# The Agricultural Revolution and the Industrial Revolution: England, 1500-1912

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Historians have long believed that the modern world commenced in Britain in the 1770s with simultaneous industrial and agricultural revolutions. I estimate agricultural productivity, output per acre and output per worker in England all the way from 1500 to 1912. These estimates show that the growing population of Industrial Revolution England was fed mainly through food imports and through switching agricultural output towards food, not through an agricultural revolution. This in turn implies output growth overall in the Industrial Revolution was lower than has been estimated. Contrary to expectation, productivity growth before 1869 was overwhelmingly from growing yields as opposed to growing labor productivity.

**Introduction**

Agricultural yields in medieval England were low compared to England by 1850. Indeed it seems that net output per acre in southern England by 1850 was about 3.2 times output per acre in 1300. If the conventional assumption that about 75 percent of the population in pre-industrial society was employed in agriculture is adopted for medieval England then output per worker grew by even more (see, for example, Allen (2000), p. 11). If there were 6 million people in England in 1300 output per farm worker in 1850 would be 4.4 times output in 1300. This implies, even assuming no change in output per unit of capital, that total factor productivity in English agriculture tripled between 1300 and 1850.[1] An agricultural revolution accompanied or preceded the Industrial Revolution.

Historians dispute, however, when and how the agricultural revolution was accomplished. Consideration of food consumption demands convinced most that the agricultural revolution exactly coincided with the Industrial Revolution (see, for example, Crafts (1985)). Such a coincidence would suggest that the Industrial Revolution was just part of very broad productivity advance in the British economy in the years 1760 to 1860. Such a broad adavnce makes it likely that the Industrial Revolution had a systematic cause rather than being just an accident.

Here I use estimates of land rental values, wages, the return on capital and output prices to estimate net farm, output per acre, and output per worker, from 1500 to 1912, as well as total factor productivity in agriculture. The new series suggest that measured agricultural productivity increased by only about 50 percent between 1500 and 1860. The majority of this growth did,

[1] See Clark (1991b).

however, occur after 1800. But even from1760 to the 1860 there was much less productivity growth than standard accounts of the Industrial Revolution, such as Crafts (1985), assume. Thus current estimates of output growth in England in the Industrial Revolution era need substantial downward revision. Further the rate of productivity growth in England in the years 1500-1789 is no greater than the growth rates Philip Hoffman finds for the Paris Basin. Finally, contrary to expectation, the source of productivity growth before 1869 is overwhelmingly growing yields as opposed to growth of labor productivity. Pre-industrial England stands out as having exceptionally high agricultural labor productivity as early as 1500.

**Agricultural Productivity**

Total factor productivity in agriculture can be approximated using the formula

$$A = \prod_{i,j} \frac{\omega_j^{\theta_j}}{p_i^{\alpha_i}}$$

where $A$ is an index of productivity, $p_i$ is the price of output $i$, and $\alpha$ is the share of output $i$ in the value of output, $\omega_j$ is the wage paid to input $j$, and $\theta_j$ is the share of input $j$ in the total payments to inputs. This formula just says that productivity can be measured as the geometric average of the each input cost relative to an index of output prices. Productivity is thus a weighted average of the "real" costs of the inputs. If the shares of the inputs in costs change over time then productivity movements can be measured by chaining productivity indices that use different cost weights for shorter periods.

Tables 1 and 2 shows the output and input price series by decade required for this

