ENGLISH AGRICULTURAL OUTPUT 1250–1450: SOME PRELIMINARY ESTIMATES

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Abstract: We provide annual estimates of agricultural output for England over the period 1250–1450. The data are extracted largely from manorial accounts but checked against tithe records for the non-demesne sector where possible. We provide separate estimates for the output of individual arable and pastoral products, and combine them into an aggregate agricultural output series. This is combined with estimates of population and the agricultural labour force to provide an overview of the path of agricultural labour productivity. Estimates from the output side are cross-checked against estimates from the income side and per capita consumption of calories. English agriculture responded positively to the crises of the fourteenth century, with agricultural labour productivity increasing substantially across the Black Death, in line with an increase in agricultural real wages. With rising living standards, the share of pastoral farming increased at the expense of arable farming.

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I. INTRODUCTION

The 200 years from *c.*1250 to *c.*1450 witnessed major swings in total population, *per capita* real wages, and aggregate economic activity with potentially far reaching consequences for agricultural production and productivity. Commodity and factor prices changed significantly over this period, both absolutely and relatively, and it is clear that farmers responded by adapting their enterprise and altering the uses made of their land. The units of production, terms of their tenure, and nature of the labour processes applied to them also changed significantly, although whether this raised, lowered, or maintained land and labour productivity at existing levels remain matters of debate. Over this long period producers also had to contend with a series of major supply-side shocks arising from extreme environmental events, of which the Great European Famine of 1315-21 was the most notable but by no means the only example. The single greatest shock of all, however, was on the demand side: in 1348-9 the Black Death precipitated a mortality of at least 30 per cent. Never since has agriculture had to cope with such a sudden and massive contraction in domestic demand or the destruction of human capital on such a large scale. On the other hand, the Black Death ended for good the problem of rural congestion, which had become such a problem on the eve of that catastrophe in many parts of the south and east of England, and thereby acted as a major catalyst of change making possible, in the fullness of time, the emergence of agrarian capitalism with its attendant transformations of land, labour, and total factor productivity in agriculture.

A period marked by such contrasts and blessed by unusually detailed and abundant sources has naturally attracted much scholarly attention. Major debates have also arisen about the productivity effects of population growth and decline, the

potentially negative ecological repercussions of prevailing patterns and methods of land use, the capacity of medieval agricultural technology to maintain let alone raise soil fertility and crop yields, the ostensibly baleful effects of feudal lordship, servile status, and villein tenure, the role of markets in shaping production decisions and consumption choices, and the extent to which the lack of large-scale urban demand inhibited investment, intensification, and innovation and thereby kept agriculture in a low-productivity trap.

Most of these debates have been fuelled by an absence of reliable and empirically well-documented estimates of the aggregate outputs of arable and pastoral products, the composition of those outputs, and their respective yields per unit of agricultural land and agricultural worker. It is this omission which this paper seeks to remedy by providing the first annual estimates of agricultural output for England over the period *c.*1250 – *c.*1450. In the absence of aggregate agricultural information, except for the annual export of wool and woollen cloth recorded by the customs accounts, an aggregate picture must perforce be reconstructed from evidence of output on individual farms and parishes as recorded by manorial and tithe accounts. The former relate exclusively to demesnes, the latter to all producers, with the result that each provides a useful cross-check on the other. The necessary datasets for this task have been assembled by Campbell (2000 and 2007a), drawing upon the archival labours of a number of other historians, most notably David Farmer, John Langdon, and Jan Titow. The method also relies upon the detailed information on the prices of agricultural products assembled by Gregory Clark, David Farmer, and Thorold Rodgers.

A brief overview of these data sources is provided in the next section. Estimates for the aggregate output of individual arable products are then given in Section III, of individual pastoral products in Section IV, and of both combined in Section V. In Section VI, the index of aggregate agricultural output is combined with estimates of population and the agricultural labour force to provide an overview of the path of agricultural labour productivity from *c.*1250 to *c.*1450. Estimates from the output side are then cross-checked against estimates from the income side and *per capita* consumption of calories in Section VII. Key conclusions from these *preliminary* estimates are summarised in Section VIII.

II. THE DATA SOURCES

Manorial accounts are the single most important source of quantifiable agricultural information for the period under examination. Each was drawn up according to a common template and accounted for the income and expenditure of cash and stock on an individual demesne farm over the course of an agricultural year. This information was supplied by the reeve who managed the demesne under the supervision of the lord of that manor's bailiff or steward (Campbell, 2000: 2). Close scrutiny by the lord's auditors ensured the accuracy of each account. As well as providing precise information on crops, animals, and livestock products, and the purchase and maintenance of capital equipment (ploughs, carts, etc) some accounts itemise the labour services provided by villeins (Campbell, 2000: 27), which can provide the basis for detailed estimates of labour productivity per worker per task (Karakacili, 2004).

The number of manors for which accounts survive varies over time. Decadal totals of those within the Medieval Accounts Database are shown in Figure 1. As will be observed, the fourteenth century is well recorded, the thirteenth and fifteenth centuries less so. Records are scarce before the 1280s, are at their most abundant in the 1320s, remain numerous until the 1350s, start to dwindle from the 1360s, and become ever scarcer from the 1390s, although a few rare series, mostly for ecclesiastically-owned manors in southern and south-western England, continue until the twilight of direct demesne management in the closing decades of the fifteenth century. Long runs of accounts for individual manors are particularly useful for the kind of exercise undertaken here and the best of these typically relate to the properties of perpetual ecclesiastical institutions (including some bishoprics), which had the administrative resources to create and preserve archives. For a few rare manors, notably East Meon, Ecchinswell, Merdon, and Overton in Hampshire all belonging to the bishop of Winchester, there are records spanning more-or-less the entire period under investigation (a longer span even than the 160 years covered by the Rothamsted experimental farm — the world's oldest agricultural research station). This means that there is a strong bias within the sample towards manors in ecclesiastical ownership and especially those belonging to large estates prone to considerable institutional inertia. Geographical coverage is also uneven and varies over time, which further complicates the methodological challenge of generalising from these data. The northern and north-western third of the country and the extreme south-west are both consistently poorly served by available data and for some time periods are without any information at all. Coverage of the midlands is also inferior. In contrast, the east and especially the south are well documented, sometimes to an almost overwhelming extent. These temporal and regional discontinuities in the coverage of

the data are likely to have a seriously distorting effect upon results crudely extrapolated to national level. Here they 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 areas in 1801, as specified in Table 1.

Care must obviously be taken in using records relating to the seigniorial sector to infer developments in agriculture as a whole. The seigniorial sector was always less important than the non-seigniorial sector and its scale and significance varied over time. Even at its peak in the early fourteenth century it probably accounted for no more than around 25 to 30 per cent of all agricultural land and output (Campbell, 2000: 26). The non-seigniorial sector is not a complete *lacunae* but the available sources are more disparate, less amenable to quantification, and to date, with a few notable exceptions, have received far less attention from historians. Thanks to the pioneering work of John Langdon much is known about relative numbers and types of draught animals on seigniorial and non-seigniorial holdings (Langdon, 1986). M. M. Postan also made memorable use of tax returns to shed light on the relative stocking densities of demesne and peasant holdings and thereby support his influential claim that the productivity of peasant holdings was inferior to that of demesnes due to shortages of animals and therefore manure (Postan, 1962). Mark Bailey has since re-examined some of this evidence (Bailey, 1989: 115-35). More recently, Ben Dodds (2006 and 2007) has pressed tithe records into use due to their unique capacity to shed light on annual variations in the aggregate grain output of all classes of producer and, sometimes, the composition of that output. A few tithe series also include wool output. The great merit of such series is that they can be used to verify or qualify trends reconstructed from equivalent information given in manorial accounts. There

is, for instance, a close correlation between year-on-year variations in crop yields derived from manorial accounts and annual variations in tithe receipts reconstructed from tithe accounts (Campbell, 2007a).

Seigniorial and non-seigniorial producers naturally faced common environmental and commercial opportunities and shared the same technology. There was also much overlap in their respective labour forces. Hence, where peasants led, lords were likely to follow, and *vice versa* (Campbell, 2000: 1). Nevertheless, the two sectors differed in the scales of their respective production units, methods of decision taking, capital resources, consumption priorities, and vulnerabilities to risks and hazards (lords profiting from bad harvests which ruined small producers). Initially, factor costs, monetary trends, and property rights encouraged lords to manage their demesnes directly and concentrate upon arable production. From the second quarter of the fourteenth century, in contrast, lords began to find it more profitable to abandon direct demesne management and lease out their demesnes, either entire or piecemeal, sometimes leasing out their flocks and herds separately from their arable. Over the next hundred years or so this movement gathered momentum until by the second quarter of the fifteenth century only a small minority of demesnes remained in hand. Obviously, as the seigniorial sector contracted so the non-seigniorial sector expanded.

Peasants could rely on family labour supplemented by hired labour and were unburdened by administrative overheads. Although lords could in theory rely on customary labour, this was rarely adequate to their needs and in practice was difficult to deal with, hence their increasing dependence upon hired labour. Yet nominal wages rose significantly following the Black Death and steeply so from the 1380s.

Production costs thus became less favourable to grain producers and from the closing decades of the fourteenth century profit margins were squeezed further by falling prices. Under these economic circumstances, those lords who continued to farm directly switched away from labour-intensive arable production to the more extensive forms of mixed husbandry and pastoral production. A few leased out their arable lands, engrossed their fold rights, and concentrated exclusively on large-scale wool production. Eventually, only those arable demesnes maintained as home farms managed to provision seigniorial households were kept in hand. The record of production on these home farms is probably as diagnostic as ever of annual variations in yields and harvest conditions but less so of market-influenced changes in farm enterprise. The picture thus provided of agriculture in the twilight of direct demesne management is consequently less sharply focused and reliable than that of direct demesne management in its heyday during the half-century or so before the Black Death. The records of these late-managed demesnes are nevertheless crucial in helping to bridge, or at least narrow, the documentary void between the mid-fifteenth and mid-sixteenth centuries when the agricultural information from probate inventories begins to come on stream.

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 regarded as broadly diagnostic 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 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.

