 30 calories per oz. The rates used by Broadberry *et al*. and Floud *et al*. tally with those in McCance and Widdowson (2006).

[Tables A4 and A5 about here]

TABLE A1. COMPARING BROADBERRY AND MULDREW CROP OUTPUT ESTIMATES					
	Millions of bushels				
BROADBERRY	Wheat	Rye	Barley	Oats	Pulses
1600s	20.70	7.85	18.59	8.44	4.01
1650s	27.01	3.70	33.50	6.14	6.53
1700s	27.94	6.70	35.20	5.70	8.25
1750s	31.48	1.51	39.67	13.03	9.03
1800s	46.32	1.36	42.67	14.06	11.07
MULDREW					
1600	14.54	4.47	16.00	9.45	2.99
1650	20.00	7.02	24.48	9.33	4.31
1700	23.20	6.50	32.64	8.48	5.10
1770	51.75	*12.39*	49.20	29.60	7.66
1800	55.87	2.31	44.23	67.14	8.32
RATIO					
1600	070	0.57	0.86	1.12	0.75
1650	0.74	1.90	0.73	1.52	0.66
1700	0.83	0.91	0.93	1.49	0.62
1750/70	1.64	8.21	1.24	2.27	0.85
1800	1.21	1.70	1.04	4.78	0.75
Source: Broadberry et *al.* (2011); Muldrew (2011: 142-3)					

TABLE A2. ESTIMATES OF CARCASS WEIGHTS AND MILK PER COW				
Item	Muldrew 1770	Allen 1750	Allen 1800	Turner *et al*. 1775-99
Milk [gals.]	400	330	380	--
Cattle [lbs.]	650	400	500	713
Calves [lbs.]	130	45	75	124
Pigs [lbs.]	260	95	110	185
Source: Allen (2005); Muldrew (2011); Turner *et al*. (2001: 186; averaging their estimates for 1775-99 and 1800-24).				

TABLE A3. MEAT FROM FARM ANIMALS (Million cwt.)			
Date	Mutton/Lamb	Beef/Veal	Pork/bacon
Floud et *al*. (2011: 210; based on Holderness, kcals/head in parentheses)			
1700	0.91 (76)	1.86 (138)	0.53 (61)
1750	1.94 (142)	2.55 (167)	1.45 (147)
1800	2.80 (138)	3.25 (143)	1.88 (128)
1850	4.18 (105)	5.38 (121)	2.55 (89)
Broadberry et *al*.			
1700-49	1.69	0.94	0.87
1750-99	2.14	1.32	1.29
1800-49	2.30	1.61	1.54
Muldrew			
1770	4.06	3.60	2.32
Source: see text			

TABLE A4. CROP CONVERSION RATIOS c. 1700-1800			
	Floud *et al*.		Campbell and Overton
Crop	[1] Proportion entering gross product	[2] Proportion net of milling and distribution losses	[3] Proportion net of storage and food conversion losses
Wheat	0.855	0.6189	0.70
Rye	0.737	0.5345	0.70
Barley	0.850	0.4000	0.68/0.30
Oats	0.280	0.4263	0.56
Source: Floud et *al*. 2011: Table D2; Overton and Campbell (1996), as reported in Apostolides *et al*. Table 20			

TABLE A5. KCAL/OZ ESTIMATES			
	Muldrew	Floud *et al*.	Broadberry *et al*.
Wheat	82.8	95	95
Rye	87.2	95	95
Barley	75.4	102	91
Oats	87.9	114	105
Source: Muldrew (2011: 143); Floud et al. (2011: 205-9); Campbell *et al*. (1993: Table 3, p. 41)			

BIBLIOGRAPHY:

Allen, Robert C. 2001. The great divergence in European wages and prices from the middle ages to the First World War. *Explorations in Economic History* 38: 411-447.

Allen, Robert C. 2005. English and Welsh agriculture, 1300-1850: output, inputs, and income. Oxford University [available at: *www.nuffield.ox.ac.uk/users/allen/unpublished/AllenE&W.pdf*]

Allen, Robert C. 2009. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge University Press.

Apostolides, Alexander, Broadberry, Stephen, Campbell, Bruce, Overton, Mark and van Leeuwen, Bas. 2008. English agricultural output and labour productivity, 1250-1850: some preliminary estimates.

Ashley, William. 1921. The place of rye in the history of English food. *Economic Journal*. 31, no. 123: 285-308.

Behrman, Jere R, Andrew D Foster, and Mark R Rosenzweig. 1997. The dynamics of agricultural production and the calorie-income relationship: evidence from Pakistan. *Journal of Econometrics* 77: 187-207.

Blackman, Janet. 1975. The cattle trade and agrarian change on the eve of the Railway Age. *Agricultural History Review*. 23[1]: 48-62.

Blanchard, Ian. 1978. Labour productivity and work psychology in the English mining industry1400-1600. *Economic History Review* 31(1): 1–24.

Bourke, PMA. 1976. The Irish grain trade, 1839-48. *Irish Historical Studies* XX: 156-69.

