ENGLISH AGRICULTURAL OUTPUT AND LABOUR PRODUCTIVITY, 1250-1850: SOME PRELIMINARY ESTIMATES

Alexander Apostolides, University of Warwick, A.Apostolides@warwick.ac.uk
Stephen Broadberry, University of Warwick, S.N.Broadberry@warwick.ac.uk
Bruce Campbell, Queen's University Belfast, b.m.campbell@qub.ac.uk
Mark Overton, University of Exeter, M.Overton@Exeter.ac.uk
Bas van Leeuwen, University of Warwick, bas.vanleeuwen1@googlemail.com

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Abstract: This paper provides annual estimates of English agricultural output and labour productivity during the period 1250-1850, based on manorial records from the medieval period, probate inventories from the early modern period and farm accounts from the modern period. Agricultural labour productivity increased sharply in the immediate aftermath of the Black Death and remained at this higher level for the rest of the medieval period. There was a further increase between the mid-fifteenth and mid-sixteenth centuries, with labour productivity remaining at this higher level until the early eighteenth century. These pre-modern increases in labour productivity were achieved without a substantial increase in output per unit of land. The early eighteenth century saw the start of a continuous upward trend in both agricultural labour productivity and land productivity.

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I. INTRODUCTION

Two very contrasting view of the development of the English economy between the late medieval period and the Industrial Revolution co-exist. One view, which has been based largely on real wage evidence, paints a bleak picture of long run stagnation from the late thirteenth century to the middle of the nineteenth century, albeit with quite large fluctuations over sustained periods (Phelps Brown and Hopkins, 1981). This view has recently been supported by Clark (2005), who provides a real wage series which shows less extreme fluctuations than that of Phelps Brown and Hopkins, but leaves the trend unchanged. Furthermore, Clark (2007a) adds new time series for land rents and capital income to arrive at a picture of long run stagnation in GDP per head. This view sits uneasily with a second view, based largely on estimates of wealth and the appearance of new products, which appears to show modest but sustained growth of living standards between the middle ages and the Industrial Revolution (Overton, Whittle, Dean and Haan, 2004; de Vries, 1994).

These two very different views of the long run development of the English economy have been able to co-exist because of the absence of reliable and empirically well grounded estimates of the output and labour productivity of the English economy over much of this period. This paper forms part of a project to reconstruct the national income of Britain and Holland between the late thirteenth century and the mid-nineteenth century. Here, we focus on agriculture, the largest sector of the economy for much of the period under consideration, providing annual estimates of agricultural output for England

over the long period 1270-1850 and putting them together with estimates of the agricultural labour force to track the path of agricultural labour productivity.

The approach builds on the pathbreaking study of Overton and Campbell (1996), which tracked long run trends in agricultural output and labour productivity, but was restricted to estimates for a small number of benchmark years. To provide annual estimates, we rely heavily on three data sets assembled for the medieval, early modern and modern periods. For the medieval period, we analyse the Medieval Accounts Database assembled by Campbell (2000; 2007), drawing upon the archival labours of a number of other historians, including David Farmer, John Langdon and Jan Titow. The information on arable yields and animal stocking densities is taken largely from manorial accounts, but is supplemented by information on the non-manorial sector from tithes. For the early modern period, we use the probate inventory database assembled by Overton, Whittle, Dean and Hann (2004), which provides indirect estimates of arable yields and animal stocking densities from the valuation of the assets left by farmers. From the early eighteenth century on, we make use of the database on farm accounts assembled by Turner, Beckett and Afton (2001).

The trends that emerge from these three datasets are broadly consistent, which increases our confidence in the underlying data. Furthermore, the national accounting perspective suggests other tests which can be conducted to demonstrate consistency.

The paper proceeds as follows. Section II provides a brief introduction to the main data sources for the three periods. Estimates of output for the arable sector are then given in section III, followed by estimates of pastoral sector output in section IV. The arable and pastoral outputs are then combined in section V to provide estimates of overall agricultural output. The index of overall agricultural output is then combined with estimates of population and the agricultural labour force in section VI to provide an overview of the path of agricultural labour productivity. Estimates from the output side are then cross-checked against estimates from the income side and per capita consumption of calories in section VII. Section VII concludes.

II. DATA SOURCES

1. The medieval period, c.1250 to c.1450

The most important data source for the medieval period is the Medieval Agricultural Database assembled by Bruce Campbell (2000; 2007). This relies heavily on manorial accounts, which were drawn up according to a common template by the reeve who managed the demesne under the close supervision of the lord's bailiff or steward (Campbell, 2000: 2). These accounts provide detailed information on crops, animals and livestock products and the purchase and maintenance of capital equipment. In some cases, they also provide information on the labour services provided by villeins, which can be used to estimate per worker labour productivity per task (Karakacili, 2004).

The number of manorial accounts which have survived varies over time, with decadal averages plotted in Figure 1. The fourteenth century is well represented, but the

records are less abundant for the thirteenth and fifteenth centuries. There is a bias within the sample towards large ecclesiastical estates with long runs of data, which provides a challenge to those wishing to generalise from the data. In particular, the geographical coverage is uneven, with the south and east of the country over-represented, sometimes to an overwhelming extent. These issues have been dealt with by applying a regional weighting scheme, with the regions defined by patterns of account survival and weighted by their respective cropped area in 1801, as specified in Table 1. Regional weights for each crop are derived from the total cropped area of each region in 1801 and the varying shares over time of the main crops within each region derived from the manorial accounts.

Care must be taken in moving from data on the seigniorial sector to inferences about the development of English agriculture as a whole, since the non-seigniorial sector was always larger than the seigniorial sector and the relative sizes varied over time. Even at its peak in the early fourteenth century, the seigniorial sector probably accounted for no more than around 25 to 30 per cent of all agricultural land and output (Campbell, 2000: 26). Although the evidence on the non-seigniorial sector is more disparate, data do exist, which can be used to verify or qualify trends reconstructed from the manorial accounts. Postan (1962) made use of tax returns to shed light on the relative stocking densities of demesne and peasant holdings, and some of his evidence has recently been re-examined by Bailey (1989: 115-135). As a result of the pioneering work of Langdon (1986), much is also known about the relative numbers and types of draught animals on seigniorial and non-seigniorial holdings. More recently, Dodds (2004; 2007) has used

tithe records to shed light on annual variations in grain output, and a few tithe series contain wool output. Campbell (2007) shows that there is a close correlation between year-on-year fluctuations in crop yields derived from manorial accounts and annual changes in tithe receipts.

Seigniorial and non-seigniorial producers faced a common environment and commercial opportunities and a common technology, while there was much overlap between their labour forces. Hence, where peasants led, lords were likely to follow and vice versa (Campbell, 2000: 1). However, there were important differences in scale of production, capital resources, consumption priorities, vulnerabilities to risks and hazards and methods of decision making. Between the mid-thirteenth century and the mid-fourteenth century, factor costs and property rights encouraged lords to manage their demesnes directly and concentrate on arable production. Following the Black Death, however, lords found it increasingly difficult to obtain customary labour, and increasingly expensive to hire wage labour, following a substantial increase in wage rates. Those lords who continued to farm directly switched away from labour intensive arable production to mixed husbandry and pastoral production, leaving arable production to peasants who could rely mainly on family labour and were unburdened by administrative overheads. Increasingly, lords thus found it more profitable to lease out their demesnes, and by the mid-fifteenth century, very few demesnes were directly managed.

In the calculations that follow, trends in grain yields per unit area on the demesne lands are taken as representative of arable farming as a whole. Patterns of demesne cropping are also treated as broadly representative of arable husbandry in general. The total amount of land under crop at its maximum is based upon the equivalent area in 1801, with allowance made for net changes in the interim arising from reclamation and enclosure on the one hand and the conversion of tillage to pasture on the other. Deviations from that maximum pre and post *c.*1300 are determined from trends in demesne sown areas and aggregate tithe receipts. Estimates of the amounts of grain consumed in the production process as seed and fodder are based upon relevant information contained in the manorial accounts. With these four items of information — crop yields, crop proportions, crop areas, and grain used as seed and fodder — it is a comparatively straightforward exercise to estimate the total net output of each crop each year. Self evidently, in the absence of significant grain imports the total net output of grain had to be sufficient, when converted into bread, pottage, and ale, to satisfy the nation's food and drink requirements at a time when grain probably supplied on average at least 75 per cent of all kilocalories consumed.

Deriving equivalent estimates for livestock is more problematic, since it is less likely that stocking densities and stock proportions within the seigniorial sector are broadly representative of all classes of producer. On the contrary, there is good evidence to suggest that significant differences existed between the relative numbers and types of animals stocked on large demesne and small peasant holdings, Moreover, these differences probably widened following the Black Death as contrasting factor costs lent

greater momentum to the shift away from arable farming within the demesne sector. This applies in particular to sheep, where trends in the seigniorial and non-seigniorial sectors were very different. The one certain fact about sheep is the numbers needed to produce the fleeces exported as wool and woollen cloth recorded from 1275 in the annual customs accounts. How many additional sheep were engaged in supplying wool to the domestic market is then a matter of estimation. For these reasons, estimates for the pastoral sector are subject to greater uncertainty than those for the arable and are likely to undergo significant revision as further information becomes available.

2. The early modern period, c.1550 to c.1750

Between the mid-sixteenth and the mid-eighteenth centuries, we rely on probate inventories for our basic information on agriculture. Probate inventories recorded the area of major crops and the stock of farm animals, as well as their values at the time of a farmer's death. From this information, it is possible to derive the key magnitudes that were recorded directly in the medieval manorial accounts: grain yields and animal stocking densities. Probate inventories containing this information first became available in the 1550s, but declined from the early eighteenth century as church courts no longer kept the inventories once probate had been granted. The number of inventories in the sample is plotted in decadal average form in Figure 2, for comparison with the manorial accounts database. Perhaps surprisingly, the early modern period is less well served than the medieval period for surviving records on the agricultural sector.

To derive grain yields from probate inventories, the starting point in Overton (1979) is the identity $v=py$, where v is the valuation per acre of growing grain recorded in probate inventories, p is the price per bushel after the harvest and y is the yield in bushels per acre. The yield is thus obtained from the valuation and the price as:

$$y = v/p \quad (1)$$

However, the calculations are more complex in practice because appraisers subtracted 10% of gross output for tithes, and care must also be taken to allow for the costs of reaping (r), threshing (t) and carting (c), which affected the value that the appraisers placed on a growing crop. Allen's (1988) valuation equation, accepted by Overton (1990) and Glennie (1991) thus becomes:

$$v = 0.9\,(py - ty - c) - r \quad (2)$$

Rearranging for comparison with equation (1), the yield becomes:

$$y = \frac{v + r + 0.9c}{0.9(p - t)} \quad (3)$$

A further complication concern the months used for the crop valuations, since appraisers often valued crops in early months of the year by listing the costs incurred in bringing the crop to its current condition, thus resulting in spuriously low yields. Allen (1988) excludes these observations by setting a minimum yield of 5 bushels per acre, but this has the disadvantage of also excluding genuinely bad harvests. We follow Overton (1979: 369) in restricting our attention to valuations in the months of June to August.

As in the medieval period, care must be taken in generalising to the national level from individual farm observations. Although inventories have survived for a wide range of farm sizes, the very largest and the very smallest farms are under-represented (Overton

and Campbell, 1992: 380). But perhaps most importantly, the geographical coverage of the probate inventories sample is heavily skewed to the south of the country (Cornwall, Durham, Hertfordshire, Kent, Lincolnshire, Norfolk, Suffolk and Worcestershire). These issues have been dealt with in a similar fashion to those of the medieval period, by applying a regional weighting scheme based on the total cropped area of each region in 1801 and the varying shares over time of the main crops within each region. Regional shares of sown acreage are taken from Turner (1981), based on the 1801 crop returns and the Early Modern Probate Inventories Database for other years.

In contrast to the medieval period, there are no continuous runs of data on individual farms, but only one-off observations determined by the death of farmers. In estimating grain yields and stocking densities, this is dealt with by assuming comparable series in similar agricultural regions, hence introducing a time series aspect, as suggested by Clark (2004). The animal sector was calculated on the basis of stocking densities (animals per hundred sown acres) that can vary from 0 (no animals on a farm) to a very high figure. A modification of Clark's (2004) method was therefore necessary, using a tobit regression in order to capture farms with a stocking density of 0. Because the variance of farm size in the early modern period is considerably higher than that of the domain sector in the medieval period, which has a strong impact on the stocking densities, we introduced dummy variables to capture farm size.