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 (Table 2). This was probably at its medieval peak — following several centuries of active reclamation and land improvement — *c.*1300, when the medieval population also attained its maximum. Nevertheless, contrary to the claims of Gregory Clark (2007: 124), it is improbable that the tillage area in 1300 could have exceeded that in 1801, when the first reasonably firm estimates of total arable area are available. Moreover, a tillage area of 10.69 million acres in 1801 can be shown to have been capable of satisfying the basic grain requirements of a national population of 8.6 million (Broadberry and van Leeuwen, 2008). By 1800 widespread disafforestation, large-scale fenland drainage, private and parliamentary enclosure, and improved ploughing technology had all allowed more land to be brought into arable production than probably ever before. Further, the combination of rapid population growth, structural economic change, and a Napoleonic blockade of continental supplies of grain to England had all given English farmers a powerful price incentive to push arable production to its limits. This 1801 figure thus sets an upper bound limit on the 1300 figure, which is here — following Overton and Campbell (1996: Table III) — taken to have been 10.53 million acres, of which 6.8 million acres were sown. The arable area in 1300 will only have been under estimated if that for 1801 has been set too low.

This 1300 figure implies an increase in the total arable of 25-30 per cent since 1086, which is consistent with what is known about developments during the

intervening years (Donkin, 1973: 98-106). The bulk of this expansion in cultivated area is assumed to have taken place by 1250, when the sown area has been set at 6.62 million acres. The 1380 figure of 4.76 million acres is obtained from the changes in sown area on the demesnes between 1300 and 1380 (Campbell *et al.*, 1996), and implies an overall contraction in the area sown of 30 per cent notwithstanding a population reduction of 45 per cent or more (Table 16A). The same method is used for the changes between 1380 and 1420, but also checked against the rate of change in tithe receipts in County Durham where the scale of the arable contraction was probably above the national average (Dodds, 2004: 261). Allowances are also made for changes in the amount of fallow as the intensity of cropping patterns increased down to 1300 and diminished thereafter (Overton and Campbell, 1996: Table V).

Table 3 gives the regional distribution of the crop totals contained in Table 2, 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 decidedly uneven geographical coverage. Each region's share of the national sown acreage is taken from the 1801 crop returns. The breakdown of the crops within each region is based upon information provided by available manorial accounts, on the assumption that demesne cropping patterns are reasonably representative of wider cropping patterns within their respective localities and regions. Although seigniorial and non-seigniorial cropping are unlikely to have been identical, when direct comparison is possible between both sectors at the level of individual manors and parishes the differences between them were rarely large (e.g. Sapoznik, 2008: Table 3). As fuller

information on non-seigniorial cropping becomes available, primarily from grain tithe receipts, so the weightings contained in Table 3 can be revised.

2. Grain yields

To calculate the total regionally-weighted output from the estimated areas sown with each crop requires information on grain yields per unit area, net of seed sown. Yields on seigniorial demesnes — calculated from information on the seed sown, areas sown, and quantities of grain harvested and threshed recorded in manorial accounts (and sometimes the medieval auditors' own calculations of yields) — are the single most abundant source of accurate data on crop yields for any period before the late nineteenth century. Using these data, annual chronologies have been reconstructed of the yields per unit area of wheat and rye (the two principal winter-sown crops), barley and oats (the two principal spring-sown crops), and pulses (i.e. beans and peas) for the entire period under investigation. The relative levels of yield per unit area on seigniorial and non-seigniorial holdings has been the subject of considerable historical speculation and debate. Some authors, taking their cue from Postan (1966), have argued that grain yields were on average higher on the demesne lands because of the latter's comparative advantage in capital, principally livestock. More recently, it has been countered that the level of labour inputs per unit area was more critical in determining yields, hence land productivity may have been higher on non-demesne holdings because of the stronger incentives faced by peasants working on their own account (Stone, 2006). Allen (2005) notes that in the light of these conflicting arguments, it is reasonable to assume that yields were not significantly different in the two sectors, and that is the assumption made here. Certainly, a big productivity differential in favour of non-seigniorial producers should have encouraged lords to

lease their demesne lands rather than manage them directly. Nevertheless, even if differences in the *level* of yields on demesne and non-demesne lands cannot be ruled out, correlation of annual variations in yields recorded by manorial accounts and aggregate grain receipts reconstructed from tithe accounts does demonstrate that yields in both sectors moved together very closely. Hence, the manorial data still provide an accurate *index* of grain yields.

Generating aggregate trends from the demesne-specific yield information is not straightforward. The number of manors with yield information varies from one year to the next (Figure 1) and the geographical distribution of those manors is never constant. Given the extent of variation in yields across manors, 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. Because, for reasons of documentary survival, most yield series for individual manors are chronologically discontinuous, each of these chronologies has been derived using regression analysis with dummy variables for each manor and for each year, as suggested by Clark (2004). Since the dispersion of grain yields across manors is very high, it is important to use a log-linear specification, otherwise a small percentage drop in output on a high-yielding manor can outweigh a large percentage increase on a low-yielding manor. Adjustment has also been made for tithes deducted at source and assumed to have been a consistent 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 2 to 6 and the mean indexed trend of all five crops in Figure 7. As will be observed, the crops differed in their overall levels of yield, with barley consistently delivering the highest yields per unit area and pulses mostly the lowest. Yields also varied a great deal from year to year and over time, with mean yields in good periods often being as much as 50 per cent above those in poor periods. The opening years of the fourteenth century, the 1330s and early 1340s, and the closing quarter of the fourteenth century delivered the best yields during the period under review, whereas yields were much lower during the 1350s and 1360s and throughout the whole of the fifteenth century. In fact, yields in the 1460s and 1470s were a quarter below the level achieved in the 1270s and 1280s and over a third less than the peak yields of the 1380s, a fact that can only partially be explained by lower seeding rates. Certain individually good or bad years also stand out clearly. The dismal yields of 1315-17 — the first three years of the Great European Famine when incessant rain repeatedly ruined harvests — are conspicuous. The harvests of 1349-51, which coincided with the Black Death, were even worse and those in 1436-7 and 1441-2 were no better. Such massive back-to-back harvest failures must have been disastrous for a society heavily dependent upon grain for its staple foodstuff and with only a tiny carryover of surplus grain from one year to the next. The broad trends in yields gross and net of seed and of seeding rates are summarised in Table 4 for overlapping 50-year periods. This identifies the period 1250-99 as having enjoyed the highest average net yields per unit area and the period 1425-74 as having experienced the lowest.

3. Consumption by working animals

In addition to making allowance for grain used as seed, calculations of the net output of the arable sector need to 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. Estimates of the number of working animals per 100 sown hectares on the demesnes are based on Campbell (2000: 124-5). Stocking densities on the demesnes (Table 5, Panel A) have been converted into the numbers of horses and oxen on all lands (Table 5, Panel B) by following Wrigley's (2006: 449) assumption that the stocking density of working animals on non-seigniorial holdings was three-quarters that on the demesnes. In making these estimates allowance has been made both for the declining share of demesne acreage and the lesser quantities of fodder consumed by immature animals. Figure 8 shows that there was a substitution of horses for oxen as working animals during this period. Since horses can do more work than oxen, this allowed a decline in the number of working animals per unit area. It is assumed that, on demesnes, a mature horse consumed 16 bushels of oats per year and a mature ox 2.72 bushels, while an immature animal consumed half that of an adult animal (Allen, 2005; Langdon, 1982 and 1986). Non-seigniorial animals had a lesser workload than these demesne animals and, consequently, will have consumed considerably less. Langdon (1982, 38) suggests that the workload of non-seigniorial horses and oxen was probably no more than half that on the demesnes. Accordingly, their fodder consumption is assumed to have been half that of demesne animals.

4. Arable output net of seed and animal consumption

Table 6 provides a convenient summary of the estimated output of the arable sector gross of tithes but net of seed and animal consumption over the period 1250-1474. Data are presented as 50-year averages to abstract from short run fluctuations, some of which were very pronounced. Output net of seed was obtained for each crop by multiplying the sown acreage from Table 2 with the net yield from Table 4. Estimated quantities of oats and pulses consumed by working animals, as specified in Table 5, have then been subtracted. Figure 9 then charts the value of all arable output per unit area sown at constant prices, an exercise which brings out the broad variations in arable productivity which occurred over this long period.

Total net output of the principal bread grains — wheat and rye — declined by over 40 per cent over the course of the period, with the bulk of that decline following the Black Death of 1348-9. Output of rye, the cheaper and less favoured of the two grains, declined more markedly than that of wheat. The scale of this decline is consistent with a reduction in demand of 50 per cent or more (Table 16) and the fact that higher incomes allowed more dietary choice (Figure 15). The contraction in the output of oats was even more pronounced, as it fell out of favour as a major component of human diets and less may also have been consumed as fodder as grazing expanded at the expense of tillage. In place of malted oats, malted dredge (a barley/oats mixture) and malted barley became the preferred brewing grains. Of all the grains, demand for barley remained the most buoyant throughout the period as a better-paid population was able to consume larger quantities of better-quality ale brewed from the best barley malt. Output of pulses also held up well. Their nitrifying

properties meant that they retained an important role within the more intensive rotations, they continued to be consumed in modest quantities by humans and livestock, and they had the merit that they could be fed un-threshed to animals. Moreover, in areas of commonfield agriculture, where it was difficult to withdraw land from tillage, increasing areas were sown with legumes as an alternative to turning them over to permanent grass. These output shifts are consistent with the well-known rise in average living standards which followed the Black Death and climaxed in the third quarter of the fifteenth century. Managers of seigniorial demesnes producing both to satisfy the consumption requirements of lordly households and supply the market were clearly responding to changes in the scale and composition of demand.

IV. PASTORAL OUTPUT

1. Number of non-working animals

The starting point for deriving the numbers of non-working animals is, again, the densities of beasts maintained on the demesne lands (Campbell, 2000: 136-7). Panel A of Table 7 shows that densities of non-working animals (in livestock units) on the demesnes increased strongly over time, almost doubling between the last half of the thirteenth century and the first half of the fifteenth century. Sheep accounted for the greater part of that gain, as is clear from Figure 10, thereby raising the crucial question whether this was a general trend or something specific to the seigniorial sector as lords engrossed sheep pastures and appropriated folding rights to themselves. Sheep, therefore, are critical to all estimates of the relative scale of the pastoral sector.

Conversion of these seigniorial densities and numbers into corresponding national densities and numbers has therefore been based on four basic 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. This in turn has to be multiplied by a factor of four since the average size of demesnes was much larger than the non-demesne sector, and the stocking density increases when farm size decreases. Second, again following Allen (2005), mature cattle have been divided into milk and beef animals in the ratio 53 to 47 per cent. 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 relatively stable in the long term (in contrast to the dynamic situation in the seigniorial sector), which 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 to 1.08 square metres per head *per annum* (on the reckoning that domestic production supplied labourers with 1 square yard (0.9144 square metres) of woollen cloth, substantial tenants with 2 square yards, and landowners with 8 square yards, weighting the different social classes according to the social table of Campbell (2007b)). Applying these assumptions to the data on Panel A of Table 7 with reference to the sown areas given in Table 2 yields the national totals of animals summarised in Panel B of Table 7.