Broadberry, Stephen, Bruce Campbell, Alexander Klein, Mark Overton, and Bas van Leeuwen. 2011. British economic growth, 1270-1870: an output-based approach. 18 December [available at: http://www2.lse.ac.uk/economicHistory/pdf/Broadberry/BritishGDPLongRun16a.pdf].

Broadberry, Stephen, Bruce Campbell, and Bas van Leeuwen. 2011a. Arable acreage in England, 1270-1871 [available at: http://www2.lse.ac.uk/economicHistory/pdf/Broadberry/acreage.pdf].

Broadberry, Stephen, Bruce Campbell, and Bas van Leeuwen. 2011b. When did Britain industrialize? Sectoral distribution of the labour force and labour productivity in Britain, 1381-1851[available at: http://www2.lse.ac.uk/economicHistory/pdf/Broadberry/SectoralsharesGB13c.pdf].

BMS Campbell and C Ó Gráda.2011. Harvest shortfalls, grain prices, and famines in preindustrial England. *Journal of Economic History*, 71[4]: 859-886.

Campbell, BMS, Galloway, JA, Keene, D and Murphy, M. 1993. *A Medieval Capital and its Grain Supply: Agrarian Production and Distribution in the London Region c.*

Clark, Gregory, Michael Huberman, and Peter Lindert. 1995. A British food puzzle, 1770-1850. *Economic History Review* 48[2]: 215-27.

Clark, Gregory. 2007. *Farewell to Alms*. Princeton: Princeton University Press.

Clark, Gregory. 2010. 1381 and the Malthus Delusion [available at: http://www.econ.ku.dk/europe/earlygrowth.htm].

Clark, Gregory and Ysbrand van der Werf. 1998. Work in Progress? The Industrious Revolution. *Journal of Economic History* 58: 830-843.

Collins, Edward JT. 1975. Dietary change and cereal consumption in Britain in the nineteenth century. *Agricultural History Review* XXIII: 97-115.

Crafts, NFR. 1983. British economic growth, 1700-1831: a review of the evidence. *Economic History Review* 36[2]: 177-99.

Crafts, NFR. 1985. Income elasticities of demand and the release of labor by agriculture during the British Industrial Revolution: a further appraisal, in Joel Mokyr (ed.) *The Economics of the Industrial Revolution*. Totowa, NJ: Rowman & Allanheld.

Cullen, LM. 1968. *Anglo-Irish Trade 1660-1800*.Manchester: Manchester University Press.

de Vries, Jan. 1984. *European Urbanization 1500-1800*. London: Methuen.

de Vries, Jan. 2008. *The Industrious Revolution: Consumer Behavior and the Household Economy, 1650 to the Present*. Cambridge: Cambridge University Press.

Dyer. Christopher. 2000. *Everyday life in medieval England*. Continuum International Publishing Group,

Dyer, Christopher. 2002. *Making a Living in the Middle Ages: the People of Britain, 850-1520*. New Haven: Yale University Press.

Westerterp-Plantenga, MS, WD van Marken Lichtenbelt, H Strobbe, and P Schrauwen. 2002. Energy metabolism in humans in lower ambient temperature. *European Journal of Clinical Nutrition* 56[4]: 288-296.

Fogel, Robert W. 1994. Economic growth, population theory, and physiology: the bearing of long-term processes on the making of economic policy. *American Economic Review* 84[3]: 369-395.

Fogel, Robert W. 2004. *The Escape form Hunger and Premature Death 1700-21*00. Cambridge: Cambridge University Press.

Fussell, GE. 1929. The size of English cattle in the eighteenth century, *Agricultural History* 3[4]: 160-181.

Grantham, George W. 1993. Divisions of labour: agricultural productivity and occupational specialization in pre-industrial France', *Economic History Review* XLVI[3]: 478-502.

Grantham, George W. 1995. Food rations in France in the eighteenth and early nineteenth centuries: a reply. *Economic History Review* 48[4]: 774-777.

Grigg, David B. 1967. The changing agricultural geography of England: a commentary on the sources available for the reconstruction of the agricultural geography of England, 1770-1850 *Transactions of the Institute of British Geographers* 41: 73-96.

Hatcher, John A. 2011. Unreal wages: long-run living standards and the 'golden age' of the fifteenth century. In Ben Dodds and Christian D Liddy, eds. *Commercial Activity, Markets and Entrepreneurs in the Middle Ages: Essays in Honour of Richard Britnell*. Woodbridge: Boydell Press, pp. 1-24.

Henderson, HCD. 1952. Agriculture in England and Wales in 1801, *Geographical Journal* 118[3]: 338-345.

Holderness, Brian A. 1989. Prices, productivity, and output. In Mingay, *Agrarian History of England and Wales,* pp. 1-118.

Hoskins, WG. 1949. The Leicestershire crop returns of 1801, in WG Hoskins, ed. *Studies in Leicestershire Agrarian History*. Leicester: Leicestershire Archaeological and Historical Society.