## Table 1: Agricultural Output and Input Prices, 1500-1912

| Period | Prices (1860-9 = 100) | Land Rental Values (s. per acre) | Taxes on occupiers as a share of rents | Real rent and taxes (1860-9 = 100) | Farm Wages (d. per day) | Real Wages (1860-9 = 100) |
|---|---|---|---|---|---|---|
| 1500-49 | 11.3 | 0.05 | 0.009 | 29.6 | 3.1 | 115.0 |
| 1550-9 | 24.3 | 0.07 | 0.009 | 17.8 | 4.4 | 76.1 |
| 1560-9 | 25.3 | 0.08 | 0.009 | 20.1 | 5.1 | 84.7 |
| 1570-9 | 26.0 | 0.11 | 0.009 | 25.6 | 5.6 | 91.6 |
| 1580-9 | 29.4 | 0.18 | 0.005 | 36.9 | 6.2 | 89.1 |
| 1590-9 | 38.6 | 0.13 | 0.005 | 21.3 | 6.3 | 69.4 |
| 1600-9 | 40.2 | 0.31 | 0.006 | 47.7 | 6.6 | 69.4 |
| 1610-9 | 47.2 | 0.38 | 0.004 | 49.6 | 7.2 | 64.2 |
| 1620-9 | 46.4 | 0.37 | 0.006 | 49.0 | 7.7 | 70.2 |
| 1630-9 | 55.5 | 0.40 | 0.007 | 44.3 | 8.1 | 62.0 |
| 1640-9 | 55.2 | 0.42 | 0.007 | 47.1 | 9.5 | 72.7 |
| 1650-9 | 55.8 | 0.43 | 0.009 | 47.9 | 10.3 | 78.5 |
| 1660-9 | 55.4 | 0.47 | 0.010 | 51.9 | 9.8 | 75.4 |
| 1670-9 | 52.9 | 0.44 | 0.011 | 51.9 | 10.2 | 81.7 |
| 1680-9 | 51.8 | 0.47 | 0.015 | 55.7 | 10.5 | 85.9 |
| 1690-9 | 56.1 | 0.45 | 0.021 | 49.8 | 9.8 | 74.0 |
| 1700-9 | 49.5 | 0.45 | 0.023 | 56.3 | 10.1 | 86.0 |
| 1710-9 | 53.2 | 0.49 | 0.031 | 57.6 | 10.1 | 80.4 |
| 1720-9 | 52.7 | 0.52 | 0.034 | 62.5 | 10.3 | 82.4 |
| 1730-9 | 48.2 | 0.50 | 0.032 | 65.8 | 11.0 | 96.2 |
| 1740-9 | 49.4 | 0.47 | 0.048 | 60.6 | 10.9 | 93.6 |
| 1750-9 | 54.0 | 0.59 | 0.039 | 69.4 | 11.0 | 85.9 |
| 1760-9 | 57.7 | 0.61 | 0.050 | 67.5 | 11.4 | 83.3 |
| 1770-9 | 66.6 | 0.70 | 0.058 | 67.9 | 12.3 | 78.0 |
| 1780-9 | 68.4 | 0.69 | 0.079 | 66.4 | 13.3 | 82.4 |
| 1790-9 | 84.5 | 0.85 | 0.094 | 67.3 | 15.1 | 75.7 |
| 1800-9 | 117.8 | 1.18 | 0.101 | 67.5 | 19.2 | 69.1 |
| 1810-9 | 130.1 | 1.51 | 0.104 | 78.5 | 22.7 | 73.8 |
| 1820-9 | 98.9 | 1.32 | 0.104 | 90.2 | 19.8 | 84.9 |
| 1830-9 | 93.3 | 1.28 | 0.082 | 90.7 | 19.7 | 89.2 |
| 1840-9 | 92.0 | 1.28 | 0.079 | 97.4 | 20.5 | 94.4 |
| 1850-9 | 90.7 | 1.35 | 0.056 | 97.6 | 21.6 | 100.6 |
| 1860-9 | 100.0 | 1.50 | 0.090 | 100.0 | 23.6 | 100.0 |
| 1870-9 | 102.4 | 1.58 | 0.101 | 107.3 | 29.6 | 122.6 |
| 1880-9 | 85.7 | 1.41 | 0.098 | 111.7 | 29.1 | 143.8 |
| 1890-9 | 73.7 | 1.21 | 0.114 | 113.4 | 29.8 | 171.2 |
| 1900-9 | 77.5 | 1.20 | (0.114) | 102.3 | 32.4 | 176.8 |
| 1910-2 | 90.4 | 1.29 | (0.114) | 87.7 | 33.0 | 154.6 |

Sources: The wage sources are, 1500-1669, Clark (1999b), 1670-1869, Clark (2001), 1870-1902, Fox (1903), 1903-1914, Arthur Bowley for Britain as a whole as reported in Mitchell (1988). Land rents and local taxes are from Clark (2002a). Prices are from Clark (2002b).

calculation. I describe the sources of these series only briefly, since except for taxes on farmland occupiers they are described in detail in other sources detailed in the notes to the table. The output price series uses 23 component series for all or parts of these years: wheat, barley, oats, rye, peas, beans, potatoes, hops, straw, hay, beef, mutton, pork, bacon, tallow, milk, cheese, butter, wool, eggs, faggots (firewood), and timber (Clark (2002b)). The land rents are the market rental values including tithe of plots of unchanging area (Clark (2002a)). The rent series thus incorporates and values in earlier years communal "waste" land only later brought into private cultivation. To these rents have been added the local rates paid by property occupiers. The level of these rates was estimated in the ways detailed in the appendix. Wages are the average day wages of adult male farm workers outside harvest using the methods described in Clark (2001). Columns 2 and 3 of table 2 give the percentage return on rent charges and bonds and mortgages using the methods described in Clark (1998c). Rent charges and bonds and mortgages had similar rates of return, except in the early seventeenth century when mortgage rates were significantly higher (probably as a result of legal disabilities suffered by the mortgage in these earlier years of its development as a financial instrument) so I use the rent charge series since it extends back to the sixteenth century. To get from the percentage return on capital to the rental price of capital, which is what is needed to calculate productivity, I make two assumptions. The first is that the price of capital goods can be approximated by an index composed of 60% the price of pastoral products, 20% the general farm output price, 17% wages, and 3% rents. The reason for this assumption is the observed composition of farmers' capital in the eighteenth and nineteenth centuries. A detailed estimate for 1861, for example, shows that it composed as follows:

| | |
|---|---|
| Live Stock | 60% |
| Implements | 11% |
| Seed, Labor, Horse and Cattle Food | 21% |
| Rent, tithe and taxes in advance | 3% |
| Maintenance of farmer | 5% |

The majority of the farmers' capital was livestock or fodder, with implements even in 1861 comprising a small share. Arthur Young gives some breakdowns of the expected composition of farmers capital in 1770, where live stock is still the most significant category at 45%, and implements are a very similar 12% (Young (1770), Volume 4, pp. 417-22). I assume that implement prices were dictated by the labor required to construct them. The implied price index for farmers' capital is close to the price index for all agricultural output. The second assumption is that the interest cost of the capital employed by farmers was the rent charge rate plus 4%. If we allow 10% depreciation on the workhorses of the farm and on the implements, and nothing on the other items of capital, then the overall depreciation rate will be roughly 2.5%. Allowing the farmer the return on capital from rent charges on land, plus 1.5% for the risk of the investment, implies that the interest cost of capital will be the return on rent charges plus 4%. The third column of table 2 shows the resulting capital rental index relative to agricultural output prices.

Figure 1 shows these three key series, rents, wages and the rental costs of capital in terms of output prices. Real capital costs are fairly constant over the years 1500 to 1912, deviating by no more than 20% from their mean level. Real wages fall from 1500 to 1600, then rise gradually towards 1860, before rising rapidly in tha late nineteenth century. Land rents in contrast show a steady upward trend from 1500 to 1912. Overall productivity will be the weighted average of