2. Pastoral sector output

Calculating the output of the pastoral sector is more speculative than the equivalent calculation for the arable sector since meat, milk, and even wool yields have all attracted less attention from historians than crop yields, notwithstanding the wealth of relevant information contained in manorial accounts. In part this reflects an enduring historiographic bias towards grain production and in part the greater complexity of the recorded information on animal products. Until more systematic work is done on the sources the estimates advanced here are necessarily provisional. More and better information on (a) the numbers of animals, (b) the proportion of those animals producing meat, milk, and wool, and (c) the yield per animal of those products, is bound to lead to their revision.

The assumptions made in estimating the numbers of animals have been discussed above and the relevant estimates are set out in Panel B of Table 7. The proportions of those animals assumed to have been producing milk, meat, and wool are set out in Table 8. For simplicity, all cows are assumed to have produced milk and all sheep are assumed to have yielded wool. Meat, however, was produced solely by those animals that were slaughtered, here (following Holderness, 1989: 147) reckoned to have been a quarter of the stock of cattle and sheep and all pigs (apart from those retained for breeding). These very raw assumptions have been qualified with additional information taken from Clark (1991) and Ecclestone (2006). How much milk, meat, and wool did each animal, on average, then produce? Table 9 sets out preferred estimates of the yield per animal, drawn from a number of sources, including Campbell (2000), Allen (2005) and Clark (1991). Finally, Table 10

combines the information contained in Tables 7B, 8, and 9 to generate a set of estimates of the total output in pastoral farming.

In contrast to the arable sector, the pastoral sector exhibited substantial growth during the first half of the period under examination, after which output levelled off and in the mid fifteenth century may even have declined somewhat, notwithstanding an absolute abundance of grazing resources. This paradox is explained by the slackness of demand from a much reduced population and a growing predominance of the more extensive forms of pastoral husbandry.

3. Hay, hides, and dairy products

Further assumptions are necessary in order to derive output estimates for hay, hides and skins for leather and parchment, and dairy products (milk, butter, and cheese). Hay output (Table 11) has been inferred from estimates of the total numbers of horses, on the assumption that each horse consumed approximately 2.4 tons of hay per year (Allen, 2005). The number of farm horses is well documented and is taken from Table 5. Numbers of non-farm horses are assumed to have varied in proportion to the number of farm horses, with the ratio of non-farm to farm horses in 1300 taken from Wrigley (2006). The results (Table 11) suggest that total hay consumption declined slightly over the course of the fourteenth century, which is consistent with the reduced output of other harvested plant products over the same period (Table 6) as labour became scarcer and costlier.

Hide and skin output over this same period was a function of the changing numbers of slaughtered (Table 8) and dead animals, their sizes, and the respective

weights of their skins. In Table 12 the shares of animals producing hides and the weights of their hides are derived from Clarkson (1989: 470, n. 259), Ecclestone (1996: 26), and Clark (1991: 216). As will be noted, total output remained relatively constant over the entire period although quite significant shifts occurred in the composition of that output, as the supply of skins from sheep rose and the supply of hides from cattle fell.

In the case of the dairy sector, it is clear that the bulk of all milk produced was used to make butter and cheese on the farm. On the estates of Bolton Priory in the Pennine uplands of the north of England in the early fourteenth century, butter was made from whole milk and cheese from skimmed milk, resulting in 30 lb of butter and 65 lb of cheese from 100 gallons of milk, or a cheese-to-butter ratio of two-to-one which is quite close to the ratio in 1700. According to Biddick (1989: Appendix 5) only a small part, around 7 to 10 per cent of the overall milk yield, was retained as fresh milk. This means that on average, 100 gallons of milk resulted in 60 lb of cheese, 30 lb of butter and 10 gallons of fresh milk. Applying these conversion ratios to the estimated output of raw milk given in Table 10 yields the output of processed dairy products given in Table 13. As will be observed, output of dairy produce rose to a peak during the late thirteenth and the first three quarters of the fourteenth century and then abated somewhat, as the continuing decline of population eroded demand for all staple foodstuffs.

V. TOTAL AGRICULTURAL OUTPUT

Multiplying the volumes of net output by the prices of their component products yields the total value of net output. The prices used for this purpose have been taken largely

from Clark (2004), who synthesises the published data of Beveridge (1939), Thorold Rogers (1866-1902) and the multi-volume *Agrarian History of England and Wales*, as well as integrating new archival material principally from the unpublished papers of Lord Beveridge and David Farmer. To this, have been added the prices of hides from Thorold Rogers (1866-1902: volumes 1-3) and of rye from Farmer (1988 and 1991). Where there are large gaps in the price data for individual products, regression analysis has been employed to interpolate the missing values. Output can be valued in both current prices and in constant 1300 prices.

Figure 11 plots arable and pastoral output in constant prices on a logarithmic scale, while Table 14 summarises the same information in growth rates, using 5-year averages. Over the 200-years under examination, arable output trended downwards (and from *c*.1390 also trended down per unit area sown, albeit with an increase in the late 15th century — Figure 9), while pastoral output displayed long-run stability. Agricultural output as a whole thus exhibited a modest decline. As a result of these trends, the pastoral sector increased its output share substantially in constant price terms. The expanding share of the pastoral sector can also be seen in current-price terms in Figure 12 and Table 15. The increase is similar in current and constant-price terms because the relative price of arable to pastoral products did not change much over the period as a whole, as shown in Figure 13.

VI. AGRICULTURAL LABOUR PRODUCTIVITY

To see what happened to labour productivity in agriculture, it is necessary to provide estimates of the total population and the share working in agriculture. While there is considerable historical agreement about the *trend* of population between 1250 and

1450 — that numbers rose to a maximum sometime before 1315, levelled off or even declined slightly between 1315 and 1348, fell dramatically as a result of the successive national plague epidemics of 1348-9, 1361, 1369, and 1375, and thereafter continued to erode until at least the third quarter of the fifteenth century — there is far less consensus about the absolute size of that population at key benchmark points in time.

The biggest controversy concerns the size of the medieval population at peak. One influential school of thought reckons that the population had grown to 6 million or even more by the opening of the fourteenth century (Hatcher, 1977; Smith, 1991; Clark 2007) but it is far from clear how such a large population could have been fed by domestic agriculture, especially given the claims of some historians that land productivity was in decline and lower on peasant holdings than on demesnes (Postan, 1966: 602-3; Miller and Hatcher, 1978: 216-17). It is also difficult to reconcile a figure of 6 or even 5 million with a range of other measures and estimates of contemporary economic activity (Campbell, 2007b). A population of 4.25 million *c.*1300 — the figure opted for here (Table 16) — presents none of these problems and accords well with the consumption data (see Section VII). By 1380 the population had fallen to *c.*2.37 million, an estimate reasonably firmly grounded in the 1377 poll tax returns. Additional observations for the periods before, between, and following these two benchmark estimates have been added by interpolation using assumptions derived from the literature. These involve the assumption of a slow rate of decline in the population from at least 1315, punctuated by the dramatic decline of the Black Death years, 1348-51, and then a number of lesser crises of diminishing scale. 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 (Tables 6, 10, 12, 13, and 15) with the agricultural population data (Table 16) produces the annual estimates of agricultural output per agricultural worker shown in Figure 14. Table 17 presents the same material in growth-rate form. The main findings are that output per agricultural worker (a) fell slightly until *c.*1285, (b) thereafter recovered slightly until the agrarian crisis of 1315-21, (c) post-crisis remained fairly static, (d) increased sharply in the immediate aftermath of the Black Death, (d) and then remained at this higher level, albeit with substantial fluctuations, throughout the rest of the period. Significantly, whereas the Black Death marks the onset of a step rise in agricultural labour productivity, the earlier disaster of the Great European Famine of 1315-21 —clearly visible in Figure 14 — had only a short-run cyclical impact. Much the same was true of the later crisis of 1436-9.

VII. CROSS-CHECKING THE OUTPUT ESTIMATES

1. Income- and output-based measures

Figure 15 charts the annual level of real wages for farm workers between 1250 and 1450, taken from Clark (2007). Comparison with the level of agricultural output per agricultural worker (Figure 14) shows that labour productivity and the real wage both (a) trended downwards during the third quarter of the thirteenth century, (b) sank to their lowest levels in the second decade of the fourteenth century at the time of the Great European Famine, (c) made a modest recovery during the decades following that disaster, (d) registered a sharp rise immediately following the massive

demographic shock inflicted by the Black Death and its subsequent manifestations, and then (e) remained at this higher level until at least the middle of the fifteenth century. Reassuringly, the two series are in broad agreement concerning the long-run trends, although, as Figure 16 brings out, there is a widening divergence between them from the final quarter of the fourteenth century, when average agricultural output per worker reached a plateau but real wages continued to rise.

The compatibility between the stories implied by these trends in real-wages and agricultural labour productivity down to *c.*1400 can be pursued more generally within the national accounting framework, where the value of net output should equal the value of the factor payments to labour, land and capital. Relevant estimates are set out in Table 18.

Starting on the income side, to calculate payments to labour, data are needed on the number of days worked and daily wages. In Panel A of Table 18 the agricultural population estimates given in Table 16 are converted into the number of agricultural families following Allen's (2005) assumption that the average family consisted of two adults and 2.5 children. 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. His 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 downward modification. Whereas Table 14 implies that there was a decline in output over the fourteenth ad fifteenth century, Allen concluded that, notwithstanding a halving of the population, agricultural output increased significantly between 1300 and 1500. This seems

implausible. Moreover, the substantial increase in days worked per family which Allen requires to achieve that rise in output is hard to square with most accounts of the response to the Black Death, which suggest a decline in labour intensity and shortening of the working day (Bowden, 1967: 593-4).

In fact, on the evidence of the estimates summarised in Panel A of Table 18 there was a substantial decrease in days worked per family between 1250 and 1450. Between 1250 and 1300 this decrease was probably due to the growing scarcity of employment. Thereafter, and especially following the Black Death, rising rates of remuneration meant that families did not have to work so hard in order to satisfy their subsistence needs; leisure, in effect, became a growing preference in the transformed employment situation which followed that disaster. On the evidence of these estimates the fourteenth and fifteenth centuries witnessed an "indolent revolution", in contrast to the "industrious revolution" hypothesised as having occurred in the early modern period (de Vries, 1994).

To estimate total rental income — Panel B of Table 18 — requires data on rents and total land in use. Rents are obtained from the rental series assembled by Clark (2001). The total land in use must include pasture and meadow as well as arable land. The arable area is taken from Table 2 but multiplied with the ratio of pasture/meadow versus arable taken from Allen (2005). Capital costs and tithes and taxes are also taken from Allen (2005). All tended to trend downwards over time and all were significantly lower by 1450 than at any earlier point in time.