It will be apparent that there remains a statistical dark age for grain yields and animal stocking densities between the decline of the manorial sector in the late fifteenth

century and the systematic appearance of probate inventories in the mid-sixteenth century. We propose to deal with this period by using information on prices and income to estimate the demand for agricultural goods, as suggested by Crafts (1976; 1985) and further explored for the modern period by Allen (1994; 2000). This can be done both by projecting forwards on the basis of a medieval demand system and by projecting backwards on the basis of an early modern demand system.

3. The modern period, c.1700 to c.1850

Perhaps surprisingly, the least well documented period is that nearest the present. However, an important step forward has recently been taken with the collection by Turner, Beckett and Afton (2001) of a sample of farm accounts from the 1720s to the outbreak of World War I. These farm accounts are much less standardised than the medieval manorial accounts, but they do provide crucial data on the amount of land in use and crops sown and harvested, which allows the derivation of grain yields. Perhaps disappointingly, data on numbers of farm animals were not systematically collected, although there are some data on sales of animals.

As with the medieval and early modern samples, the modern sample of farm records is uneven in both temporal and spatial coverage. Figure 3 sets out the chronological distribution of the sampled farm records. Although the evidence is relatively thin for the first half of the eighteenth century, this period can be bolstered by the surviving probate inventories. The sample is stronger for the first half of the nineteenth century. The spatial distribution of farm records is more even than for the

medieval and early modern periods, with the north and west of the country almost as well represented as the south and east (Turner, Beckett and Afton, 2001: 64). Nevertheless, it is still important to apply a regional weighting scheme, as for the earlier periods. There is, of course, a danger that the surviving records are biased towards the better run farms, since there was no requirement to keep farm accounts. However, the farm accounts data are checked against the probate inventory data in the first half of the eighteenth century and against the official output data from the late nineteenth century to gauge yield levels.

Given the lack of data on animal stocking densities in the farm accounts, animal numbers have been gleaned from estimates by agricultural historians for benchmark years, and interpolated using data on annual sales at Smithfield Market from Mitchell (1988: 708). Pastoral sector outputs have also been checked against estimates using the demand approach outlined in the previous section, the results of which are discussed in Broadberry and van Leeuwen (2008).

III. ARABLE OUTPUT AND ITS COMPONENTS

1. Land use

The starting point for any estimate of the output of the arable sector is the total area under crop, which is set out in Table 2A. For most benchmark years, the data are taken from Overton and Campbell (1996). Firm estimates of land use only became available in the agricultural returns for 1871, which therefore provides the starting point for the series. For 1830, the figures come from the tithe files and for 1800, 1750 and 1700 from estimates by contemporaries (Holderness, 1989). The estimates for 1600 have been

inferred by extrapolating backwards from these later figures. For the medieval period, the starting point is the estimate for 1300, when the population attained its medieval peak. Contrary to the claims of Clark (2007a: 124), it is unlikely that the sown area in 1300 could have been above the 1800 acreage. Estimates for 1420, 1380, and 1250 are obtained by extrapolation from 1300 on the basis of trends in the cropped acreage on demesnes and tithe data (Campbell *et al.,* 1996). Total arable land in use fell across the Black Death as population declined sharply, and increased continuously from a low point in the fifteenth century.

Having obtained estimates of the overall arable acreage in use, the next step is to allocate it between fallow and the major crops sown. This information is taken from the three datasets described in section II. The amount of fallow land is first subtracted in Table 2A, and the resulting sown area is allocated between the major crops in Table 2B. The proportion in fallow was typically around one third in the medieval period, falling below a quarter in the early modern period and to just 3.5 per cent by 1871. The regional distribution of the crop totals contained in Table 2B is given in Table 3 for the seven regional groupings adopted for structuring and weighting the available agricultural data. These weightings are crucial to the process of aggregating to a national level from data that are intrinsically local and of uneven geographical coverage. Each region's share of the national sown acreage is taken from the 1801 crop returns. Within each region, the breakdown of crops is based upon information provided by the medieval and early modern databases, and for later periods by Holderness (1989) and Overton (1996). Amongst the principal winter-sown crops, wheat remained important throughout the

period, but rye and maslin (a mixture of wheat and rye) declined sharply during the early modern period. Amongst the spring-sown crops, barley and dredge (a mixture of barley and oats) remained important throughout the period, but oats declined in relative importance. The biggest increase in the use of arable land was in potatoes and other crops, particularly after 1700. The most rapid increase in other crops was in clover and root crops such as turnips, parsnips and rape. Since clover fixes more nitrogen, its growing use led to a substantial improvement in soil quality (Overton, 1996: 110). The increasing share of turnips in sown acreage provided a more solid food base for the animal stock in the winter and increased opportunities for manuring the land, since the animals were allowed to graze on the land (Overton, 1996: 99-101).

2. Grain yields

To calculate the output from the estimated areas sown with each crop requires information on grain yields per unit area, net of seed sown. For the medieval and modern periods, direct information on the seed sown, areas sown and quantities of grain harvested and threshed can be obtained from manorial accounts and farm records. For the early modern period, grain yields have to be estimated indirectly from probate inventories following the approach set out in Section II.2, based on the work of Overton (1979; 1990), Allen (1988) and Glennie (1991).

Generating aggregate trends in grain yields from the information obtained from individual manors, probate inventories and farm accounts is not straightforward. The first problem concerns the regional weightings. Given the extent of variation in yields across

individual units of observation, it is necessary to ensure an appropriate regional coverage and to allow for the changing spatial composition of the sample. The available dataset has therefore been subdivided into the seven regional groupings identified in Table 1. Separate chronologies reconstructed for each of these regions have then been combined into a single weighted master chronology for the country as a whole. The early modern probate inventory data are necessarily one-off observations rather than time series, and the time series are typically rather short and discontinuous in the modern farm accounts and medieval manorial accounts databases. The chronologies are therefore derived using regression analysis with dummy variables for each farm and for each year, as suggested by Clark (2004). Since the dispersion of grain yields across farms is very high, it is important to use a log-linear specification, otherwise a small percentage drop in output on a high-yielding farm can outweigh a large percentage increase on a low-yielding farm. Adjustment has also been made for tithes deducted at source and assumed to have been 10 per cent of the gross harvested crop.

Annual variations and long-term trends in yields obtained in this way for wheat, barley, rye, oats and pulses are shown in Figures 4 to 8. In addition, summary information on gross yields per acre, seeding rates and net yields is presented in Table 4 as fifty-year averages, to abstract form short run fluctuations, which were very pronounced. As will be observed, the crops differed in their overall levels of yield, with rye delivering higher yields per acre than wheat in the medieval and early modern periods, with barley also delivering higher yields than oats in the medieval and early modern periods, and with pulses producing the lowest yields of all crops throughout the

period. Yields also varied a great deal from year to year and over longer periods of time. Although there is an unfortunate gap between the late fifteenth century and the mid-sixteenth century, the three data sets appear to tell a consistent story, with yields declining during the late medieval period from around 1300, picking up again during the early modern period from the mid-sixteenth century, and growing more rapidly during the modern period from the early eighteenth century. Eleven year moving averages have been shown as well as the annual data, to help to abstract from the high degree of short run volatility.

3. Consumption by working animals

In addition to making allowance for grain used as seed, calculation of the net output of the arable sector must take account of consumption of oats and pulses by animals working on the farm. For pulses it is assumed, following Allen (2005), that half of output was consumed by working farm animals and others, mainly swine, being fattened for meat. Oats consumed as fodder has been derived by estimating the number of working animals and consumption per animal.

For the medieval and early modern periods, respectively, estimates of the number of working animals per 100 sown aces can be obtained from the medieval accounts and probate inventory databases. For the early modern period, these stocking densities are assumed to apply to the whole agricultural sector and hence are simply multiplied with the sown acreage to produce estimates of the numbers of working animals. However, for the medieval period, the demesne stocking densities have been converted into the

numbers of horses and oxen on all lands using Wrigley's (2006: 449) assumption that the stocking density of animals on non-seigniorial holdings was three-quarters that on the demesnes. In making these estimates, allowance has been made for both the declining share of demesne acreage and the lesser quantities of fodder consumed by immature animals. For the modern period, direct estimates of animal numbers are taken from John (1989) and Allen (2005), since data on stocking densities are unavailable.

As with the crop yields, a regional weighting scheme is needed to derive the stocking densities for the country as a whole from the observations on individual demesnes and farms. The regional groupings chosen are different from those used for arable farming, reflecting the four main types of pastoral farming. Table 5 sets out the regional weights for the pastoral sector in 1300 and 1870. It is noteworthy that although by 1870 dairying had spread to counties where it had been scarce in 1300, the core activities of farms, especially in the north-western counties, had shifted towards the fattening of cattle.

Figure 9 sets out the numbers of mature working animals per 100 sown acres, while numbers of animals are shown in Table 6. There was a gradual process of substitution of horses for oxen as working animals, beginning in the medieval period. Whereas oxen outnumbered horses in the mid-fourteenth century, by the late eighteenth century Young (1771: 203) noted that the ratio of working farm horses to oxen in the northern counties was about ten to one. However, in many southern and eastern counties,

the ox had already been replaced by the horse several decades earlier (Perkins, 1975: 4). The use of oxen had more or less died out by the nineteenth century.

Overton and Campbell (1996) estimate the total consumption of oats by animals in 1800 as 70 percent of total net output. Assuming non-farm horses ate slightly more oats than farm horses, dividing the share of output consumed by animals by the number of animals results in an average consumption of 26 bushel per mature horse, since the number of oxen was set to zero from 1800 onwards. This is consistent with the estimate of Vancouver (1808) that a working horse consumed half a peck (one eighth of a bushel) during winter and periods of intensive work, which would amount to roughly 200 days a year. For both oxen and horses, immature animals are assumed to consume half the amount of mature animals (Allen, 2005 and Langdon, 1982; 1986), and the share of immature animals is assumed to be 35 percent (Wrigley, 2006). For the medieval period, the proportion of oats consumed by animals is assumed to be 50 per cent in 1600 and at most 30 per cent in 1300 (Overton and Campbell, 1996; Wrigley, 2006). Allowance is also made for the lower consumption per animal on non-demesne lands in 1300, as suggested by Langdon (1982), but with the difference disappearing by 1500 as the demesne sector effectively disappeared. Consumption of oats per animal in 1300 was 16 bushels for a horse and 2.72 bushels for an ox on demesne lands (or 8 and 1.36 bushels, respectively, on average across demesne and non-demesne lands).

4. Arable output net of seed and animal consumption

Table 7 provides a convenient summary of the estimated output of the arable sector, gross of tithes but net of seed and animal consumption. Output net of seed was obtained for each crop by multiplying the sown acreage from Table 2 with the net yields from Table 4, interpolating the sown area where necessary. Estimated consumption of oats and pulses by working animals, as specified in Table 6, was then subtracted to arrive at arable output net of seed and arable consumption.

During the medieval period, output of wheat and rye, the principal bread grains, declined substantially from the peak of the late thirteenth century, with a sharp fall in line with population following the Black Death of the mid-fourteenth century. The output decline was even sharper for oats, which fell out of favour as a crop for human consumption. In place of malted oats, malted dredge (a barley/oats mixture) and malted barley became the preferred brewing grains, and demand for barley remained buoyant. Output of pulses also held up well during the medieval period.

By the end of the sixteenth century, output of the major grains was back to the peak pre-Black Death level. Output of wheat continued to increase after 1600, while rye declined. This reflected the growing preference for the more expensive bread grain. The output of barley also increased markedly in line with the demand for better quality ale brewed from the best barley malt. Output of pulses also grew throughout the early modern and modern periods, but less rapidly than wheat and barley, while potatoes became an important crop during the eighteenth century. Output of oats, net of consumption by farm horses, fluctuated more erratically.