## Table 2: Capital Costs and Productivity, 1500-1912

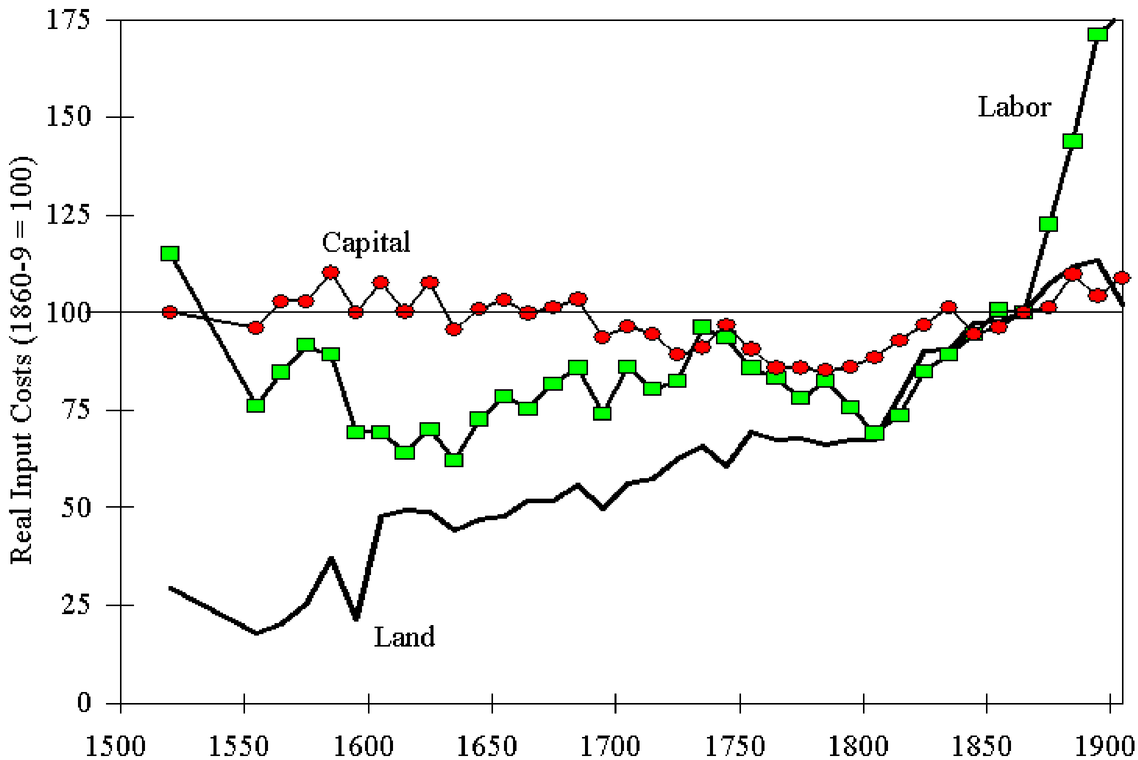
| Period | Return on rent charges (%) | Return on bonds and mortgages (%) | Capital Price (1860-9 = 100) | Real Capital Rental (1860-9 = 100) | Productivity – 1860 input weights (1860-9 = 100) |
|---|---|---|---|---|---|
| 1500-49 | 5.13 | - | 10.2 | 100.0 | **63.9** |
| 1550-9 | - | - | 20.8 | 96.1 | **43.4** |
| 1560-9 | 5.32 | - | 22.9 | 102.8 | **48.2** |
| 1570-9 | 5.07 | - | 24.2 | 102.8 | **55.1** |
| 1580-9 | 5.91 | - | 26.8 | 110.3 | **64.2** |
| 1590-9 | 5.89 | - | 32.1 | 100.1 | **45.3** |
| 1600-9 | 6.07 | 7.74 | 35.3 | 107.6 | **64.2** |
| 1610-9 | 5.85 | 7.86 | 39.5 | 100.3 | **62.5** |
| 1620-9 | 6.26 | 7.00 | 39.9 | 107.6 | **65.2** |
| 1630-9 | 5.79 | 6.94 | 44.4 | 95.6 | **58.2** |
| 1640-9 | 5.78 | 6.74 | 46.8 | 100.9 | **64.3** |
| 1650-9 | 5.60 | 5.29 | 49.3 | 103.3 | **67.1** |
| 1660-9 | 5.40 | 5.47 | 48.3 | 99.8 | **67.8** |
| 1670-9 | 5.46 | 5.81 | 46.5 | 101.4 | **70.3** |
| 1680-9 | 5.30 | 5.33 | 47.3 | 103.4 | **74.2** |
| 1690-9 | 5.00 | 5.26 | 48.0 | 93.7 | **65.4** |
| 1700-9 | 4.67 | 5.00 | 45.2 | 96.5 | **73.6** |
| 1710-9 | 4.94 | 4.87 | 46.2 | 94.4 | **72.0** |
| 1720-9 | 4.39 | 4.86 | 45.9 | 89.1 | **74.5** |
| 1730-9 | 4.07 | 4.67 | 44.7 | 91.0 | **81.4** |
| 1740-9 | 4.48 | 4.14 | 46.3 | 96.8 | **78.6** |
| 1750-9 | 4.27 | 4.06 | 48.7 | 90.7 | **79.4** |
| 1760-9 | 4.05 | 4.16 | 50.6 | 85.9 | **76.8** |
| 1770-9 | 4.17 | 4.27 | 57.4 | 85.8 | **74.9** |
| 1780-9 | 3.93 | 4.65 | 60.3 | 85.2 | **75.8** |
| 1790-9 | 4.13 | 4.69 | 73.5 | 86.1 | **73.8** |
| 1800-9 | 4.48 | 4.85 | 100.9 | 88.4 | **71.5** |
| 1810-9 | 4.72 | 4.86 | 113.7 | 92.8 | **78.9** |
| 1820-9 | 4.48 | 4.69 | 92.7 | 96.8 | **89.1** |
| 1830-9 | 4.88 | 4.69 | 87.4 | 101.2 | **91.8** |
| 1840-9 | 4.28 | 4.64 | 86.1 | 94.4 | **95.6** |
| 1850-9 | 4.10 | 4.62 | 88.4 | 96.2 | **98.6** |
| 1860-9 | 4.21 | 4.76 | 100.0 | 100.0 | **100.0** |
| 1870-9 | 4.04 | 4.66 | 106.1 | 101.4 | **112.2** |
| 1880-9 | 4.26 | 4.26 | 93.6 | 109.8 | **123.4** |
| 1890-9 | 3.57 | 3.86 | 83.3 | 104.2 | **132.2** |
| 1900-9 | 3.83 | 3.95 | 88.6 | 108.9 | **129.3** |
| 1910-2 | 3.79 | - | 99.1 | 107.4 | **117.6** |

Sources: Table 1. Returns on capital are from Clark (1998c).

these series with the weights being given by the shares of each input in total costs. We shall discuss below what the appropriate weights are, but it should be immediately evident from figure 1 that whatever the plausible range of weights, English agriculture must have experienced only modest productivity gains in the years 1500 to 1869.