Totalling the agricultural wage estimates given in Panel A with the income from rents, capital, tithes, and taxes given in Panel B, yields the total agricultural incomes given in Panel C of Table 18. Both the trend and the level of the estimated income from agriculture matches well the estimates made of the value of agricultural output, also shown in Panel C of Table 18. The income estimates are consistently within 6 per cent of the output estimates.

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 food consumption per head. 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 will *on average* have been supplied by grain. In periods of greatest poverty, such as the first half of the fourteenth century, this proportion may have been as great as 80 per cent. Massimo Livi-Bacci (1991) believes that for a population to have been adequately fed required an average intake of 2,000 kilocalories *per capita* per day. Adult males labouring on the land would have required about twice this. Net grain output by domestic agriculture when processed into pottage, bread, and ale thus needed to be able to deliver at least 1,500 kilocalories per person per day for the population's basic subsistence needs to have been met unless that population was sufficiently affluent to devote a larger share of its food budget to dairy produce, meat, and fish.

In 1800, when the total population, total arable and total grain areas, composition of the grain area, and net grain yield per unit area are all reasonably

securely documented, English agriculture augmented by imports delivered an average *per capita* daily grain supply of approximately 1,627 kilocalories. Such a diet was anything but generous and is consistent with the poor harvests and low real wages then prevailing. Possibly, too, *per capita* grain intake declined with industrialisation and urbanisation. Equivalent estimates for a series of benchmark years between 1300 and 1450 are given in Table 19 (output of the major grains in Table 6 has been converted to kilocalories and then divided by the population estimates given in Table 16). As will be noted, after allowance for grain set aside as seed, consumed by animals as fodder, lost in storage, and wasted in the milling, malting, baking, and brewing processes, only a little over half of the gross harvest was actually consumed as food and drink. Nevertheless, this was higher than the estimated extraction rate in 1801.

The results from this exercise imply that the estimated levels of grain output were less equal to society's needs in 1300 than in 1380, after the Black Death. Certainly, on the grain estimates advanced in this paper, it is difficult to see how the minimum subsistence requirements of a population larger than 4.25 millions could have been met. Moreover, it is arguable that what mattered was not the supply of grain in *average* years when harvests were close to normal, but the supply in *extreme* years, such as 1315-16 and 1437-8, when production net of seed was reduced by a third or more for two consecutive years. In 1300 a daily *per capita* supply of 1,298 kilocalories from grain will have meant that the population will have been hit hard by any failure of the harvest. By 1380 the massive reduction in population precipitated by plague had clearly resulted in some alleviation of this situation and output trends

(Table 15) imply that pastoral products were already making an increased contribution to daily diets.

Subsequently, as the population continued to shrink, purchasing power rose, and pastoral output expanded yet further in relative importance, so the dietary contribution of pastoral products grew to the point where *per capita* consumption of grain-based kilocalories began to fall (Table 19). By 1450 a population with almost twice the purchasing power was consuming *per capita* slightly less grain than in 1300 and no doubt consuming an increasing proportion of that grain in liquid rather than solid form. Probably, too, people were better able to indulge their dietary preferences for the higher qualities of bread baked from wheat and ale brewed from barley malt. In this case, the fact that *per capita* grain supply fell some way short of minimum subsistence requirements testifies to the comparative affluence of the times and the general buoyancy of the pastoral sector.

VIII. REFLECTIONS AND CONCLUSIONS

This paper has presented the first annual estimates of English agricultural output and labour productivity over the critical 200 years between 1250 and 1450 when producers were challenged by some of the greatest supply- and demand-side shocks on historical record. These estimates are, of course, no better than the quality and coverage of the empirical data upon which they are based, the methodologies applied to those data in order to aggregate chronologically and spatially discontinuous farm-level information to a national level, and the assumptions which that task necessarily entails. More and better data, more rigorously tested methodologies, and better-informed assumptions are bound to deliver improved results. Because of the

unavoidable reliance upon information derived from manorial accounts, this is very much a view of English agriculture from the demesne. Upon the representativeness of the seigniorial data hinge (a) the absolute level and volume of agricultural output at benchmark points in time, (b) the magnitude of short-term variations, (c) the amplitude of long-term trends, and (d) the scale of associated shifts in the composition of production and, in particular, the balance struck between the arable and pastoral sectors. These estimates therefore provide a yardstick against which results from the non-seigniorial sector may be evaluated. Indeed, systematic research into the non-seigniorial sector is now an urgent priority.

In terms of the absolute volume of medieval agricultural output, the present estimates offer little comfort for those who have argued for a population *c.*1300 of 6 million or more. Feeding even a population of 4.25 million presented a major challenge and was achieved with little margin over bare subsistence. To have fed a population 40 per cent larger again would only have been possible if (a) significantly more land was under grain crops in 1300 than in 1801 (notwithstanding all the evidence and arguments to the contrary), (b) mean yields per unit area across the entire non-seigniorial sector as a whole were substantially — i.e. at least 50 per cent — higher than on demesnes (even though several influential medieval historians have argued the contrary), (c) the production mix and consumption patterns of non-seigniorial producers successfully delivered significantly higher net kilocalorie yields of processed food per unit area than those achieved by the demesne sector, or (d) pastoral products contributed a consistently larger share of kilocalories than has been assumed here. The onus is upon those who subscribe to population estimates in excess of 4.25 million to demonstrate whether any of these alternative scenarios, singly or in

combination, actually applied. This will require evidence rather than rhetoric and, in particular, evidence which allows direct comparison between the seigniorial and non-seigniorial sectors. Tithe records obviously lend themselves to this purpose, especially when parishes with recorded tithe receipts coincide with demesnes with extant manorial accounts. So far, however, such results as have emerged from the comparative study of manorial accounts and tithe receipts have tended to endorse the picture of arable output provided by the former. Nevertheless, such systematic comparative work is in its early days.

Chronologically, the story conveyed by these estimates is less contentious, at least down to *c.*1400. The broad trends in the volume of agricultural output over time, the ratio of arable to pastoral output, the relative importance of specific crops and categories of livestock, and agricultural labour productivity all accord with standard accounts of agricultural change over these 200 years. Insofar as there is a key difference, it is that these trends are here quantified and brought into sharper chronological focus than ever before. The long-term chronology of yields offers some surprises. The disastrous harvests of 1315-17 stand out clearly but the massive yield downturn that lasted from the late 1340s to the mid 1370s is actually far more striking. The higher yields of the final years of the fourteenth century are ostensibly consistent with the Ricardian assumption that mean yields rose as inferior land was taken out of cultivation and rotations became less demanding and exhausting. Nevertheless, the declining yields of the fifteenth century and absolutely low yields of the middle years of that century are at variance with such Ricardian reasoning. Rather, they imply a Boserupian correlation between the costs and supply of labour on one hand and the yield per unit area of arable land on the other. They also hint at the

over-arching influence of environmental conditions, both in terms of short-term weather generated production shocks, as in the case of the harvest failures of 1315-17 and 1437-8, and in terms of more subtle and enduring shifts in growing conditions. Quite possibly the lower yields of the fifteenth century arose from a general deterioration in growing conditions.

The estimates of agricultural labour productivity offer particular food for thought. A clear distinction is obviously to be drawn between the aggregate estimates offered here and the measurement of output per employed worker per task per hour worked. In fact, one implication of the absolutely low level of *average* agricultural output per agricultural worker prevailing by the end of the thirteenth century is that there were insufficient agricultural tasks to keep those workers fully occupied. Maybe their productivity was high when employed (Karakacili, 2004) but the over-supply of labour meant that marginal labour productivity was low with correspondingly high levels of under- and un-employment in agriculture. These problems of rural congestion were resolved by the massive reduction in population precipitated by the Black Death, which is why that catastrophe stands out in all the time series as such a watershed event. Average labour productivity rose following the Black Death, not because employed workers necessarily performed their tasks better, but because there were fewer under- and un-employed agricultural workers. As a result the real wages of farm workers improved dramatically and rural households found that they needed to work for fewer hours in order to satisfy their basic subsistence requirements. Instead of enforced idleness workers found that they could choose leisure. Yet, although the 75 per cent gain in agricultural labour productivity was revolutionary, this was no agricultural revolution for, once the initial productivity

benefits of reduced numbers had been harvested, further significant gains were not forthcoming. In fact, when the purchasing power of a farm worker's wage was at its peak in the middle decades of the fifteenth century, average agricultural output per farm worker remained at only half the level that would be achieved in the eighteenth century.

This suggests that one of the principal ways of raising average agricultural output per agricultural worker within pre-industrial European agriculture was by reducing the overall size of the agricultural workforce and preventing the build up of excess population on the land. In the fourteenth century the Black Death provided a brutal solution to this problem but in later centuries, at least in England, the vigorous expansion of non-agricultural employment via the growth of trade, commerce, and industry, served much the same purpose. Claims for an English agricultural revolution in the seventeenth and eighteenth centuries may thus have been overstated. Rather, English agriculture was the beneficiary of revolutionary developments taking place at that time elsewhere in the economy. In the long-run what mattered most for productivity growth within the agricultural sector was the sustained growth of other branches of economic activity capable of absorbing and employing the excess labour which would have had such a harmful effect upon agricultural labour productivity had it remained on the land. In England before 1450 these non-agricultural sectors remained in their infancy with the result that by the standards of later centuries levels of land and labour productivity were both comparatively unimpressive.