IV. PASTORAL OUTPUT

1. Numbers of non-working animals

The starting point for deriving the numbers of non-working animals is again the stocking densities. As with the working animals, particular care must be taken for the medieval period in moving from the stocking densities on the demesnes to the numbers of animals in the country as a whole. Conversion of the seigniorial stocking densities into corresponding national densities and numbers of animals is based on four key assumptions. First, following Allen (2005), it has been assumed that due to their high unit capital value, the density of cattle was one-third lower on the non-demesne lands. Second, again following Allen (2005), mature cattle have been divided into milk and beef animals in the ratio 53 to 47 percent. Third, swine, a quintessentially peasant animal, are assumed to have been stocked at double the density by non-seigniorial producers (Wrigley, 2006). Fourth, aggregate sheep numbers are assumed to have been stationary in the long term, in contrast to their dynamic growth in the seigniorial sector. This is consistent with trends in exports, inferred levels of domestic demand, and the decline in average fleece weights noted by Stephenson (1988: 380). Total sheep numbers have been set at 15 million in 1300, in line with the estimate of Wrigley (2006: 448). This was the number of animals needed to supply the wool export trade as recorded by the customs accounts (Britnell, 2004: 417) and a domestic consumption equivalent of 1.18 square yards per head *per annum*, on the reckoning that domestic production supplied labourers with 1 square yard of woollen cloth, substantial tenants with 2 square yards and landowners with 8 square yards, weighting the different social classes according to the

social tables of Campbell (2008). Applying these assumptions to the stocking densities on the demesnes yields the national stocking densities for the medieval period, which can be compared with the national stocking densities obtained directly from the early modern probate inventories database. Applying these stocking densities to the sown acreage yields the animal numbers shown in Figure 10 and Table 8. Since stocking densities are unavailable for the modern period, animal numbers for benchmark years during this period are taken directly from contemporary estimates, summarised in John (1989). Data for intervening years are interpolated using data on annual sales at Smithfield Market from Mitchell (1988: 708). Since sales data for pigs are unavailable in this source, fluctuations in pig numbers are assumed to follow fluctuations in cattle numbers, on the basis of the strong relationship between the two series in the medieval and early modern periods.

2. Pastoral sector output

Calculating the output of the pastoral sector is more speculative than the equivalent calculation for the arable sector, since the percentages of animals producing specific products and the yields per animal have attracted less attention from historians than crop yields. Until more systematic work is done on the sources, the estimates advanced here are necessarily provisional.

The proportions of animals assumed to have been producing milk, meat and wool are set out in Table 9. For simplicity, all cows are assumed to have produced milk and all sheep to have yielded wool. Meat, however, was produced only by those animals that

were slaughtered. Following Holderness (1989: 147), it is assumed that a quarter of the stock of cattle and sheep and all pigs, apart from those retained for breeding, were slaughtered. These basic assumptions have been qualified with additional information from Clark (1991) and Ecclestone (2006).

The next step in the calculations involves the estimation of yields of milk, meat and wool per animal. Table 10 sets out preferred estimates, drawn from a number of sources, including Clark (1991), Allen (2005), Stephenson (1988) and Britnell (2004). Finally, Table 11 combines the information in Tables 8, 9 and 10 to provide estimates of output in the pastoral farming sector.

3. Hay, hides and dairy products

Further assumptions are needed to derive output estimates for hay, hides and skins (for leather and parchment), and dairy products (milk, butter and cheese). Hay output in Table 12 has been inferred from estimates of the total number of horses, on the assumption that each horse consumed approximately 2.4 tons of hay per year (Allen, 2005). Hay consumption fluctuated without a clear trend during the medieval period, then increased strongly from the seventeenth century.

Hide and skin output was a function of the numbers of animals, the proportions slaughtered or dying, and the respective weights of their skins. The numbers of animals are taken from Tables 6 and 8, while the percentages of animals yielding hides are taken from Clark (1991) and Ecclestone (1996). The percentages of animals providing hides is

assumed to be stable throughout the period, but hide weights changed over time with the size of animals. Hide weights are established for benchmark years of 1300 and 1800 and interpolated log-linearly. The hide weights for 1800 are based on the estimates of Clarkson (1989), while those for 1300 rely also on the work of Ecclestone (1996). Total output of hides and skins declined during the medieval period, although the supply of skins from sheep remained relatively stable while the supply from cattle and oxen fell. From the sixteenth century there was a clear upward trend in the supply of hides, with strong growth from cattle as well as sheep. There was also a substantial increase in the supply of hides from horses, reflecting the growing use of horses both on and off farms.

In the dairy sector, the bulk of the milk output in Table 11 was used on the farm to produce butter and cheese. The breakdown of the total milk production between butter, cheese and fresh milk is shown in Table 14. For the medieval period, the cheese to butter ratio is based on Biddick's (1989: Appendix 5) study of the estates of Bolton Priory in the Pennine uplands of northern England. For the modern period, the division between fresh milk, butter and cheese is taken from Holderness (1989: 169-170), who provides data for 1750, 1800 and 1850. The breakdown for other years is based on log-linear interpolation. The output of the dairy sector as a whole is constrained to move in line with total milk output in Table 11, declining during the medieval period but trending upwards strongly from the sixteenth century. The share of fresh milk in total milk output was stable during the medieval period, but increased from the late seventeenth century. The ratio of butter to cheese also increased during the modern period, with butter becoming more important over time. The high share of cheese in dairy output during the medieval period was a

result of the fact that butter spoils quickly, so that it was not a practical way of preserving the nutrients of milk (Dyer, 1988). However, this changed from the early eighteenth century as a result of improvements in hygiene and the introduction of the barrel churn, mounted on a wooden stand so that it could revolve, and fitted with handles to turn it (Fussell, 1963: 217).

V. TOTAL AGRICULTURAL OUTPUT

Multiplying the output volumes by their prices yields the total value of net output. The price data are taken largely from Clark (2004), who synthesises the published data of Beveridge (1939), Thorold Rogers (1866-1902: volumes 1-30) and the multi-volume *Agrarian History of England and Wales*, as well as integrating new archival material, principally from the unpublished papers of William Beveridge and David Farmer. To this, have been added the prices of hides from Thorold Rogers (1866-1902: volumes 1-30) and of rye from Farmer (1988; 1991). Where there are large gaps in the price data for individual products, regression analysis has been used to interpolate the missing values. Output can be valued in both current prices and in constant 1700 prices.

Figure 11 plots arable, pastoral and total agricultural output in constant prices on a logarithmic scale, while Table 15 summarises the same information in growth rate form, using 5-year averages. During the medieval period, arable output exhibited a downward trend, while pastoral output showed long run stability. Agriculture as a whole thus showed a modest decline in output. As a result of these trends, the pastoral sector increased its share of output in constant price terms. The increasing share of the pastoral

sector during the medieval period can also be seen in current price terms in Figure 12 and Table 16. The current price share is affected by the trend in the relative price of pastoral to arable products, as well as the real growth rates of the two sectors, but during the medieval period there was no long run shift in the relative price ratio (Figure 13). From the mid-sixteenth century, arable and pastoral output grew at similar rates in real terms. This resulted in a declining share of the pastoral sector in current price output because of a fall in the relative price of pastoral products.

VI. AGRICULTURAL LABOUR PRODUCTIVITY

To see what happened to labour productivity, it is necessary to provide estimates of the total population and the share working in agriculture. Although the population of England has been reconstructed firmly by Wrigley and Schofield (1989) and Wrigley et al. (1997) for the period since the compulsory registration of births, marriages and deaths, estimates before 1541 are more speculative. The biggest controversy concerns the size of the population before the Black Death, with the 1380 data more firmly grounded in the poll tax returns. In Table 17, the population in 1300 is set at 4.25 million, following Overton and Campbell (1996: Table II). This lies well below the 6 million suggested by Hatcher (1977) and Smith (1991), but is better in accordance with the consumption data (see section VII). Additional observations have been added between 1300 and 1380 by interpolation using assumptions derived from the literature. This involves the assumption of a slow rate of decline in the population, punctuated by the dramatic decline of the Black Death years, 1348-51, and a number of smaller crises. The agricultural population

is obtained by subtracting estimates of the urban and rural non-agricultural population from Overton and Campbell (1996: Table II).

Combining the agricultural output series with the agricultural population data produces our estimates of agricultural output per labourer in Figure 14. Table 18 presents the same material in growth rate form. The first main finding is that agricultural labour productivity increased sharply in the immediate aftermath of the Black Death and remained at this higher level for the rest of the medieval period, albeit with substantial fluctuations. The second main finding is that there was a further step-up in agricultural labour productivity between the mid-fifteenth and mid-sixteenth centuries, with labour productivity remaining at this higher level until the early eighteenth century, but again with substantial fluctuations. Contrary to the long run stagnationist view of writers such as Phelps Brown and Hopkins (1981) and Clark (2007a), then, the English economy was characterised by trend labour productivity growth through the medieval and early modern periods, averaging out at nearly 0.2 per cent per annum between 1250 and 1700. England on the eve of the Industrial Revolution was therefore a much richer and more developed economy than pre-Black Death England. A third main finding is that the improvement in labour productivity became a much more continuous process from the early eighteenth century. Fourth, the rate of labour productivity growth slowed down substantially during the second half of the eighteenth century before strong growth resumed during the first half of the nineteenth century.

It should be noted that the increase in output per worker across the Black Death resulted largely from an increase in land per worker rather than an increase in output per unit of land, which is shown here in Figure 14. Although there is some evidence of a small increase in output per acre between the medieval and early modern periods, the main source of the rising output were worker was again an increase in land per worker as the number of people working in agriculture continued to decline until the early sixteenth century. The more continuous labour productivity growth from the early eighteenth century was accompanied by strongly rising output per unit of land.

VII. CROSS-CHECKING THE OUTPUT ESTIMATES

1. Income and output based measures

Figure 16 charts the indexed daily real wage of an unskilled farm labourer between 1250 and 1850. In contrast to the upward trend of agricultural output per worker, daily real wages in agriculture stagnated over the long run. Putting the two series together in Figure 17 inevitably raises the issue of their compatibility. Here, this issue is pursued within the framework of historical national accounting, where the value of net output should equal the value of factor payments to labour, land and capital.

Starting on the income side, data on daily wages and the number of days worked are needed to calculate payments to labour. The agricultural population estimates from Table 17 are converted into the number of agricultural families in panel A of Table 19 on the assumption that the average family consisted of two adults and 2.5 children (Allen, 2005). Allen (2005) then calculates the number of days needed to produce the output and

divides this by the number of families to arrive at the days worked per family. Allen's figure for days worked per family in 1300 has to be increased in order to reconcile it with the data and results presented here. In contrast, his estimate for 1500 requires substantial adjustment downwards, for two reasons. First, the estimate of output in the late fifteenth century presented here on the basis of the medieval accounts database is substantially lower than that assumed by Allen, who finds that despite a halving of the population, agricultural output increased between 1300 and 1500. Second, the substantial increase in days worked per family which Allen requires to achieve that increase in output would be hard to square with most accounts of the response to the Black Death, which suggest a decline in labour intensity (Bowden, 1967: 593-594). On the evidence summarised in Panel A of Table 19, there was a substantial decrease in the number of days worked per family between 1270 and 1450, consistent with an "indolent revolution" in contrast to the suggestion of an "industrious revolution" in the early modern period (de Vries, 1994). The industrious revolution can be seen in the substantial increase in days worked per family between the sixteenth and nineteenth centuries.

To estimate total rental income requires data on rents and total land in use, set out in Panel B of Table 17. Rents are obtained from the data of Clark (2001) and Turner *et al.*, 1997). The total land in use has to include pasture and meadow as well as arable land, and is taken from Table 2, but multiplied with the ratio of pasture and meadow to arable land from Allen (2005). Capital costs and tithes and taxes are also taken from Allen (2005). Adding together wages, rents, capital incomes and tithes and taxes yields the total incomes in Panel C, which matches reasonably well the value of output.

2. Consumption and output

An alternative way of assessing the credibility of the output estimates is to see what they imply about the level and sufficiency of consumption per head. Converting the output of the major grains in Table 7 to kilocalories and dividing by the population from Table 17 yields the per capita consumption levels shown in Table 20. Figures in this table are 20-year averages, to abstract from short run fluctuations. It is reasonable to assume that in a relatively poor and predominantly agrarian economy such as that of medieval England, at least three-quarters of daily kilocalorie food requirements were on average supplied by grain. Livi-Bacci (1991) believes that for a population to have been adequately fed required an average food intake of 2,000 kilocalories *per capita* per day. Adult males labouring on the land would have required about twice this. Net grain output in agriculture when processed into pottage, bread and ale, thus needed to be able to deliver at least 1,500 kilocalories per person per day to meet the basic subsistence needs of the population until that population was sufficiently affluent to devote a larger share of its budget to dairy produce, meat and fish or meet a substantial proportion of its food requirements from imports.