I can approximate, for example, the shares in costs of farmers' capital, labor and land in 1860-9. The total rent payment will just be the land rental values from the income tax in the 1860s, with an addition of local rates charged to occupiers: £47.5 million. The total wage bill in agriculture, which includes both explicit wage payments and implied wage payments to farmers and their family members, is estimated from day wages and labor force numbers derived from the census by assuming three things. First I assume there was full employment of male farm workers. Clark (2001) explains why the assumption of full employment for agricultural laborers is a reasonable one. Second I assume that the collective earnings of children and women were 20 percent those of men. The 1851 population census suggests that even if all farmers' resident female relatives are assumed to work on the farm the numbers of adult women and of youths participating in agriculture by 1851 was relatively small. So even if women's and youths' wages were as high as 60 percent those of men, adult males earned 83 percent of all labor earnings (explicit or implicit) in agriculture in 1851. The third assumption I make accommodates the fact that there was a cadre of more skilled workers in agriculture – farm bailiffs and farmers themselves – who would have an explicit or implied labor income much greater than those of simple farm laborers. Assuming one worker in ten fell in this class, and that they on average earned twice what laborers earned, we need to increase earnings by another 10 percent above those of the unskilled males to allow for this class. Thus my estimate of total implied wage earnings in agriculture is that they were 130 percent of the annual earnings of full time male

**Figure 1: Real Rents, Wages and Capital Rental Costs, 1500-1912**




Source: Tables 1 and 2.

workers: £46.6 million.

Charles Wratislaw gives a detailed estimate of the farmers' capital stock 1861 which suggests that the tenant needed to supply on average £8.68 in capital per acre. Other estimates from 1838 and 1878 suggest respectively £10 and £12 per acre.[2] Wratislaw omits any allowance for the cost of the maintenance of the farmer over the course of the year. Assuming the average farmer expends £100 on himself in 1861, Wratislaw's capital per acre, adjusted to the prices of the 1860s, would be £9.3. This makes a total capital stock for the 26.524 acres of land in crops, garden and wood in England and Wales in the 1860s of £247 million, and annual implied capital rentals of £20.2 million. Thus in the 1860s wages were 40.8% of costs, rent, tithe and taxes 41.5% and the payments for rental of the farmers' capital 17.7%.

The last column of table 2 shows implied agricultural productivity over time if I assume input cost shares were constant at the level of the 1860s. Total agricultural productivity rises by only about 56% in the 340 years between the 1520s and the 1860s. And in the period of the famous agricultural revolution from the 1760s to the 1860s the rise is a modest 31%.

**Labor and Capital Inputs**

If I can infer the numbers of workers and the amount of capital before 1860, then I get two things. First a better estimate of productivity movements since I can then estimate by period the share of different inputs in costs. Second estimates of total agricultural output, output per acre and output per farm worker.

This way of measuring net output will have both advantages and weaknesses compared to traditional attempts to estimate output by estimating crop yields. Such methods include the

2 Wratislaw (1861), Tomson (1847), Squarey (1878).

probate inventory studies of Mark Overton and others, the recent farm account based estimates of Michael Turner, John Beckett, and Bethany Afton, and the labor input method used by Clark (1991a). These crop yield methods are limited by our lack of knowledge of how much of the potential agricultural land was devoted to crop production, and how much to each crop. Also these methods look just at the arable sector, which was only half of the output of English agriculture. Input cost measures avoid such problems. But they are limited by the need to estimate the quantities of labor and capital inputs.

I estimate the number of farm workers from the population censuses from 1801 on. The share of males employed in agriculture declined from about 37 percent circa 1801 to 10 percent circa 1911. This gives the figures shown in table 3 for males in agriculture from 1800-9 on. There is little direct evidence on the size of the agricultural labor force before 1801. Peter Lindert's work on English occupations suggests that the farm labor force was no more than 53 percent of the male population in the 1750s (Lindert (1980), Lindert and Williamson (1982)). I assume the figure for this decade and that the share of male laborers in agriculture fell linearly until 1800-9. Before 1760 England was largely self sufficient in agricultural produce. Thus I estimate the share of labor in agriculture based on the share estimated for 1750-9, but make an adjustment for estimated income levels relative to 1750-9, since the share of consumption devoted to agricultural products is higher when income is lower. I assume an income elasticity of 0.6 for agricultural products, and that labor productivity was the same in agriculture as in the rest of the economy. This implies that the share of labor employed in agriculture was never higher than 60 percent after 1500. Robert Allen assumes a higher share of labor was employed in