FIGURE 1: Number of sampled manors per year (decadal averages)

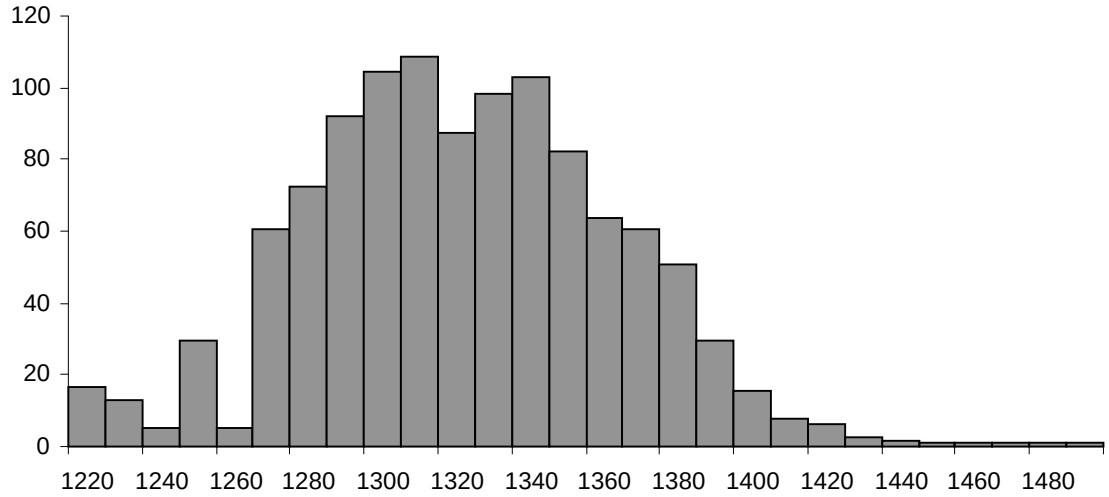


TABLE 1: Regional shares of the national sown area in 1801

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)

Year	A. Total area (millions of acres): Total arable	Fallow arable	Sown arable	B. Sown area (millions of acres): Wheat	Rye	Barley	Oats	Pulses
1250	10.30	3.68	6.62	1.89	0.71	1.13	2.67	0.22
1300	10.53	3.77	6.76	2.22	0.50	1.05	2.62	0.37
1380	7.98	3.22	4.76	1.52	0.30	1.01	1.55	0.39
1420	7.09	2.97	4.13	1.26	0.25	0.94	1.31	0.36

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

TABLE 3: Regional weights 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. 1380:	**Wheat**	**Rye**	**Barley**	**Oats**	**Pulses**
East Anglia	9.5	23.7	28.2	9.3	22.1
Eastern counties	22.2	1.0	7.5	19.1	21.7
Southern counties	18.3	11.6	23.1	9.7	10.5
Southwest	13.9	2.3	0.4	12.0	3.9
Southeast	9.0	5.4	11.3	5.4	14.7
Midlands	6.9	19.0	14.9	4.0	14.7
North	20.1	37.1	14.6	40.5	12.3
England	100.0	100.0	100.0	100.0	100.0
C. 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

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.

FIGURE 2: Weighted national average wheat yields per acre gross of tithe and seed (bushels)

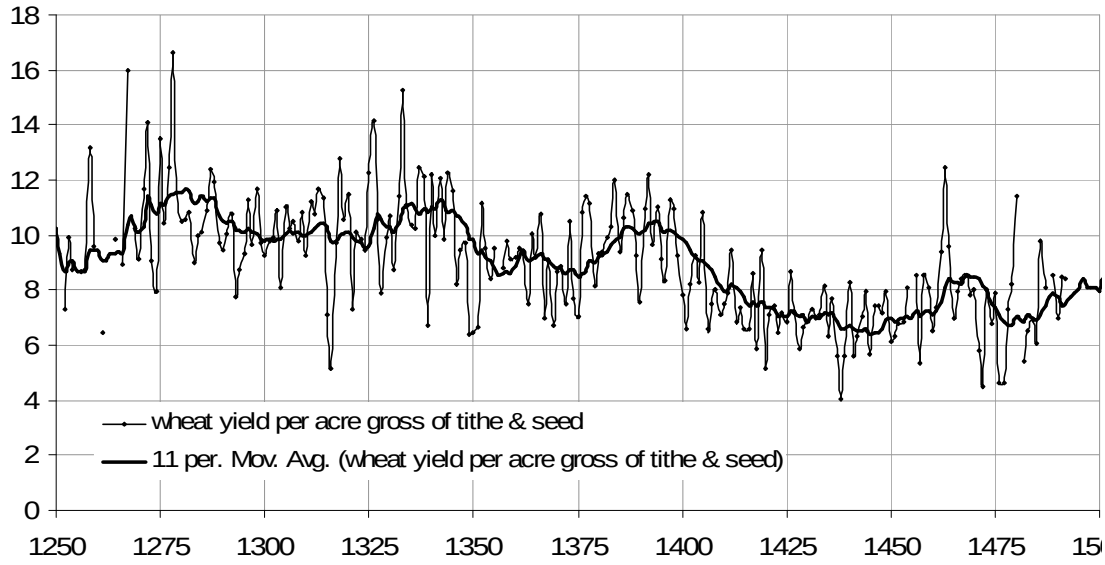


FIGURE 3: Weighted national average rye yields per acre gross of tithe and seed (bushels)

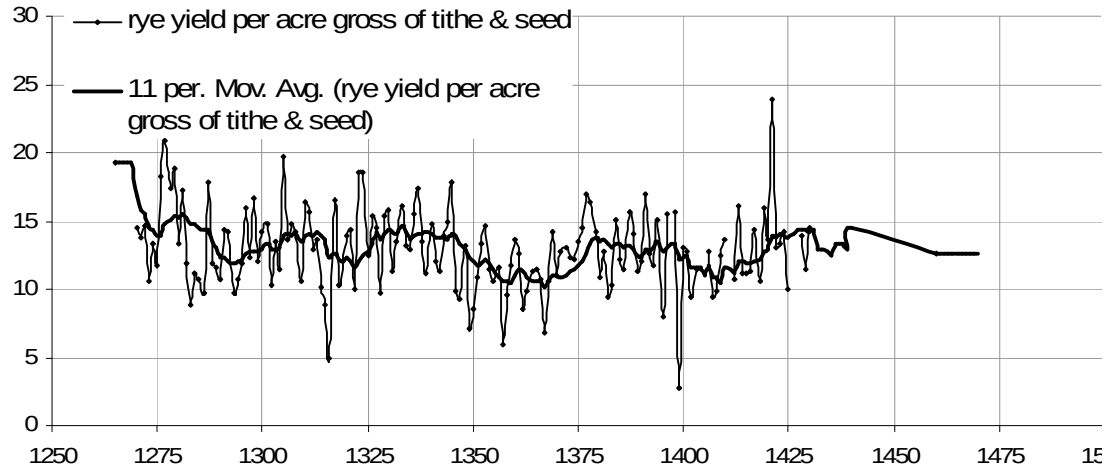


FIGURE 4: Weighted national average barley yields per acre gross of tithe and seed (bushels)

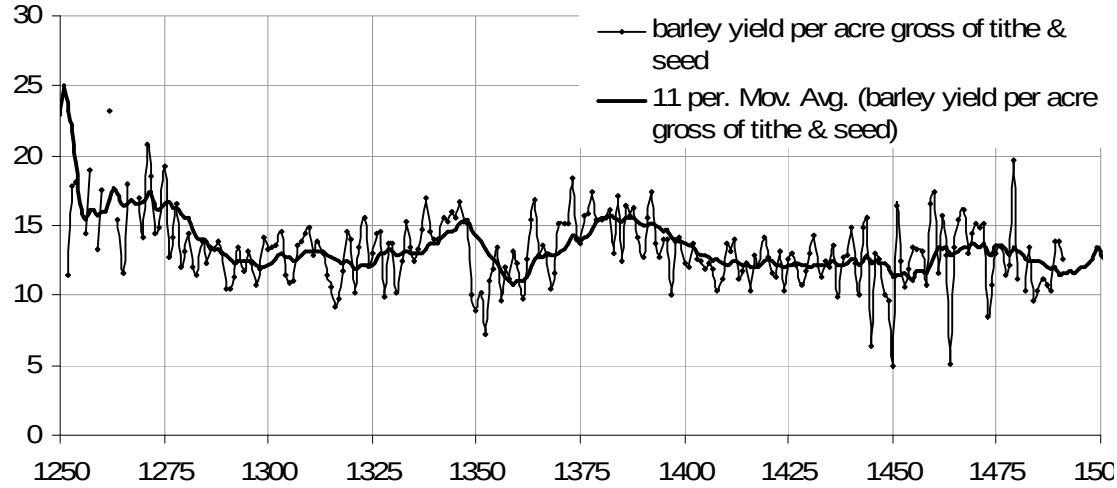


FIGURE 5: Weighted national average oats yields per acre gross of tithe and seed (bushels)

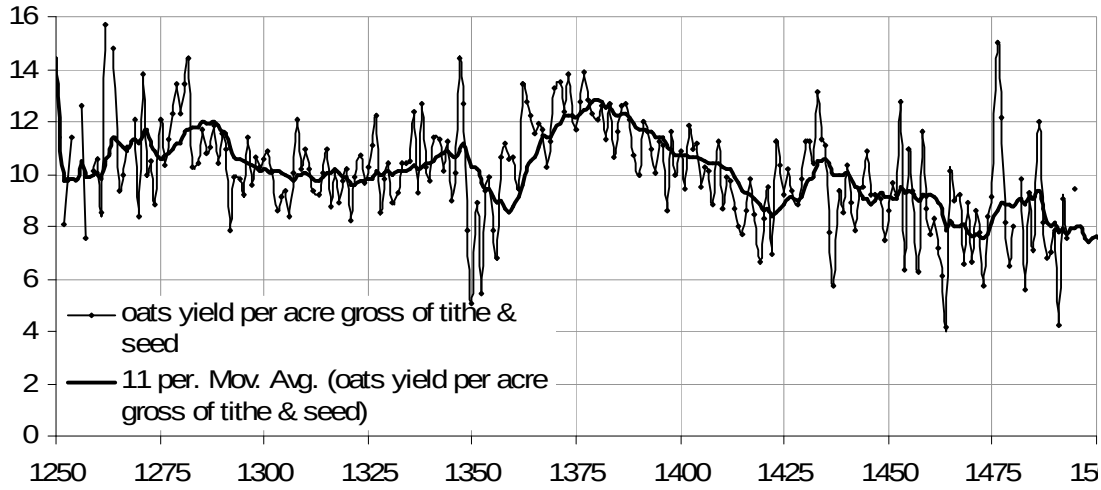


FIGURE 6: Weighted national average pulse yields per acre gross of tithe and seed (bushels)

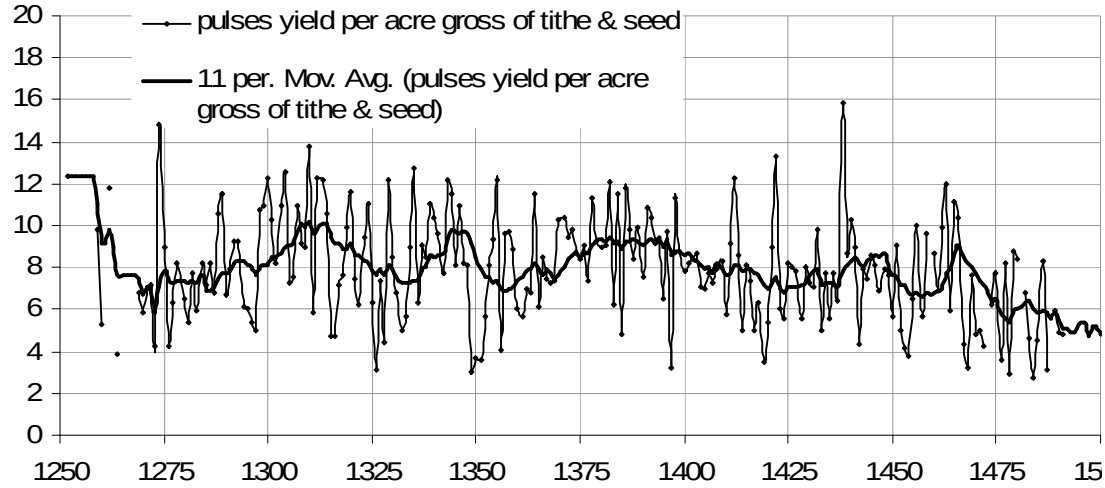


FIGURE 7: All crops yield per acre gross of tithe and net of seed (indexed on 1300-49)