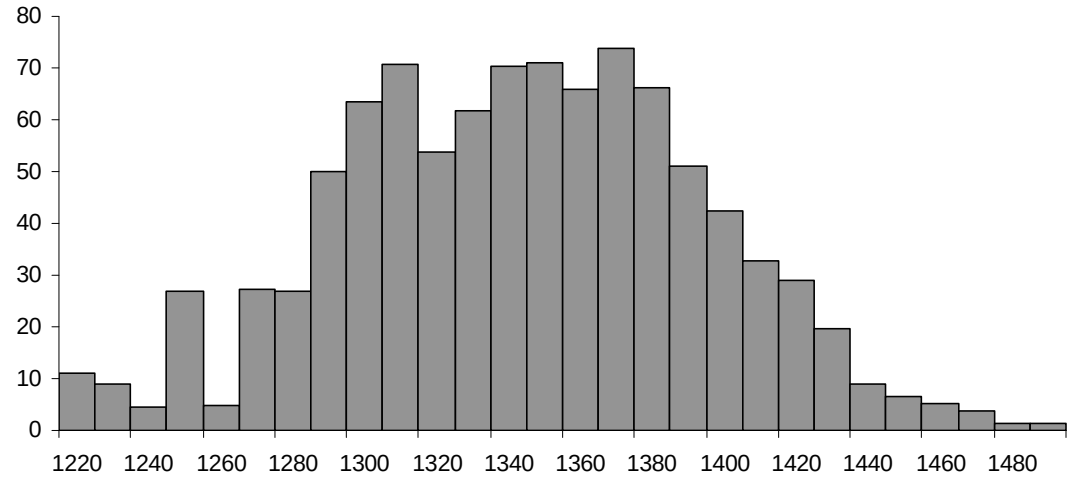
The estimates suggest that grain output was sufficient to meet society's needs after the Black Death, but was significantly less so in 1300. The picture of English society in the half century before the Black Death that emerges from this table is one of an economy under pressure. Note also that it is hard to see how a population much above the 4.25 million assumed her could have been sustained, given the grain yields and the

levels of land use underpinning the output estimates. Although per capita grain consumption fell back subsequently, the growing share of the pastoral sector would have provided a higher proportion of kilocalories in 1450 and 1600. By the eighteenth century, the increase in population was once more putting pressure on the adequacy of the diet, but by 1800, per capita consumption of kilocalories from grain production, supplemented by potatoes and grain imports, was again above sufficiency.

VIII. CONCLUSIONS

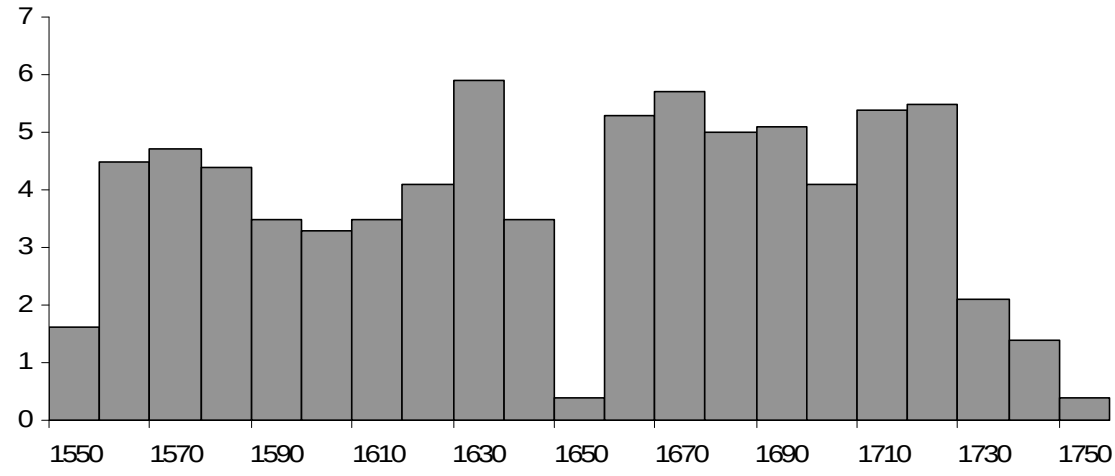
This paper has provided the first annual estimates of English agricultural output and labour productivity during the period 1250-1850. The estimates rest on a detailed reconstruction of arable and pastoral farming, built up from manorial records during the medieval period, probate inventories during the early modern period and farm accounts during the modern period. Agricultural labour productivity increased sharply in the immediate aftermath of the Black Death and remained at this higher level for the rest of the medieval period. There was a further increase between the mid-fifteenth and mid-sixteenth centuries, with labour productivity remaining at this higher level until the early eighteenth century. These pre-modern increases in labour productivity were achieved without a substantial increase in output per unit of land. The early eighteenth century saw the start of a continuous upward trend in both agricultural labour productivity and land productivity.

FIGURE 1: Number of sampled manors per year in the middle ages (decadal averages)



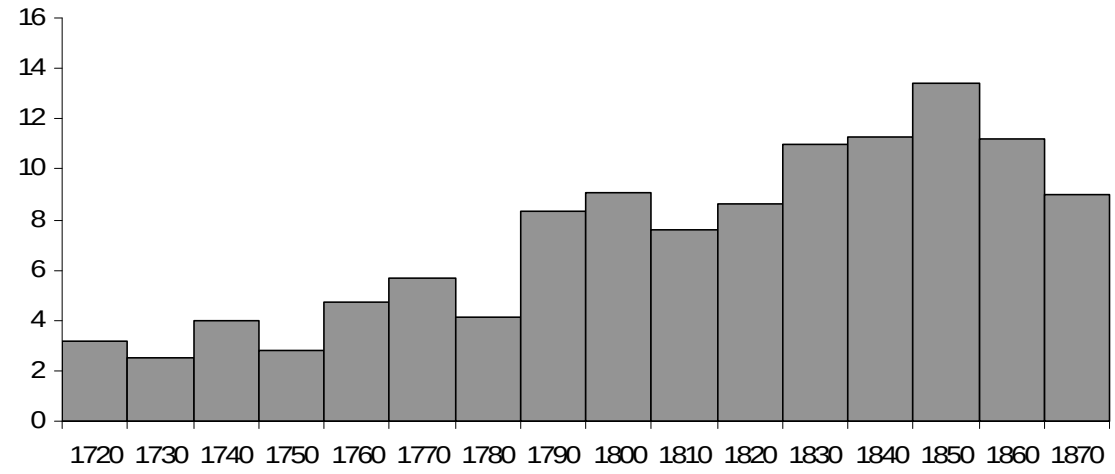
Source: Medieval Accounts Database.

FIGURE 2: Number of sampled observations per year in the early modern period (decadal averages)



Source: Early Modern Probate Inventories Database

FIGURE 3: Number of sampled observations per year in the modern period (decadal averages)



Source: Modern Farm Accounts Database

TABLE 1: Regional shares of the national sown area in 1801

Region	**Counties**	**%**
East Anglia	Norfolk and Suffolk:	15.3
Eastern counties	Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Huntingdonshire, & Lincolnshire:	16.7
Southern counties	Berkshire Gloucestershire, Hampshire, Herefordshire, Wiltshire, & Worcestershire:	15.5
Southwest	Cornwall, Devon, Dorset, & Somerset:	8.9
Southeast	Kent, Middlesex, Surrey, & Sussex:	8.5
Midlands	Buckinghamshire, Leicestershire, Northamptonshire, Oxfordshire, Rutland, & Warwickshire:	9.1
North	Cheshire, Cumberland, Derbyshire, Durham, Lancashire, Northumberland, Nottinghamshire, Shropshire, Staffordshire, Westmorland, & Yorkshire:	26.0

Source: Turner (1981: Table 1).

TABLE 2: Arable land use (millions of acres)

A. Total area

	Total arable	Fallow arable	Sown arable
1250	10.30	3.68	6.62
1300	10.53	3.77	6.76
1380	7.98	3.22	4.76
1420	7.09	2.97	4.13
1600	8.23	2.00	6.23
1700	9.00	1.80	7.20
1750	9.90	1.50	8.40
1800	10.69	1.20	9.49
1830	14.19	1.33	12.86
1871	13.83	0.48	13.35

B. Sown area

	Wheat	Rye/ Maslin	Barley/ Dredge	Oats	Pulses	Potatoes	Other crops	Total sown
1250	1.89	0.71	1.13	2.67	0.22	0.00	0.00	6.62
1300	2.22	0.50	1.05	2.62	0.37	0.00	0.00	6.76
1380	1.52	0.30	1.01	1.55	0.39	0.00	0.00	4.76
1420	1.26	0.25	0.94	1.31	0.36	0.00	0.00	4.13
1600	1.72	0.71	1.34	1.22	0.57	0.00	0.68	6.23
1700	1.87	0.40	1.71	1.08	0.92	0.00	1.21	7.20
1750	1.84	0.06	1.41	1.71	0.92	0.08	2.46	8.40
1800	2.44	0.06	1.38	1.93	0.78	0.16	2.90	9.49
1830	3.40	0.06	2.00	1.60	0.60	0.29	5.20	12.86
1871	3.32	0.06	1.96	1.45	0.90	0.39	5.66	13.35

Sources: Overton and Campbell (1996: Tables III, V); Campbell, Bartley and Power (1996); Medieval Accounts Database; Holderness (1989).

TABLE 3: Regional weights for the arable sector by year and crop (%)

A. 1300

	Wheat	Rye	Barley	Oats	Pulses
East Anglia	9.2	25.2	41.3	5.8	32.5
Eastern counties	24.2	5.2	1.9	19.3	10.9
Southern counties	16.1	18.0	21.8	12.3	13.3
Southwest	13.4	2.5	0.5	10.4	4.1
Southeast	7.4	7.2	10.8	7.0	21.4
Midlands	11.3	7.2	10.4	7.3	6.6
North	18.5	34.6	13.3	37.9	11.2
England	100.0	100.0	100.0	100.0	100.0

B. 1420

	Wheat	Rye	Barley	Oats	Pulses
East Anglia	7.4	31.6	29.2	8.0	21.7
Eastern counties	22.6	0.0	7.0	18.9	25.5
Southern counties	19.1	3.7	24.2	8.8	13.0
Southwest	15.0	1.3	0.2	12.8	1.5
Southeast	10.6	3.2	9.3	7.3	7.8
Midlands	5.0	22.8	15.4	3.3	17.9
North	20.4	37.4	14.7	40.9	12.5
England	100.0	100.0	100.0	100.0	100.0

C. 1600

	Wheat	Rye	Barley	Oats	Pulses
East Anglia	9.3	41.1	17.5	6.0	15.9
Eastern counties	13.4	7.4	23.4	12.2	32.4
Southern counties	20.0	8.9	21.2	4.3	20.6
Southwest	12.2	0.3	4.4	18.3	0.3
Southeast	14.8	0.1	8.3	7.5	2.8
Midlands	9.6	4.0	10.3	6.9	15.2
North	20.7	38.1	15.0	44.8	12.7
England	100.0	100.0	100.0	100.0	100.0

D. 1830

	Wheat	Rye	Barley	Oats	Pulses
East Anglia	15.8	NA	24.3	3.5	12.7
Eastern counties	17.2	NA	17.7	13.6	29.5
Southern counties	14.9	NA	16.9	9.8	12.9
Southwest	8.3	NA	10.1	9.3	5.5
Southeast	9.0	NA	5.6	11.3	10.6
Midlands	8.6	NA	10.1	6.9	15.0
North	26.1	NA	15.3	45.6	13.8
England	100.0		100.0	100.0	100.0

Sources and notes: Regional shares of sown acreage from the 1801 crop returns (Turner, 1981); crop shares within each region for each year derived from the Medieval Accounts Database, the Early Modern Probate Inventories Database and Overton (1996). The original shares for the medieval and early modern periods were calculated as 50 year averages.