## Table 3: Labor Inputs in Agriculture, England, 1500-1912

| Period | Population (m.) | Share of males in Agriculture Preferred Estimate | Males in Agriculture Preferred Estimate (000) | Farm Wages (£. m.) | Share of males in Agriculture Alternative Estimate | Males in Agriculture Alternative estimate (000) | Farm Wages (£. m.) Alternative Estimate |
|---|---|---|---|---|---|---|---|
| 1500-49 | 2.78 | 0.55 | 367 | 2.3 | 0.75 | 502 | 3.0 |
| 1550-9 | 3.24 | 0.58 | 455 | 3.9 | 0.75 | 586 | 5.0 |
| 1560-9 | 3.21 | 0.60 | 464 | 4.6 | 0.75 | 580 | 5.7 |
| 1570-9 | 3.50 | 0.59 | 496 | 5.4 | 0.75 | 633 | 6.9 |
| 1580-9 | 3.55 | 0.60 | 513 | 6.2 | 0.75 | 643 | 7.7 |
| 1590-9 | 4.16 | 0.59 | 594 | 7.3 | 0.75 | 753 | 9.3 |
| 1600-9 | 4.12 | 0.59 | 591 | 7.6 | 0.75 | 745 | 9.6 |
| 1610-9 | 4.43 | 0.58 | 621 | 8.7 | 0.75 | 802 | 11.2 |
| 1620-9 | 4.70 | 0.59 | 671 | 10.1 | 0.75 | 850 | 12.7 |
| 1630-9 | 4.88 | 0.59 | 697 | 11.0 | 0.75 | 882 | 14.0 |
| 1640-9 | 5.08 | 0.59 | 722 | 13.3 | 0.75 | 919 | 17.0 |
| 1650-9 | 5.26 | 0.57 | 729 | 14.7 | 0.75 | 951 | 19.2 |
| 1660-9 | 5.23 | 0.56 | 712 | 13.7 | 0.75 | 946 | 18.2 |
| 1670-9 | 5.11 | 0.56 | 685 | 13.6 | 0.75 | 924 | 18.4 |
| 1680-9 | 5.06 | 0.56 | 679 | 13.9 | 0.75 | 915 | 18.7 |
| 1690-9 | 5.05 | 0.55 | 672 | 12.8 | 0.75 | 912 | 17.4 |
| 1700-9 | 5.16 | 0.55 | 687 | 13.5 | 0.75 | 933 | 18.3 |
| 1710-9 | 5.33 | 0.54 | 697 | 13.7 | 0.75 | 964 | 19.0 |
| 1720-9 | 5.45 | 0.53 | 696 | 13.9 | 0.75 | 986 | 19.7 |
| 1730-9 | 5.36 | 0.52 | 678 | 14.5 | 0.70 | 905 | 19.3 |
| 1740-9 | 5.67 | 0.52 | 712 | 15.1 | 0.65 | 888 | 18.9 |
| 1750-9 | 5.87 | 0.53 | 742 | 15.9 | 0.60 | 848 | 18.1 |
| 1760-9 | 6.25 | 0.49 | 745 | 16.5 | 0.55 | 745 | 16.5 |
| 1770-9 | 6.56 | 0.47 | 748 | 17.9 | 0.50 | 748 | 17.9 |
| 1780-9 | 7.14 | 0.44 | 751 | 19.5 | 0.45 | 751 | 19.5 |
| 1790-9 | 7.77 | 0.40 | 753 | 22.2 | 0.40 | 753 | 22.2 |
| 1800-9 | 8.59 | 0.37 | 756 | 28.3 | | | |
| 1810-9 | 9.77 | 0.35 | 813 | 35.9 | | | |
| 1820-9 | 11.35 | 0.33 | 894 | 34.5 | | | |
| 1830-9 | 13.16 | 0.30 | 937 | 35.9 | | | |
| 1840-9 | 15.78 | 0.26 | 975 | 39.0 | | | |
| 1850-9 | 17.77 | 0.24 | 1,036 | 43.5 | | | |
| 1860-9 | 19.97 | 0.21 | 1,013 | 46.6 | | | |
| 1870-9 | 22.75 | 0.17 | 956 | 55.2 | | | |
| 1880-9 | 25.78 | 0.15 | 921 | 52.2 | | | |
| 1890-9 | 28.83 | 0.12 | 845 | 49.1 | | | |
| 1900-9 | 32.12 | 0.10 | 810 | 51.1 | | | |
| 1910-12 | 34.30 | 0.10 | 785 | 53.1 | | | |

Sources: See the text.

agriculture in England before 1700. He assumes, for example, that agriculture employed 74 percent of labor in 1500 (Allen (2000)). I thus also construct an alternative labor input series which has 75% of the population employed in agriculture from 1500 to 1720-9, and then has an evenly declining share to 1800-9. These alternative estimates are also shown in table 3.

To estimate the amount of capital employed before 1860 I assume that there was a fixed capital-output ratio. The reason for this assumption is in part the importance of livestock, seeds, and labor payments in the farmers' capital stock in 1861 and the unimportance of implements. There is no reason to believe that the required stock of draft animals per unit of output was any less in the years before 1860, the turnover of meat producing animals was any faster, or the seed per unit of grain output.