Johnson, F, A Mavrogianni, M Ucci, A Vidal-Puig, and J Wardle. 2011. Could increased time spent in a thermal comfort zone contribute to population increases in obesity?, *Obesity Reviews* 12[7]: 453-551.

Kelly, Morgan, Joel Mokyr, and Cormac Ó Gráda. 2012. Precocious Albion: human capital, living standards, and the industrial revolution.

Kelly, Morgan and Cormac Ó Gráda. 2011. Living standards and mortality in England since the middle ages: the poor law versus the positive check [available at: http://irserver.ucd.ie/dspace/bitstream/10197/2659/1/wp10_26.pdf].

Koepke, Nicola and Joerg Baten. 2005. The biological standard of living in Europe during the first two millennia. *European Review of Economic History*. 9: 61-95.

Livi Bacci, Massimo. 1991. *Population and Nutrition: An Essay on European Demographic History*. Cambridge: Cambridge University Press.

Logan, Trevon D. 2009. The transformation of hunger: the demand for calories past and present. *Journal of Economic History*. 69[2]: 388-408.

McCance, RA and EM Widdowson. 1960. *The Composition of Foods.* London: HMSO, London.

McCloskey, Deirdre N. 2010. *Bourgeois Dignity: Why Economics Can't Explain the Modern World. Chicago:* University of Chicago Press.

Mingay, Gordon E. ed. 1989. *The Agrarian History of England and Wales VI, 1750-1870.* Cambridge: Cambridge University Press.

Moore-Colyer, RJ. Livestock, in Mingay, *Agrarian History of England and Wales,* pp. 313-83.

Muldrew, Craig. 2011. *Food, Energy and the Creation of Industriousness*. Oxford: Oxford University Press.

Overton, Mark and BMS Campbell,. 1996. Production et productivité dans l'agriculture anglais, 1086-1871. *Histoire et Mésure* 11: 255-297.

Persson, Karl-Gunnar. 2009a. *An Economic History of Europe, 600 to the Present.* Cambridge: Cambridge University Press.

Persson, Karl-Gunnar. 2009b. The End of the Malthusian Stagnation Thesis [available at: http://www.econ.ku.dk/europe/earlygrowth.htm].

Salaman, Redcliffe N. 1949. *The History and Social Influence of the Potato*. Cambridge: Cambridge University Press.

Leigh Shaw-Taylor, EA Wrigley, RS Davies, PM Kitson, G Newton and AEM Satchell. 2010. The occupational structure of England c.1710 to c.1871: work in progress.

Sheail, John.1971. Changes in the supply of wild rabbits I790-I9I0. *Agricultural History Review* 19(2): 175-177.

Shils, Maurice Edward and Moshe Shike. 2006. *Modern Nutrition in Health and Disease*, 10th ed. Amsterdam: Kluwer.

Skoufias, Emmanuel, Vincenzo Di Maro, Teresa Gonzalez-Cossio, and Sonia Rodriguez Ramirez. 2009. Nutrient consumption and household income in rural Mexico. *Agricultural Economics* 40: 657–675.

Skoufias, Emmanuel, Sailesh Tiwari, and Hassan Zaman. 2011. Crises, food prices, and the income elasticity of micronutrients: estimates from Indonesia, *World Bank Economic Review*, available online November 22.

Solar, Peter M. 1989. The Great Famine was no ordinary subsistence crisis. In EM Crawford, ed. *Famine: The Irish Experience 900-1900*. Edinburgh: John Donald, pp.112-133.

Subramanian, Shanker and Angus Deaton. 1996. The demand for food and calories. *Journal of Political Economy* 104[1]: 133-62.

Thomas, Brinley. 1982. Feeding England during the Industrial Revolution: a view from the Celtic fringe. *Agricultural History*, 56[1]: 328-342.

Thomas, David. 1958-60. The acreage returns of 1801: a test of their accuracy. *Bulletin of the Board of Celtic Studies* 18: 379-83.

Thomas, D and Strauss, J. 1997. Health and wages: evidence on men and women in urban Brazil. *Journal of Econometrics* 77[1]: 159–85.

Toutain, Jean-Claude. 1995. Food rations in France in the eighteenth and early nineteenth centuries: a comment. *Economic History Review*. XLVIII[4]: 769-773.

Trow-Smith, Robert. 1959. *A History of British Livestock Husbandry 1700-1900*. London: Routledge & Kegan Paul.

Turner, Michael E. 1981. Arable in England and Wales: estimates from the 1801 Crop Return. *Journal of Historical Geography* 7[3]: 291-302.

Turner, Michael E. 1998. Counting sheep: waking up to new estimates of livestock numbers in England c. 1800. *Agricultural History Review* 46[2]: 142-61.

Turner, Michael, John V Beckett, and Bethanie Afton. 2001. *Farm Production in England, 1700–1914.* Oxford: Oxford University Press.

Voth, Hans-Joachim. 1998. Time and work in eighteenth-century London. *Journal of Economic History* 58[1]: 29-58.

Woolgar, CM. 2006. *Food in Medieval England: Diet and Nutrition.* Oxford: Oxford University Press.

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