TABLE 4:Mean yields per acre gross of tithes

A. Yield per acre gross of seed (bushels)

	Wheat	Rye	Barley	Oats	Pulses
1250-1299	11.27	13.73	14.41	10.91	8.93
1300-1349	10.77	13.31	13.36	10.21	8.77
1350-1399	9.96	12.00	13.67	11.12	8.43
1400-1449	8.28	13.01	12.20	9.52	7.71
1450-1499	8.94	16.75	12.74	8.42	6.57
1550-1599	10.38	11.71	12.40	11.87	10.62
1600-1649	12.95	18.78	15.16	14.97	11.62
1650-1699	13.86	16.69	16.48	14.82	11.39
1700-1749	16.36	17.32	19.38	16.27	13.23
1750-1799	19.54	20.37	25.38	24.90	17.19
1800-1849	25.56	22.02	29.70	32.37	20.35
1850-1899	29.19	28.68	27.08	35.36	18.80

B. Seed sown per acre (bushels)

	Wheat	Rye	Barley	Oats	Pulses
1250-1299	2.56	3.02	4.16	3.67	2.90
1300-1349	2.53	2.95	3.90	3.61	2.63
1350-1399	2.49	2.79	3.92	3.63	2.57
1400-1449	2.39	2.55	3.75	2.97	2.30
1450-1499	2.45	2.79	4.18	2.48	2.08
1550-1599	2.50	2.50	4.00	4.00	3.00
1600-1649	2.50	2.50	4.00	4.00	3.00
1650-1699	2.50	2.50	4.00	4.00	3.00
1700-1749	2.57	2.50	4.30	4.00	3.00
1750-1799	2.27	2.50	3.50	4.00	3.00
1800-1849	2.41	2.50	3.80	4.00	2.50
1850-1899	2.50	2.50	3.27	4.00	2.50

C. Yield per acre net of seed (bushels)

	Wheat	Rye	Barley	Oats	Pulses
1250-1299	8.71	10.71	10.25	7.24	6.03
1300-1349	8.24	10.36	9.46	6.60	6.14
1350-1399	7.46	9.21	9.74	7.49	5.86
1400-1449	5.89	10.46	8.44	6.55	5.42
1450-1499	6.48	13.96	8.56	5.95	4.49
1550-1599	7.88	9.21	8.40	7.87	7.62
1600-1649	10.45	16.28	11.16	10.97	8.62
1650-1699	11.36	14.19	12.48	10.82	8.39
1700-1749	13.79	14.82	15.08	12.27	10.23
1750-1799	17.26	17.87	21.88	20.90	14.19
1800-1849	23.16	19.52	25.90	28.37	17.85
1850-1899	26.69	26.18	23.82	31.36	16.30

Sources and notes: Gross Yield per acre taken from the Medieval Accounts Database, the Early Modern Probate Inventories Database and the Modern Farm Accounts Database. Seed sown per acre from the Medieval and Modern Databases. Pulses for the modern period and all seeds sown for the early modern period are taken from Overton and Campbell (1996), Allen (2005).

FIGURE 4: Weighted national average wheat yields per acre, gross of tithe and seed (bushels)

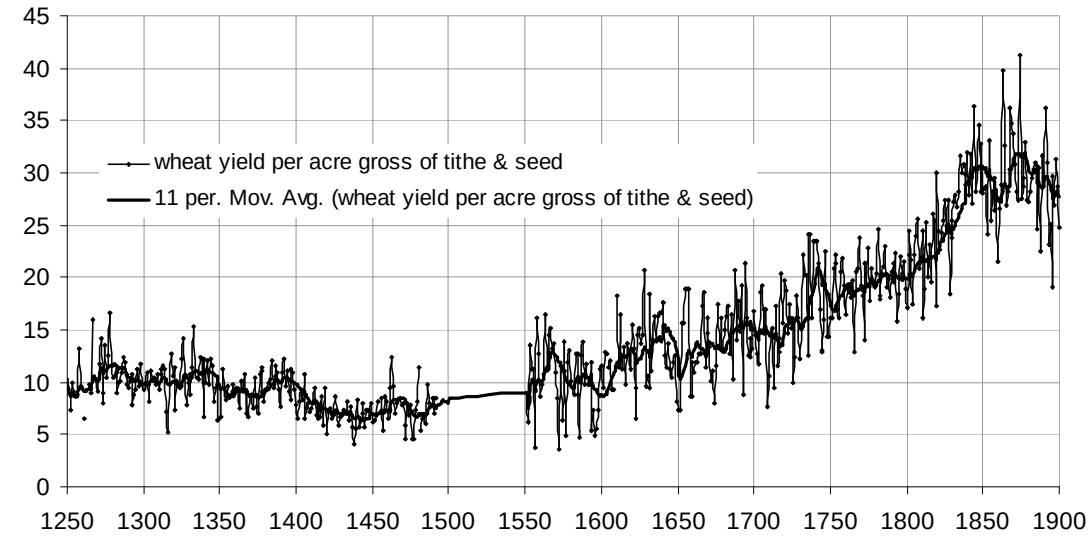


FIGURE 5: Weighted national average rye yields per acre, gross of tithe and seed (bushels)

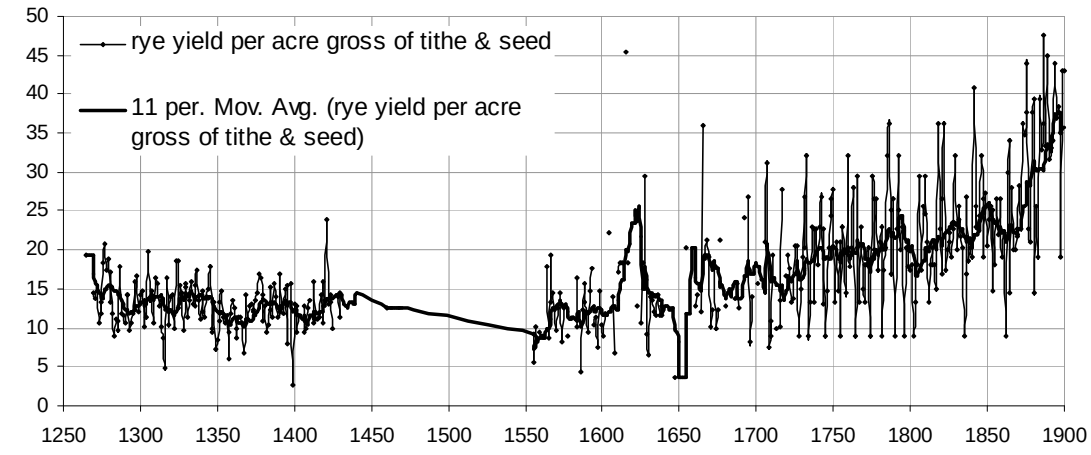


FIGURE 6: Weighted national average barley yields per acre, gross of tithe and seed (bushels)

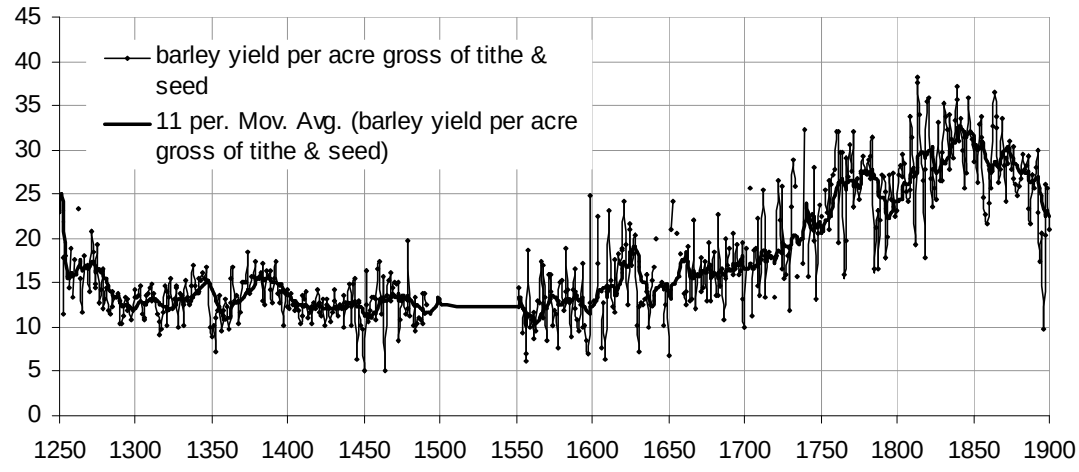


FIGURE 7: Weighted national average oats yields per acre, gross of tithe and seed (bushels)

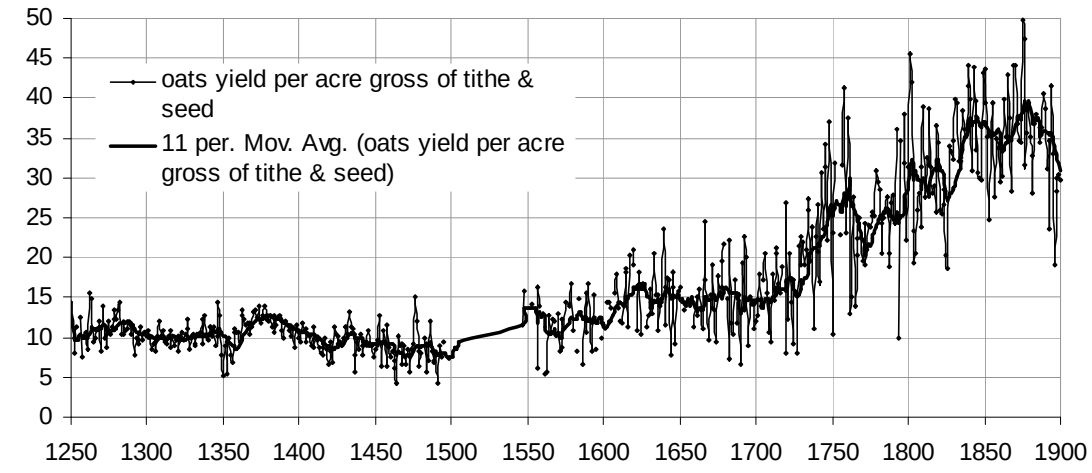


FIGURE 8: Weighted national average pulses yields per acre, gross of tithe and seed (bushels)

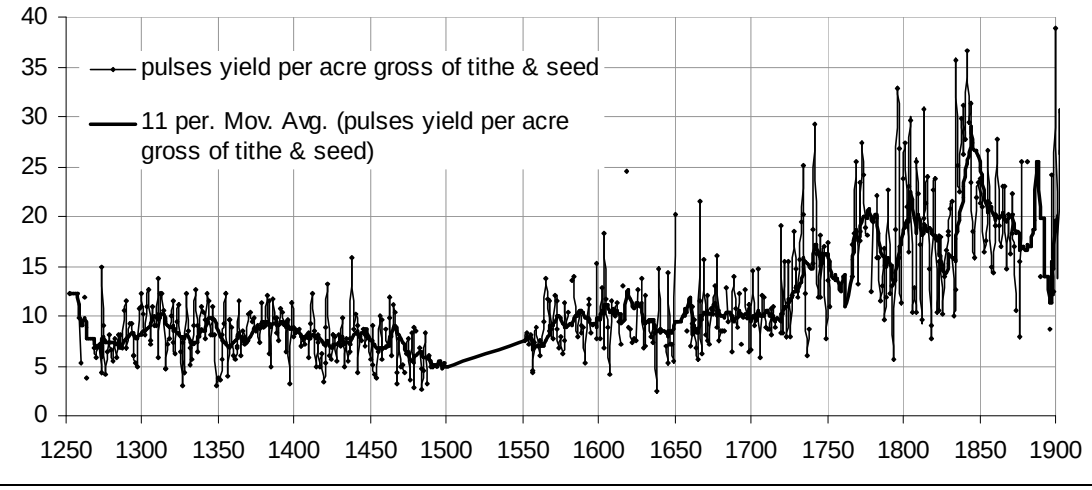


TABLE 5: Regional weights for the pastoral sector by type of farming and year

A. 1300

Type of Pastoral Farming	Counties	%
Mixed enterprises with some dairying on grass / mixed husbandry	Essex & Herefordshire	7.2
Fattening on arable, leys and grass/ mainly cattle based husbandry	Bedfordshire, Cambridgeshire, Huntingdonshire, Lincolnshire, Norfolk, Suffolk & Yorkshire (East Riding)	27.7
Rearing with some fattening / extensive mixed husbandry	Cheshire, Cornwall, Cumberland, Derbyshire, Devon, Dorset, Durham, Hampshire, Gloucestershire, Lancashire, Leicestershire, Northumberland, Nottinghamshire, Shropshire, Somerset, Staffordshire, Westmoreland, Wiltshire & Yorkshire (North and West Riding)	42.1
Primarily dairying / cattle husbandry	Berkshire, Buckinghamshire, Herefordshire, Kent, Middlesex, Northamptonshire, Oxfordshire, Rutland, Sussex, Surrey, Warwickshire & Worcestershire	23.0

B. 1870

Type of Pastoral Farming	Counties	%
Mixed enterprises with some dairying on grass / mixed husbandry	Berkshire, Buckinghamshire, Hertfordshire, Kent, Northamptonshire & Oxfordshire	14.7
Fattening on arable, leys and grass / mainly cattle based husbandry	Bedfordshire, Cambridgeshire, Essex, Huntingdonshire, Leicestershire, Lincolnshire, Norfolk, Northumberland, Nottinghamshire, Rutland, Suffolk, Sussex, Warwick & Yorkshire (East Riding)	41.6
Rearing with some fattening / extensive mixed husbandry	Cornwall, Cumberland, Devon, Durham, Gloucestershire, Herefordshire, Shropshire, Westmoreland, Worcestershire & Yorkshire (North and West Riding)	25.0
Primarily dairying / cattle husbandry	Cheshire, Derbyshire, Dorset, Hampshire, Lancashire, Middlesex, Somerset, Staffordshire, Surrey & Wiltshire	18.6

Sources: Campbell and Bartley (2006); Whetham and Orwin, (1971: 131); Medieval Accounts Database.