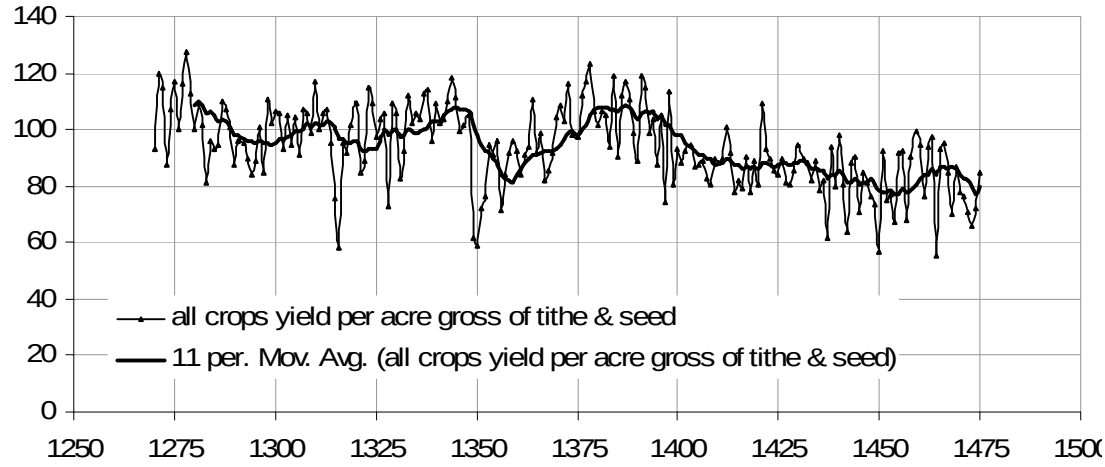


TABLE 4: Mean yields per acre gross of tithes.

A. Yield per acre gross of seed (bushel):

Period	Wheat	Rye	Barley	Oats	Pulses
1250-1299	11.27	13.73	14.41	10.91	8.93
1275-1324	11.09	13.46	12.86	10.47	8.46
1300-1349	10.77	13.31	13.36	10.21	8.77
1325-1374	10.07	12.23	13.31	10.61	8.05
1350-1399	9.96	12.00	13.67	11.12	8.43
1375-1424	9.49	12.89	13.48	10.53	8.26
1400-1449	8.28	13.01	12.20	9.52	7.71
1425-1474	8.52	14.65	12.54	8.93	7.44

B. Seed sown per acre (bushel):

Period	Wheat	Rye	Barley	Oats	Pulses
1250-1299	2.56	3.02	4.16	3.67	2.90
1275-1324	2.57	3.00	3.96	3.72	2.71
1300-1349	2.53	2.95	3.90	3.61	2.63
1325-1374	2.50	2.86	3.91	3.66	2.59
1350-1399	2.49	2.79	3.92	3.63	2.57
1375-1424	2.44	2.64	3.84	3.30	2.51
1400-1449	2.39	2.55	3.75	2.97	2.30
1425-1474	2.43	2.62	3.97	2.67	2.19

C. Yield per acre net of seed (bushel):

Period	Wheat	Rye	Barley	Oats	Pulses
1250-1299	8.71	10.71	10.25	7.24	6.03
1275-1324	8.52	10.45	8.90	6.75	5.75
1300-1349	8.24	10.36	9.46	6.60	6.14
1325-1374	7.57	9.37	9.40	6.95	5.46
1350-1399	7.46	9.21	9.74	7.49	5.86
1375-1424	7.05	10.25	9.63	7.23	5.75
1400-1449	5.89	10.46	8.44	6.55	5.42
1425-1474	6.09	12.04	8.57	6.27	5.25

Sources: Derived from Medieval Accounts Database. All yields have been corrected to include tithes, assumed to have been one tenth of the original harvest.

FIGURE 8: Working animals per 100 sown acres on demesnes (5-year moving averages)

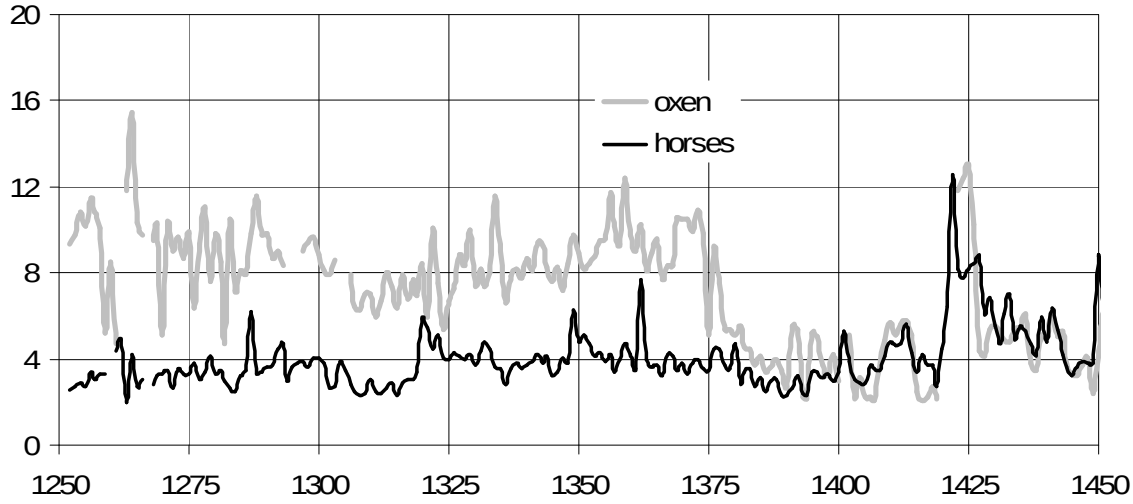


TABLE 5: Consumption of oats and pulses by working animals

A. Stocking densities on demesnes:

	Working animals per 100 sown acres:		Livestock units* per 100 sown acres	Oxen per 100 horses
Period	Horses	Oxen		
1250-1299	3.44	9.62	14.98	279.64
1275-1324	3.48	8.79	14.03	252.16
1300-1349	3.66	8.12	13.40	221.86
1325-1374	4.06	8.95	14.79	220.48
1350-1399	3.67	7.06	12.14	192.44
1375-1425	3.95	4.62	9.49	116.89
1400-1449	5.05	4.93	10.97	97.63
1425-1474	7.19	6.15	14.56	85.54

B. Consumption by working animals in England:

	Total number of working animals (millions)		Total farm-animal consumption (millions bushels)	
Period	Horses	Oxen	Oats	Pulses
1250-1299	0.24	0.46	2.79	0.86
1275-1324	0.24	0.42	2.77	1.01
1300-1349	0.24	0.37	2.80	1.15
1325-1374	0.24	0.36	3.00	1.04
1350-1399	0.19	0.26	2.51	1.12
1375-1425	0.18	0.15	2.31	1.07
1400-1449	0.23	0.14	2.89	1.00
1425-1475	0.27	0.16	3.73	1.00

Sources and notes: Derived from Medieval Accounts Database.

* Livestock units compare different animals on the basis of relative feed requirements. Ratios from Campbell (2000: 104-7): (horses x 1.0) + (oxen x 1.2).

TABLE 6: Arable output net of seed and animal consumption

	Wheat (m. bu.)	Rye (m. bu.)	Barley (m. bu.)	Oats (m. bu.)	Pulses (m. bu.)
1250-1299	17.83	6.66	11.62	16.58	0.86
1275-1324	18.03	5.31	9.39	14.35	1.01
1300-1349	16.37	4.45	9.77	11.91	1.15
1325-1374	13.43	3.46	9.59	10.13	1.04
1350-1399	11.60	2.89	9.78	9.54	1.12
1375-1425	9.90	2.85	9.43	8.13	1.07
1400-1449	7.68	2.87	8.15	5.84	1.00
1425-1474	8.07	4.30	8.57	4.46	1.00

Sources and notes: 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, and the figures after 1420 were assumed to be constant. Consumption by working animals from Table 5.

FIGURE 9: Arable output per acre sown (at constant prices) (1300=100)

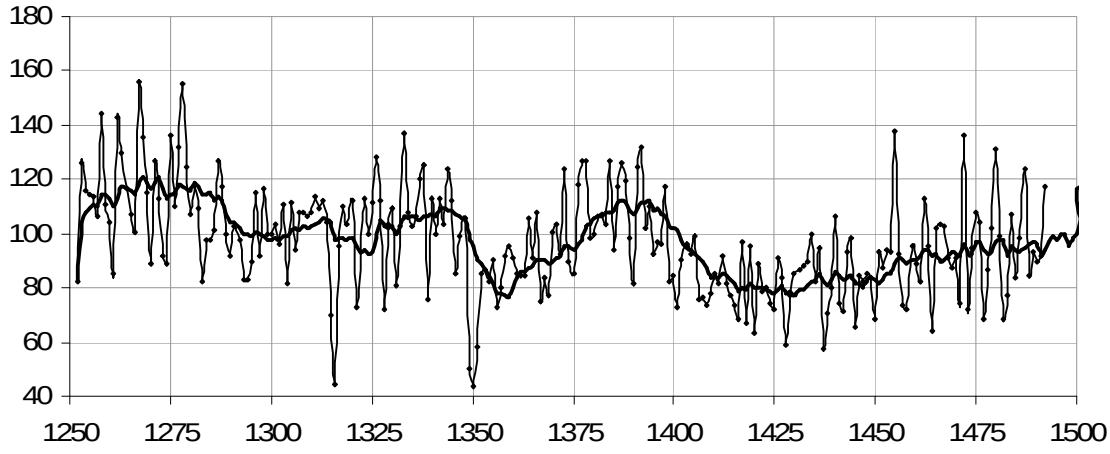


FIGURE 10: Non-working livestock per 100 sown hectares on demesnes (5-year moving averages)