I can do a check on this assumption for 1770 when Arthur Young in his account of his Northern Tour reports frequently local views on the required amount of farmers' capital per acre, quoted as how many £ of capital were required per £ of rent paid by the farmer. The average figure quoted was that a farmer taking a new letting would need a capital equal to 4.04 times the rent (Young (1770), Volume 4, pp. 417-22). Young argues that farmers tended to increase their capital stock in the years after a letting so that this figure would underestimate the average capital stock of farmers. With a constant capital-output ratio the implied ratio of farmers' capital to land rents circa 1770 is very similar at 4.37. The implied payments for capital under this assumption are shown in table 4.[3]

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[3] The value of the capital stock in each period was calculated as the sum of the payments to land and labor divided by (v-(r+d)) where v = the output-capital ratio in 1860-9 ( = 0.473), r = the interest rate for each period, and d = the depreciation rate = .025). This multiplied by (r+d) gave the implied payments to farmers' capital.

**Table 4: Net Agricultural Output, England, 1500-1912**

| Period | Farmers' Capital per acre (£.) | Assumed Capital Payments (£. m.) | Total land rents and local taxes (£. m.) | Nominal Net Farm Output (£. m.) Preferred Labor | Nominal Net Farm Output (£. m.) Alternative Labor |
|---|---|---|---|---|---|
| 1500-49 | 0.35 | 0.8 | 1.6 | **4.7** | 5.6 |
| 1550-9 | 0.50 | 1.2 | 2.1 | **7.1** | 8.5 |
| 1560-9 | 0.63 | 1.6 | 2.4 | **8.5** | 9.9 |
| 1570-9 | 0.80 | 1.9 | 3.2 | **10.5** | 12.4 |
| 1580-9 | 1.05 | 2.7 | 5.1 | **14.1** | 16.0 |
| 1590-9 | 0.92 | 2.4 | 3.9 | **13.6** | 16.0 |
| 1600-9 | 1.47 | 3.9 | 9.1 | **20.6** | 23.1 |
| 1610-9 | 1.64 | 4.3 | 11.1 | **24.1** | 27.1 |
| 1620-9 | 1.80 | 4.9 | 10.8 | **25.7** | 29.1 |
| 1630-9 | 1.78 | 4.6 | 11.6 | **27.3** | 30.8 |
| 1640-9 | 2.15 | 5.6 | 12.3 | **31.2** | 35.7 |
| 1650-9 | 2.41 | 6.1 | 12.7 | **33.5** | 39.0 |
| 1660-9 | 2.35 | 5.9 | 13.6 | **33.2** | 38.6 |
| 1670-9 | 2.33 | 5.8 | 13.0 | **32.5** | 38.3 |
| 1680-9 | 2.51 | 6.2 | 13.7 | **33.8** | 39.7 |
| 1690-9 | 2.18 | 5.2 | 13.3 | **31.3** | 36.8 |
| 1700-9 | 2.39 | 5.5 | 13.2 | **32.2** | 38.0 |
| 1710-9 | 2.40 | 5.7 | 14.6 | **34.0** | 40.3 |
| 1720-9 | 2.49 | 5.5 | 15.6 | **35.1** | 42.0 |
| 1730-9 | 2.65 | 5.7 | 15.1 | **35.2** | 41.0 |
| 1740-9 | 2.70 | 6.1 | 14.2 | **35.4** | 39.9 |
| 1750-9 | 2.94 | 6.4 | 17.8 | **40.1** | 42.8 |
| 1760-9 | 2.94 | 6.3 | 18.5 | **41.3** | 41.3 |
| 1770-9 | 3.25 | 7.1 | 21.4 | **46.4** | 46.4 |
| 1780-9 | 3.46 | 7.3 | 21.5 | **48.3** | 48.3 |
| 1790-9 | 4.10 | 8.8 | 27.0 | **58.0** | 58.0 |
| 1800-9 | 5.46 | 12.3 | 37.7 | **78.3** | 78.3 |
| 1810-9 | 7.18 | 16.6 | 48.5 | **101.0** | 101.0 |
| 1820-9 | 7.08 | 15.9 | 42.3 | **92.7** | 92.7 |
| 1830-9 | 7.06 | 16.6 | 40.2 | **92.7** | 92.7 |
| 1840-9 | 7.45 | 16.4 | 42.5 | **97.8** | 97.8 |
| 1850-9 | 8.18 | 17.6 | 42.0 | **103.1** | 103.1 |
| 1860-9 | 9.30 | 20.3 | 47.5 | **114.3** | 114.3 |
| 1870-9 | 11.03 | 23.5 | 52.2 | **130.9** | 130.9 |
| 1880-9 | 10.77 | 23.6 | 45.4 | **121.2** | 121.2 |
| 1890-9 | 10.01 | 20.1 | 39.7 | **108.9** | 108.9 |
| 1900-9 | 10.22 | 21.2 | 37.6 | **110.0** | 110.0 |
| 1910-12 | 10.33 | 21.3 | 37.6 | **112.1** | 112.1 |

Source: See the text.