FIGURE 9: Working animals in England (mlns)

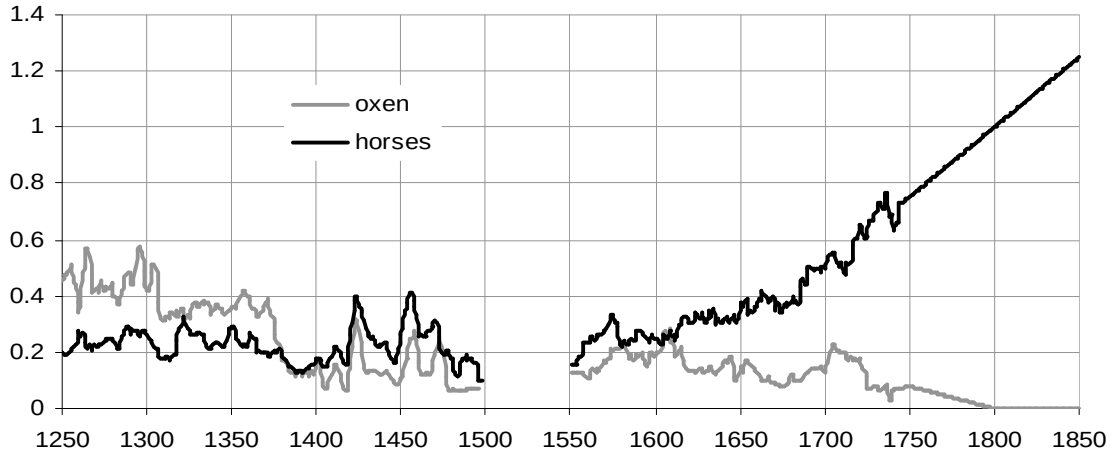


TABLE 6: Consumption of oats and pulses by working animals

A. Number of working animals (millions)

	Horses	Oxen	Livestock Units* per 100 Acres	Oxen per 100 Horses
1250-1299	0.24	0.46	10.63	189.23
1300-1349	0.24	0.37	10.38	154.97
1350-1399	0.19	0.26	9.68	136.19
1400-1449	0.23	0.14	8.50	62.08
1450-1499	0.23	0.14	8.01	60.10
1550-1599	0.25	0.17	7.73	68.83
1600-1649	0.30	0.17	8.10	56.03
1650-1699	0.40	0.11	8.47	28.32
1700-1749	0.63	0.13	12.11	19.97
1750-1799	0.87	0.04	13.20	4.63
1800-1849	1.12	0.00	13.50	0.00

B. Total farm-animal consumption (million bushels)

	Oats	Pulses
1250-1299	2.79	0.86
1300-1349	2.80	1.15
1350-1399	2.51	1.12
1400-1449	2.89	1.00
1450-1499	3.53	0.91
1550-1599	4.45	1.69
1600-1649	5.47	1.97
1650-1699	7.56	2.42
1700-1749	12.32	2.58
1750-1799	17.94	3.14
1800-1849	23.63	3.28

Sources and Notes: Derived from Medieval Accounts Database; Early Modern Probate Inventories Database; Allen (2005); John (1989 Tales III.1 and III.2). Livestock units compare different animals on the basis of relative feed requirements. Livestock Ratios from Campbell (2000: 104-107): (Horses x 1) + (Oxen x 1.2).

TABLE 7: Arable output net of seed and animal consumption (million bushels)

	Wheat	Rye	Barley	Oats	Pulses	Potatoes
1250-1299	17.83	6.66	11.62	16.58	0.86	NA
1300-1349	16.37	4.45	9.77	11.91	1.15	NA
1350-1399	11.60	2.89	9.78	9.54	1.12	NA
1400-1449	7.68	2.87	8.15	5.84	1.00	NA
1450-1499	8.95	5.82	7.96	4.18	0.91	NA
1550-1599	12.93	5.31	10.73	5.03	2.42	NA
1600-1649	18.37	7.26	16.13	7.47	3.54	NA
1650-1699	20.85	6.30	20.47	4.58	5.60	NA
1700-1749	25.83	2.73	24.29	8.86	6.97	0.80
1750-1799	36.25	1.10	30.55	20.90	8.48	17.30
1800-1849	72.33	1.18	46.76	23.91	8.86	37.87

Source: Output gross of tithe and net of seed derived by multiplying sown area from Table 2 with net yields from Table 4. The sown area from Table 2 was interpolated where necessary. Consumption by working animals is taken from Table 6.

FIGURE 10: Non-working livestock in England in Millions (5-year Average)

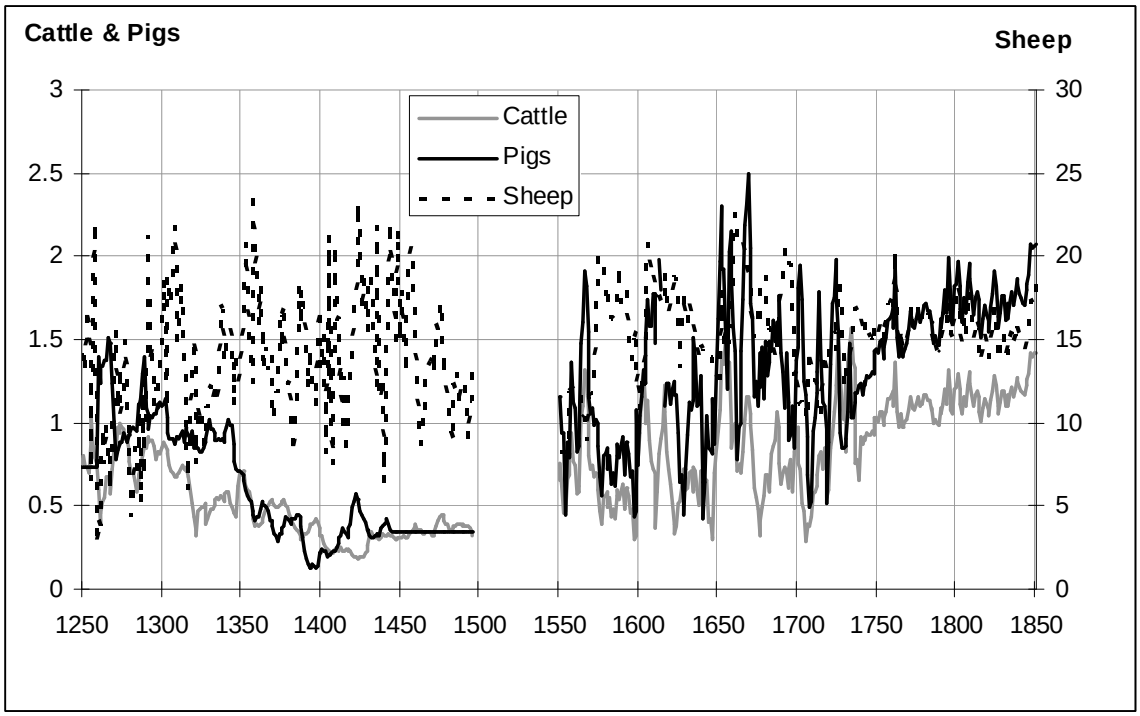


TABLE 8:Non-working animals

A. Numbers of non-working animals in England (millions)

	Milk cattle	Beef cattle	Calves	Sheep	Swine	Livestock Unites per 100 Acres
1250-1299	0.77	0.69	0.77	10.88	1.03	53.47
1300-1349	0.59	0.53	0.59	13.66	0.92	53.84
1350-1399	0.45	0.41	0.45	14.67	0.39	59.19
1400-1449	0.26	0.24	0.26	15.13	0.34	55.63
1450-1499	0.36	0.33	0.36	13.41	0.35	55.79
1550-1599	0.65	0.58	0.65	14.05	0.94	66.04
1600-1649	0.71	0.64	0.71	16.07	1.13	69.32
1650-1699	0.85	0.77	0.85	17.31	1.50	77.36
1700-1749	0.87	0.79	0.87	14.04	1.22	71.63
1750-1799	1.09	0.99	1.09	16.08	1.59	80.85
1800-1849	1.18	1.07	1.18	15.54	1.76	71.39

Sources and notes: Derived from Medieval Accounts Database; Early Modern Probate Inventory Database; Allen (2005); John (1989 Tales III.1 and III.2).
* Livestock units compare different animals on the basis of relative feed requirements. Ratios from Campbell (2000: 104-107): (adult cattle for beef and milk x 1.2) + (immature cattle x 0.8) + (sheep and swine x 0.1).

TABLE 9: Percentages of animals producing specific products

	Milk	Beef	Veal	Mutton	Pork	Wool
1300	100	25	15.18	26	49	100
1420	100	25	17.54	26	49	100
1600	100	25	21.07	25	76.86	100
1830	100	25	25	25	100	100

Sources: Holderness (1989: 147); Clark (1991); Ecclestone (1996).

TABLE 10: Yields per animal

Years	Milk (gallons)	Beef (lb)	Veal (lb)	Mutton (lb)	Pork (lb)	Wool (lb)
1250-1299	100.00	168.00	29.00	22.00	64.00	1.53
1300-1349	107.01	177.90	30.73	23.17	65.29	1.77
1350-1399	122.69	199.73	34.54	25.75	67.99	1.62
1400-1449	140.67	224.23	38.83	28.60	70.81	1.38
1450-1499	161.28	251.74	43.65	31.78	73.74	1.32
1550-1599	212.01	317.30	55.15	39.22	79.97	1.79
1600-1649	243.07	356.23	61.99	43.57	83.28	2.08
1650-1699	278.69	399.93	69.68	48.41	86.73	2.42
1700-1749	319.52	449.00	78.33	53.78	90.32	2.81
1750-1799	366.34	504.08	88.05	59.74	94.06	3.27
1800-1849	420.02	565.93	98.98	66.37	97.96	3.80

Sources and notes: Beef, pork, milk, and mutton are obtained from Clark (1991: 216), while veal is taken from Allen (2005: Table 6). Wool yield index from Stephenson (1988: Table 3), with the benchmark of 1.4 lb in 1300 from Britnell (2004: 416). The missing years were interpolated log-linearly.

TABLE 11: Total output in pastoral farming

Years	Milk (m. gals)	Beef (m. lb)	Veal (m. lb)	Mutton (m. lb)	Pork (m. lb)	Wool (m. lb)
1250-1299	77.30	29.11	3.29	62.21	32.25	16.84
1300-1349	62.77	23.42	2.82	82.15	29.27	23.92
1350-1399	55.36	20.25	2.59	98.04	12.93	24.00
1400-1449	37.21	13.32	1.81	112.75	11.97	20.88
1450-1499	58.13	20.41	2.93	110.06	13.35	17.57
1550-1599	136.59	46.10	7.30	140.52	49.72	25.68
1600-1649	170.49	56.41	9.36	174.72	71.40	33.32
1650-1699	235.75	76.44	13.27	209.50	105.92	41.85
1700-1749	280.86	89.02	16.22	189.35	97.69	39.64
1750-1799	400.60	124.29	23.60	240.11	144.42	52.54
1800-1849	497.00	150.95	29.27	257.66	172.13	59.00

Source: Total output estimates are derived by multiplying animal numbers from Table 8 with the percentage of animals producing in Table 9. The resulting numbers of producing animals are then multiplied with the animal yields from Table 10.

TABLE 12: Consumption of hay by non-farm horses

Years	Non-Farm Horses (Million)	Hay Consumption (Million Tons)	Hay Consumption (£ Million)
1250-1299	0.05	0.11	0.01
1300-1349	0.05	0.11	0.03
1350-1399	0.04	0.09	0.02
1400-1449	0.04	0.10	0.03
1450-1499	0.04	0.11	0.03
1550-1599	0.05	0.12	0.12
1600-1649	0.06	0.15	0.33
1650-1699	0.09	0.22	0.53
1700-1749	0.16	0.37	0.94
1750-1799	0.33	0.79	2.97
1800-1849	0.67	1.60	8.51

Source: Non-farm horses for 1300 from Wrigley (2006: 448-450), and for 1700 onwards from Allen (1994: 102) and Feinstein (1978: 70). All other years obtained by interpolation on the basis of the number of farm horses.