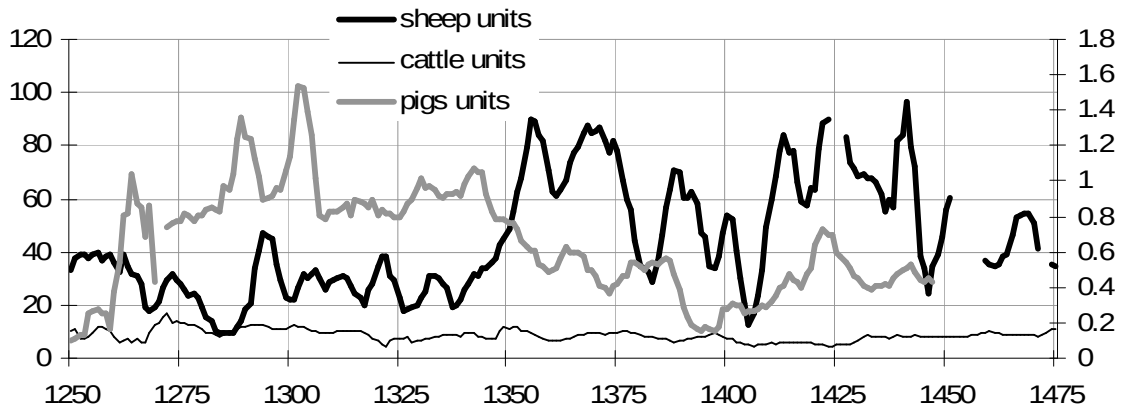


TABLE 7: Non-working animals

A. Stocking densities on demesnes

Years	Animal units per 100 sown acres				Immature cattle per 100 adults
	Cattle (mature + immature)	Sheep	Swine	Livestock units*	
1250-1299	10.61	27.86	0.74	39.27	94.2
1275-1324	10.38	26.18	0.97	37.65	88.1
1300-1349	8.84	28.44	0.95	38.44	77.7
1325-1374	8.53	51.65	0.74	61.18	73.7
1350-1399	8.51	63.01	0.47	72.48	55.4
1375-1425	6.82	53.33	0.40	60.74	74.9
1400-1449	6.47	59.09	0.44	66.27	66.1
1425-1474	8.16	55.28	0.46	63.98	91.0

B. Number of non-working animals in England (millions)

	Milk cattle	Beef cattle	Immature cattle	Sheep	Swine
1250-1299	0.77	0.69	0.77	10.88	1.03
1275-1324	0.74	0.66	0.74	12.66	0.99
1300-1349	0.59	0.53	0.59	13.66	0.92
1325-1374	0.51	0.46	0.51	14.13	0.69
1350-1399	0.45	0.41	0.45	14.67	0.39
1375-1425	0.32	0.29	0.32	14.02	0.31
1400-1449	0.26	0.24	0.26	15.13	0.34
1425-1474	0.32	0.28	0.32	15.34	0.35

Sources and notes: Derived from Medieval Accounts Database.

* Livestock units compare different animals on the basis of relative feed requirements. Ratios from Campbell (2000: 104-7): (adult cattle x 1.2) + (immature cattle x 0.8) + (sheep and swine x 0.1).

TABLE 8: Percentage of animals producing specific products

Product:	Milk	Beef	Veal	Mutton	Pork	Wool
% of animals:	*100*	*25*	*14.2*	*26*	*49*	*100*

Sources: Holderness (1989: 147); Clark (1991); Ecclestone (2006).

TABLE 9: Yield per animal

Years	Milk (litres)	Beef (kg)	Veal (kg)	Mutton (kg)	Pork (kg)	Wool (kg)
1250-1299	100	168	29	22	64	1.5
1275-1324	102	170	29	22	64	1.6
1300-1349	107	178	31	23	65	1.8
1325-1374	115	188	33	24	67	1.8
1350-1399	123	200	35	26	68	1.6
1375-1425	131	212	37	27	69	1.5
1400-1449	141	224	39	29	71	1.4
1425-1474	151	238	41	30	72	1.3

Sources and notes: Beef, pork, milk, and mutton are obtained from Clark (1991: 216), while veal is taken from Allen (2005: Table 6). The missing years were interpolated. Wool yield index from Stephenson (1988: Table 3), with the benchmark of 1.4 lb (0.6 kg) in 1300 from Britnell (2004: 416).

TABLE 10: Total output in pastoral farming

Years	Milk (m. gallons)	Beef (m. lb.)	Veal (m. lb.)	Mutton (m. lb.)	Pork (m. lb.)	Wool (m. lb.)
1250-1299	77.3	29.1	3.3	62.2	32.2	16.8
1275-1324	74.6	28.0	3.3	73.4	31.1	20.1
1300-1349	62.8	23.4	2.8	82.2	29.3	23.9
1325-1374	58.7	21.7	2.7	89.9	22.3	25.0
1350-1399	55.4	20.2	2.6	98.0	12.9	24.0
1375-1425	41.2	14.9	2.0	99.0	10.7	20.9
1400-1449	37.2	13.3	1.8	112.8	12.0	20.9
1425-1474	47.9	17.0	2.4	120.0	12.8	19.8

Sources and notes: Output is obtained by multiplying the number of animals from Table 7 with the animal yields from Table 8 and the of percentage animals producing each product from Table 9.

TABLE 11: Consumption of hay by non-farm horses

Period	Farm horses (millions)	Non-farm horses (millions)	Hay consumption (m. tonnes)
1250-1299	0.24	0.05	0.11
1275-1324	0.24	0.05	0.11
1300-1349	0.24	0.05	0.11
1325-1374	0.24	0.05	0.11
1350-1399	0.19	0.04	0.09
1375-1425	0.18	0.04	0.09
1400-1449	0.23	0.04	0.10
1425-1474	0.27	0.05	0.13

Sources and notes: Number of farm horses from Table 5; non-farm horses from Wrigley (2006) and Medieval Accounts Database; hay consumption per horse from Allen (2005).

TABLE 12: Output of hides and skins from working and non-working animals

	Horses (m. lb)	Oxen (m. lb)	Cattle (m. lb)	Calves (m. lb)	Sheep (m. lb)	Total (m. lb)
1250-1299	0.67	2.31	9.70	0.91	2.94	16.53
1275-1324	0.68	2.10	9.27	0.89	3.45	16.40
1300-1349	0.67	1.88	7.53	0.75	3.81	14.63
1325-1374	0.68	1.89	6.67	0.68	4.08	14.01
1350-1399	0.56	1.39	6.01	0.63	4.37	12.97
1375-1425	0.55	0.82	4.27	0.46	4.32	10.43
1400-1449	0.69	0.78	3.63	0.40	4.82	10.31
1425-1474	0.84	0.89	4.44	0.51	5.04	11.71

Sources and notes: Hide weights from Clarkson (1989: 470, n. 259), who provides hide weights both for the eighteenth century and before, and Ecclestone (1996: 23): ox hide = 56 lb; cattle skin = 56 lb; calf skin = 8 lb. Clarkson does not provide the weight of a horse skin for the pre-1800 period, which is here assumed to have been lower by the same proportion as that of the other hides for the pre-1800 period, i.e. 21.4 lb relative to a sheep's fleece weighing 1.04 lb. 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 13% of mature horses. Absolute number of animals from Tables 5 and 7.

TABLE 13: Output of processed dairy products

Years	Fresh milk (m. gallons)	Cheese (m. lb)	Butter (m. lb)
1250-1299	7.73	45.22	20.87
1275-1324	7.46	43.64	20.14
1300-1349	6.28	36.72	16.95
1325-1374	5.87	34.32	15.84
1350-1399	5.54	32.39	14.95
1375-1425	4.12	24.12	11.13
1400-1449	3.72	21.77	10.05
1425-1474	4.79	28.01	12.93

Sources and notes: Raw milk output from Table 10. Conversion ratios to fresh milk, cheese, and butter from Biddick (1989: Appendix 5).

FIGURE 11: Indexed output in arable and pastoral agriculture (1300 = 100, log scale)

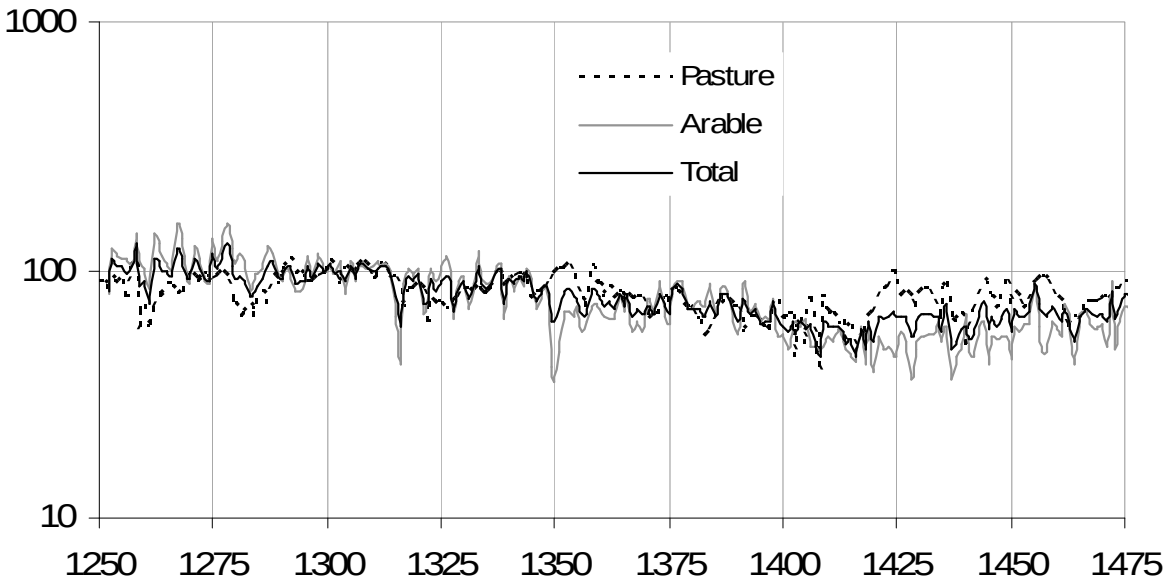


TABLE 14: Output growth in agriculture in constant 1300 prices (5-year moving averages)

Years	Arable sector (% *per annum*)	Pastoral sector (% *per annum*)	Total agriculture (% *per annum*)
1250-1300	*-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*
1250-1475	*-0.23*	*-0.04*	*-0.15*

Sources: Derived from Medieval Accounts Database.

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

FIGURE 13: Ratio of pastoral to arable prices (1300=100)

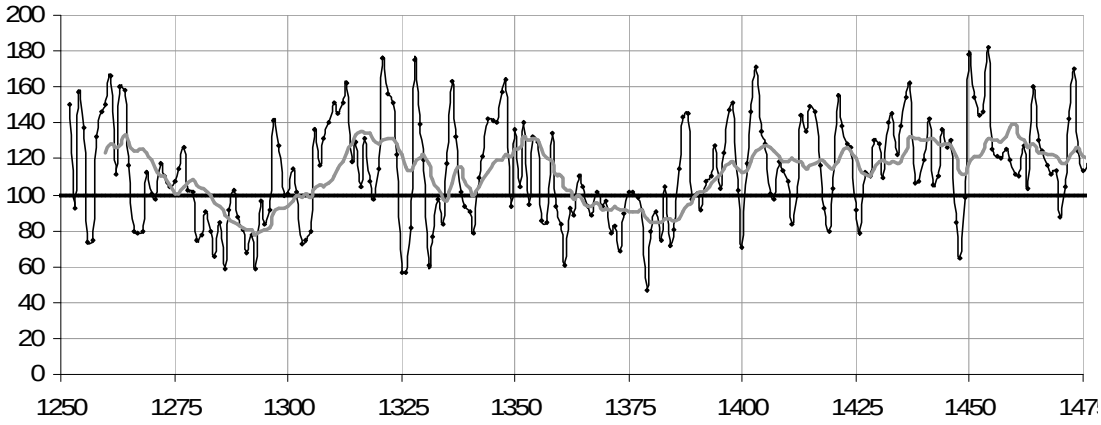


TABLE 15: Agricultural output weights in current prices, 20-year averages (%)

A. Arable products

Year	Wheat	Rye	Barley	Oats	Pulses	Total arable products
1300	*20.1*	*2.5*	*6.7*	*6.1*	*1.1*	*36.4*
1380	*17.7*	*2.0*	*13.2*	*5.8*	*1.5*	*40.2*
1420	*11.8*	*1.8*	*8.3*	*2.9*	*1.1*	*25.9*

B. Pastoral products

Year	Dairy	Beef	Mutton	Pork	Wool	Hay	Hides	Total pastoral products
1300	*8.1*	*2.2*	*13.9*	*21.4*	*15.8*	*0.7*	*1.3*	*63.6*
1380	*6.4*	*2.0*	*19.4*	*11.9*	*18.6*	*0.9*	*0.7*	*59.8*
1420	*4.6*	*1.3*	*29.1*	*14.9*	*20.7*	*1.6*	*1.9*	*74.1*

Sources: Derived from Tables 6 and 10 and from the Medieval Accounts Database

TABLE 16: 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			
1300	4.25	3.34	1250-1300	*0.22*	*0.18*
1348	3.83	3.01	1300-1348	*-0.22*	*-0.22*
1351	2.56	2.01	1348-1380	*-1.50*	*-1.62*
1380	2.37	1.79			
1420	2.32	1.75	1380-1450	*-0.06*	*-0.06*
1450	2.28	1.72			
			1250-1450	*-0.26*	*-0.29*

Sources and notes: Derived from Overton and Campbell (1996: Table II). Assumed decline 1300-1348 is 10%; assumed decline arising from the Black Death of 1348-9 is 40%.

FIGURE 14: Indexed agricultural output per agricultural worker (1300 = 100)

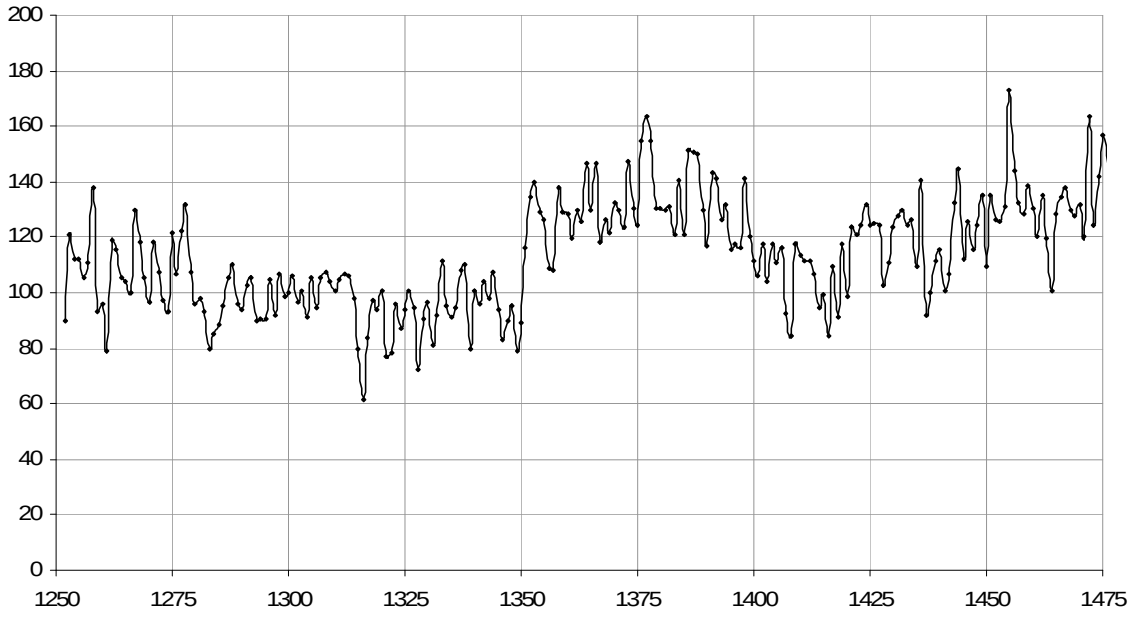
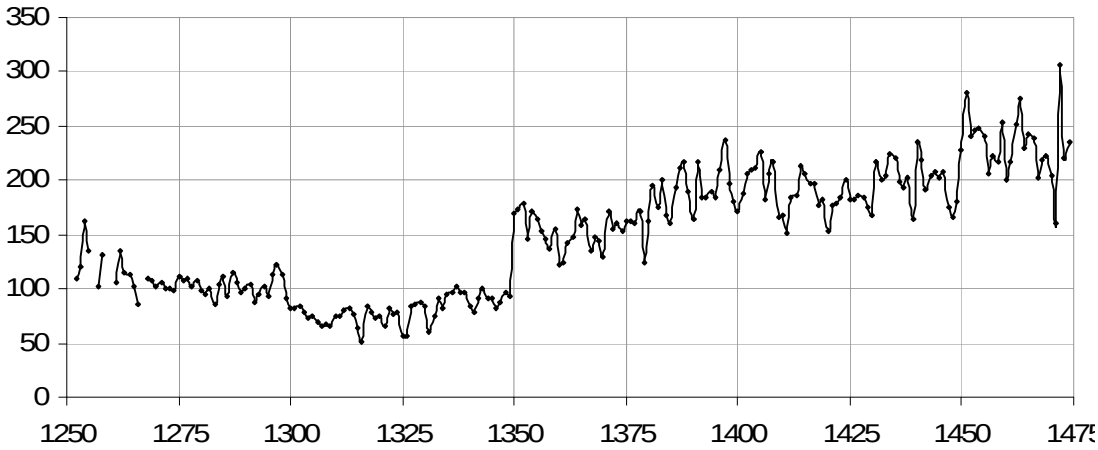


TABLE 17: Average annual growth rate of agricultural output per agricultural worker

Years	Growth rate (% *per annum*)
1250-1300	*-0.27*
1200-1348	*-0.32*
1348-1399	*0.61*
1400-1449	*0.08*
1450-1474	*0.48*
1250-1474	*0.12*

Source: Derived from Medieval Accounts Database

FIGURE 15: Indexed daily real wage of an unskilled farm worker (1300 = 100)



Sources and notes: Nominal farm wage from Clark (2007), deflated using the price series from Clark (2004), Thorold Rogers (1866-1902), and Farmer (1988; 1991), weighted into one series of agricultural prices using the volumes constructed from the Medieval Accounts Database.

FIGURE 16: Indexed daily real wage of an unskilled farm worker and agricultural output per agricultural worker (11-year moving averages; 1300 = 100)

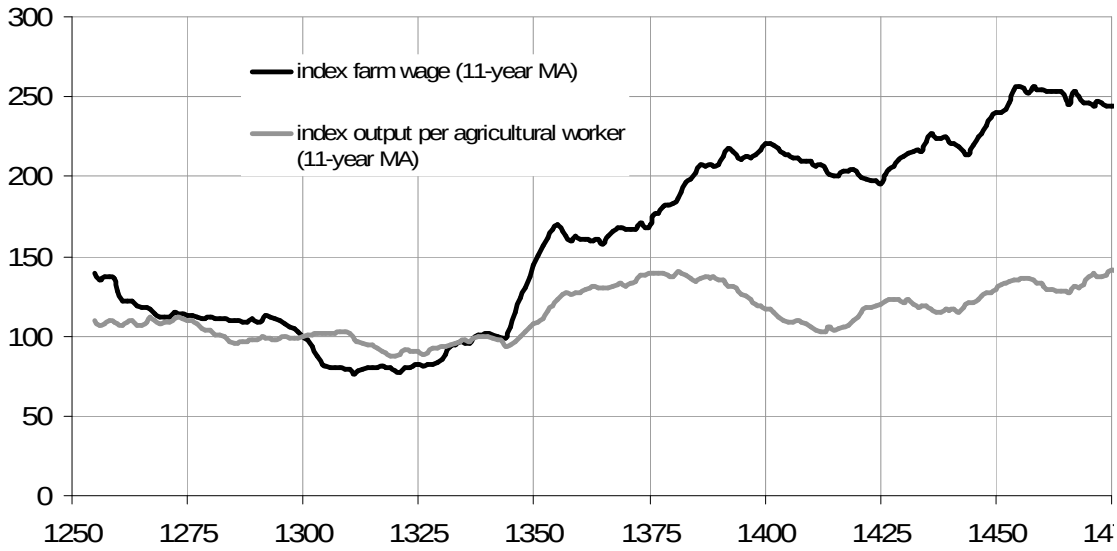


TABLE 18: Income and output values in agriculture (5 year averages)

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

B. Rents and other non-wage incomes:

Years	Rent (s. per acre)	Hectares (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

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

*Sources and notes:*Wage per day is taken from Clark (2007). 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), capital costs and tithes and taxes from Allen (2005).

TABLE 19: *Per capita* daily kilocalorie consumption of wheat, rye, barley and oats

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	*53*
1800	*3,361	*1,627	*51*

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 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, while 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 1801 the estimates provided by Broadberry and van Leeuwen (2008) are used based on the assumptions provided by Overton and Campbell (1996: Tables XII and XIII).
*Imports included

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