Table 13: Output of hides and skins from working and non-working animals

Years	Horses (m. lb)	Oxen (m. lb)	Cattle (m. lb)	Calves (m. lb)	Sheep (m. lb)	Hides (m. lb)
1250-1299	0.67	2.31	9.70	0.91	2.94	16.53
1300-1349	0.66	1.84	7.41	0.74	3.69	14.34
1350-1399	0.54	1.33	5.70	0.60	3.97	12.14
1400-1449	0.63	0.71	3.31	0.37	4.09	9.12
1450-1499	0.66	0.67	4.55	0.54	3.63	10.05
1550-1599	0.75	0.92	8.91	1.15	4.39	16.12
1600-1649	0.96	0.98	10.32	1.38	5.47	19.11
1650-1699	1.45	0.78	14.04	1.94	7.35	25.55
1700-1749	2.33	0.85	14.96	2.16	6.37	26.67
1750-1799	3.35	0.28	19.37	2.90	7.78	33.68
1800-1849	4.38	0.00	21.31	3.25	7.77	36.71

Sources: Absolute numbers of animals from Tables 6 and 8. Percentages of animals yielding hides from Clark (1991: 216) and Ecclestone (1996: 26), namely: 25% of beef cattle, 14.2% of immature cattle, 26% of sheep, 9% of mature oxen and 135 of mature horses. Hide weights: 1300 from Clarkson (1989: 470, n.259) and Ecclestone (1996: 23): oxen = 56 lb; cattle = 56 lb; calves = 8 lb; sheep = 1.04 lb; horses = 21.4 lb.; 1800 from Clarkson (1989: 470, n.259): oxen = 80 lb; cattle = 80 lb; calves = 11 lb; sheep = 2 lb; horses = 30 lb.; other years obtained using log linear interpolation.

TABLE 14: Output of processed dairy products

Years	Fresh milk (m. gals)	Cheese (m. lb)	Butter (m. lb)
1250-1299	7.73	45.22	20.87
1300-1349	6.28	36.72	16.95
1350-1399	5.54	32.39	14.95
1400-1449	3.72	21.77	10.05
1450-1499	5.81	34.01	15.70
1550-1599	19.64	71.47	38.59
1600-1649	30.95	83.00	49.58
1650-1699	54.20	106.68	70.62
1700-1749	73.28	122.08	85.49
1750-1799	87.98	179.05	132.35
1800-1849	129.80	206.37	154.71

Source: The division of total milk production between cheese, butter and fresh milk for the medieval period was derived from Biddick (1989). For the modern period, Holderness (1989: 169-170) provides estimates for 1750, 1800 and 1850. Other years are obtained using log linear interpolation.

Figure 11: Indexed output in arable and pastoral agriculture (1700=100, log scale)

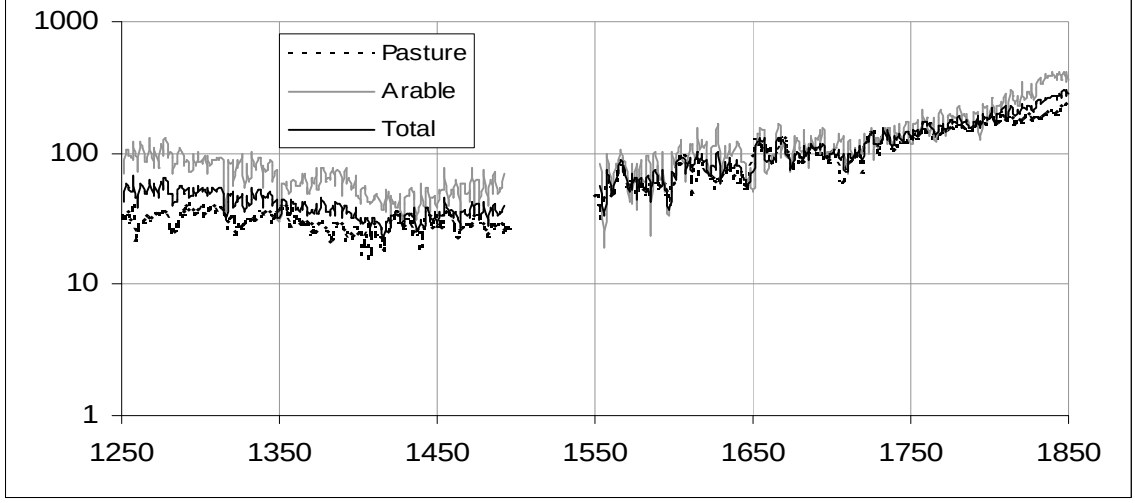


TABLE 15: Output growth in agriculture in constant 1700 prices (5-year moving averages)

Years	Arable sector (% *per annum*)	Pastoral sector (% *per annum*)	Total agriculture (% *per annum*)
1265-1300	-0.14	0.12	-0.04
1300-1348	-1.05	-0.26	-0.68
1348-1400	-0.08	-0.52	-0.29
1400-1450	-0.22	0.27	0.02
1450-1475	0.76	0.09	0.42
1475-1555	0.04	0.39	0.22
1555-1600	0.44	0.48	0.47
1600-1650	-0.55	0.56	0.14
1650-1700	0.90	0.02	0.32
1700-1750	0.66	0.51	0.57
1750-1800	0.85	0.65	0.73
1800-1850	1.05	0.51	0.76
1250-1348	-0.56	-0.02	-0.32
1250-1700	0.03	0.24	0.13
1250-1850	0.23	0.32	0.27
1700-1850	0.86	0.58	0.70

Sources: Derived from Medieval Accounts Database; Early Modern Probate Inventories Database; Modern Farm Accounts Database.

FIGURE 12: Percentage share of pastoral output in total agriculture output (at current prices)

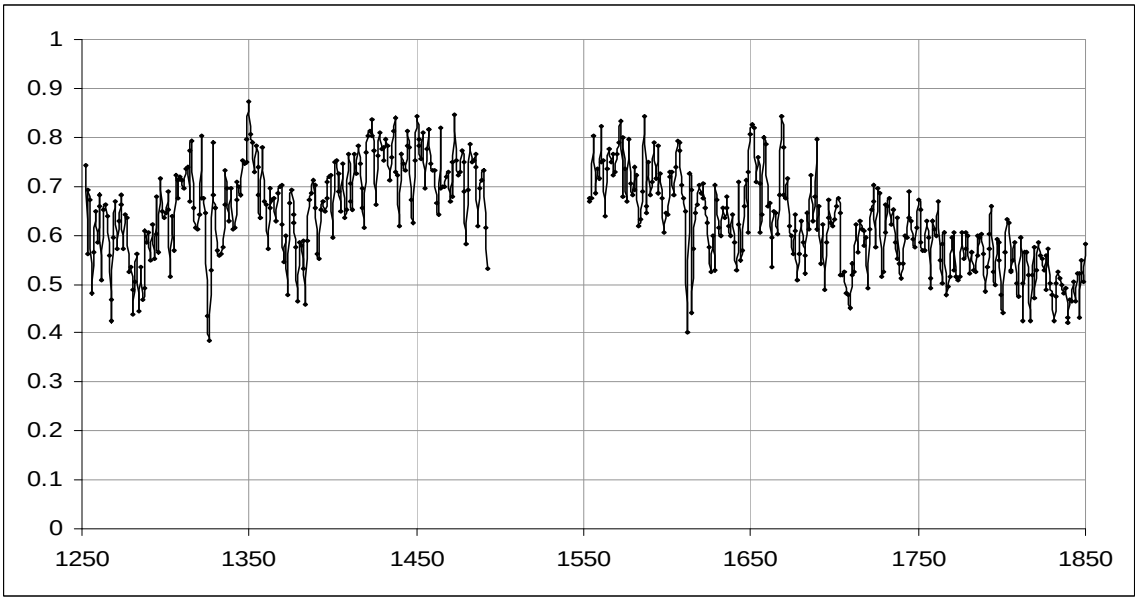


FIGURE 13: Index of ratio of pastoral to arable prices (1700=100)

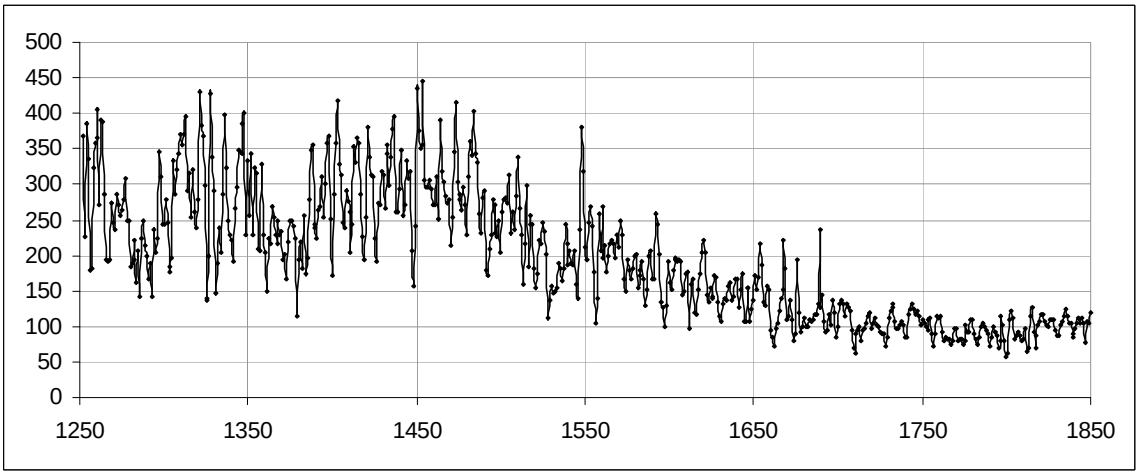


TABLE 16: Agricultural output weights in current prices, 20-year averages (%)

A. Arable products

Year	Wheat	Rye	Barley	Oats	Pulses	Potatoes	Total arable products
1300	20.1	2.5	6.7	6.1	1.1	0.0	36.4
1380	17.7	2.0	13.2	5.8	1.5	0.0	40.2
1420	11.8	1.8	8.3	2.9	1.1	0.0	25.9
1600	12.9	4.6	6.4	2.1	2.2	0.0	28.2
1700	22.5	3.4	11.2	1.0	3.6	0.0	41.8
1800	24.9	0.4	9.0	4.8	3.0	2.8	44.8
1850	28.6	0.3	9.6	2.9	2.5	6.7	50.6

B. Pastoral products

Year	Dairy	Beef	Pork	Mutton	Hay	Wool	Hides	Total pastoral products
1300	8.1	2.2	21.4	13.9	0.7	15.8	1.3	63.6
1380	6.4	2.0	11.9	19.4	0.9	18.6	0.7	59.8
1420	4.6	1.3	14.9	29.1	1.6	20.7	1.9	74.1
1600	12.5	3.4	31.9	10.6	1.2	10.3	1.9	71.8
1700	13.9	3.8	19.0	10.6	3.1	6.5	1.4	58.2
1800	18.5	5.8	10.4	8.0	8.3	3.4	0.8	55.2
1850	19.4	4.2	9.8	5.4	7.4	2.7	0.5	49.4

Sources: Derived from Medieval Accounts Database; Early Modern Probate Inventories Database; Modern Farm Accounts Database.

TABLE 17: Population totals and trends

Years	Population totals (millions)		Years	Growth rates (% *per annum*)	
	Total population	Agricultural population		Total population	Agricultural population
1250	3.80	3.05	1250-1300	0.23	0.18
1300	4.25	3.34	1300-1348	0.00	-0.22
1348	3.83	3.01	1348-1400	-1.14	-1.02
1400	2.34	1.77	1400-1450	-0.05	-0.06
1450	2.28	1.72	1450-1500	-0.05	-0.06
1500	2.22	1.67	1500-1550	0.61	0.39
1550	3.02	2.03	1550-1600	0.62	0.69
1600	4.11	2.87	1600-1650	0.51	0.25
1650	5.31	3.25	1650-1700	-0.04	-0.31
1700	5.20	2.78	1700-1750	0.25	-0.13
1750	5.89	2.60	1750-1800	0.77	0.38
1800	8.62	3.14	1800-1850	1.31	0.10
1850	16.51	3.30			

Sources and notes: Derived from Overton and Campbell (1996: Table II) and Wrigley et al. (2006). Assumed decline arising from the Black Death of 1348-1349 is 40%.

FIGURE 14: Indexed agricultural output per agricultural worker (1700 = 100)

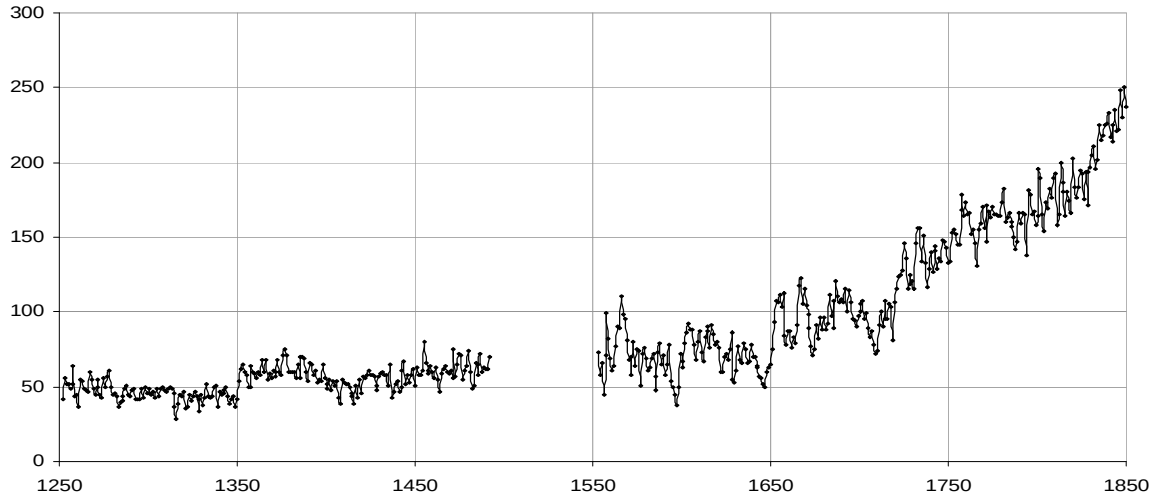


FIGURE 15: Index of arable output per acre at constant prices (1700=100)

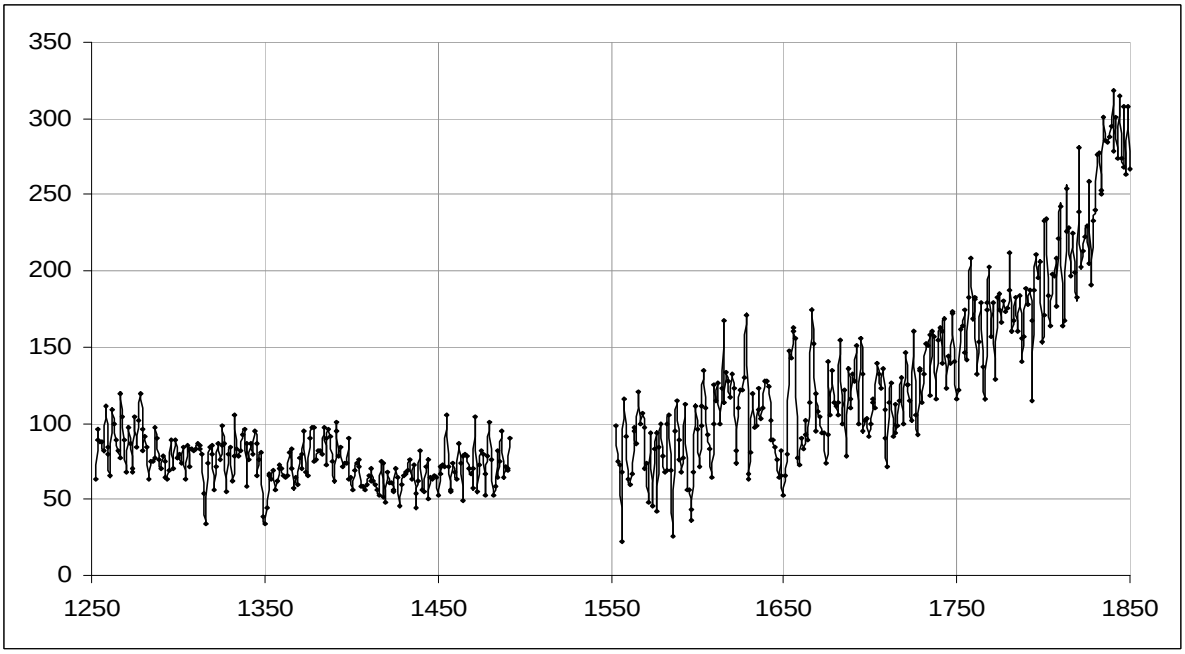


TABLE 18: Average annual growth rate of agricultural output per agricultural worker

Years	Growth rate (% per annum)
1265-1300	-0.27
1300-1348	-0.32
1348-1400	0.61
1400-1450	0.08
1450-1475	0.48
1475-1555	-0.05
1555-1600	-0.16
1600-1650	-0.11
1650-1700	0.64
1700-1750	0.70
1750-1800	0.37
1800-1850	0.63
1250-1348	-0.22
1250-1700	0.15
1250-1850	0.26
1700-1850	0.58

Sources: Derived from Tables 15 and 17.

FIGURE 16: Indexed daily real wage of an unskilled farm worker (1700=100)

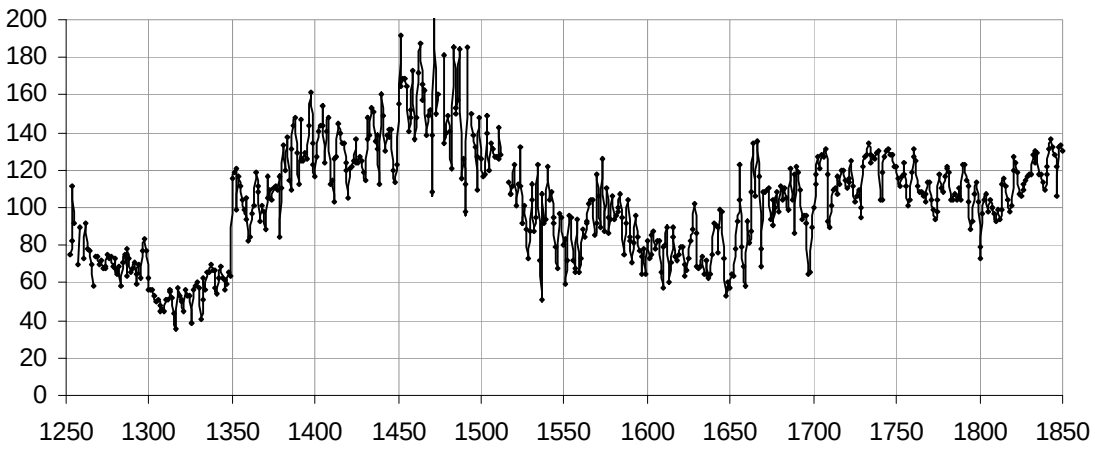


FIGURE 17: Indexed daily real wage of an unskilled farm worker and agricultural output per agricultural worker (11-year moving averages; 1700=100)

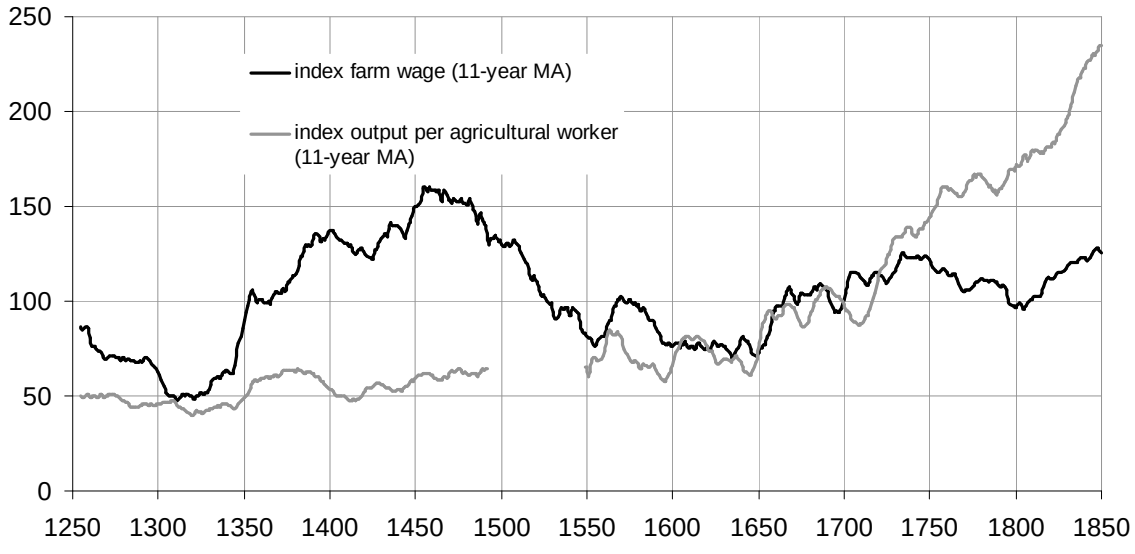


TABLE 19: Income and output values in agriculture (5 year averages)

A. Annual wage bill:					
Years	Agricultural families (millions)	Days worked per family	Total days worked (millions)	Wage (d. per day)	Wage bill (£m.)
1250	0.68	315	213	1.13	1.00
1300	0.74	381	282	1.26	1.48
1380	0.40	331	132	2.93	1.61
1450	0.38	266	102	3.40	1.44
1600	0.64	404	258	6.22	6.68
1700	0.62	405	249	8.94	9.29
1800	0.69	473	327	16.04	21.89
1850	0.73	539	396	18.07	29.83
B. Rents and other non-wage incomes:					
Years	Rent (s. per acre)	Acres (millions)	Total rent (£m.)	Capital costs (£m.)	Tithes and taxes (£m.)
1250	0.945	12.30	0.58	0.22	0.32
1300	0.941	12.53	0.59	0.30	0.45
1380	0.931	10.73	0.50	0.30	0.30
1450	0.922	11.09	0.51	0.27	0.20
1600	6.588	15.21	5.01	2.17	1.05
1700	11.731	18.98	11.13	2.88	2.13
1800	22.579	28.13	31.76	10.46	5.44
1850	31.292	30.03	46.99	17.62	3.97
C. Income and output values (£m.):					
Years	Total incomes	Value of output			
1250	2.13	2.06			
1300	2.82	2.99			
1380	2.71	2.74			
1450	2.42	2.26			
1600	14.91	15.50			
1700	25.43	25.87			
1800	69.54	69.75			
1850	98.41	98.76			

Sources and notes: Wage per day is taken from Clark (2007b). Following Burnett (2004), we assume that the female wage was 45% of the male wage. Women worked 13.6 per cent of total hours worked. Hence the average male and female wage should be 0.864*male wage+0.136*0.45*male wage. Rents from Clark (2001), and after 1750 from Turner et al. (1997), capital costs and tithes and taxes from Allen (2005).

TABLE 20: *Per capita* daily kilocalorie consumption of wheat, rye, barley, oats and potatoes

Years	Kcal. net of seed	Kcal. net of seed, losses, & fodder	% food extraction rate
1300	2,241	1,298	*58*
1380	3,192	1,715	*54*
1450	2,356	1,271	*52*
1600	2,236	1,153	*52*
1700	*2,526	*1,202	*48*
1800	*3,361	*1,627	*48*
1830	*3,365	*1,679	*52*
1850	*3,474	*1,713	*49*

Sources and notes: This Table is based on 20-year averages. Kilocalories per bushel for the medieval period are taken from Campbell *et al.* (1993: 41). Following Overton and Campbell (1996: Table XIII), storage losses are assumed to have been 10%, with food conversion losses of 20% for wheat and rye, 22% for barley, and 44% for oats when processed into bread, and 70% for barley and oats when malted and brewed into ale/beer. For the post Black Death period (1380 and 1420) patterns of grain consumption are assumed to have been equivalent to those for 1600 given by Overton and Campbell (1996: Table XII): 98% of wheat and rye and all oats not fed to livestock were eaten. However, we assumed that 50% of barley was eaten and the remainder brewed. For the pre-Black Death period it is assumed that 60% of barley was eaten and only 40% brewed. For 1600-1850 the estimates of Overton and Campbell (1996: Tables XII and XIII) were followed.
*Includes net grain imports and potatoes.

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