The final two columns of table 4 show the implied nominal net output of the agricultural sector from 1500 to 1912. I have not included purchases of inputs such as fertilizers and cattle feed (in the form of oil cake), which would show as additions to net output. These only became important in the latter nineteenth century. By the 1860's payments for such inputs were still less than 3% of net output.

The calculated output also assumes that the farmer earns nothing for his entrepreneurship beyond the assumed wage of a bailiff plus the normal return on the capital he employs. This assumption is consistent with the idea that in a competitive sector like agriculture entrepreneurial returns were low.

Dividing the value of net output by the price index yields an estimate of real net output, which is shown as the second column of table 5. Figure 2 shows the real net output series, which is also by implication a series for real **net** yield per acre: gross output minus the parts used within the farm sector such as seeds and animal feed. Net output per acre roughly tripled from 1500 to 1860. Thus output per acre had not advanced from the levels of 1300 by the sixteenth century.

Implied net output per worker is shown as the third column of table 5, and also in figure 2. Before 1860-9 output per adult male worker consistently grows by less than yields. Output per worker grows faster than yields only after 1860. Thus output per worker in 1500-39 is estimated at 96% of its level 340 years later in 1860-9! Even in the early seventeenth century real net output per worker is nearly 85% of its level of 1860-9.

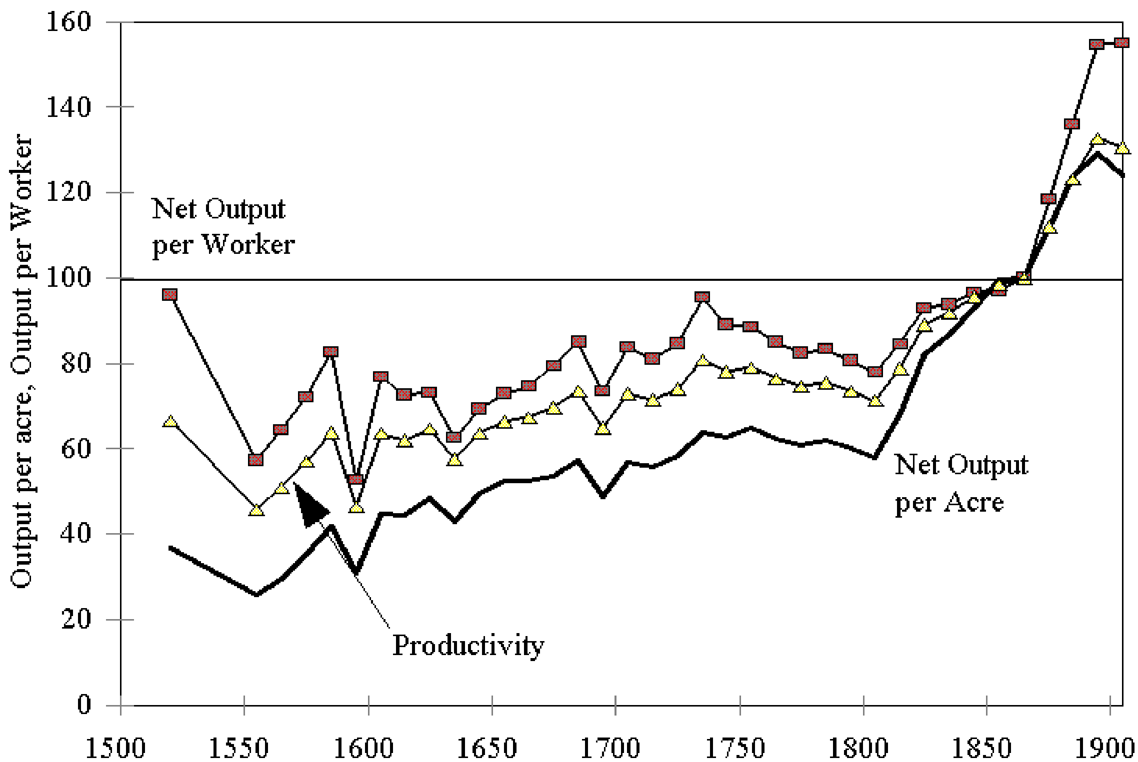
Table 6 shows the equivalent estimates if we assume 75% of labor was in agriculture before 1720. Figure 3 shows again the series for output per acre, output per worker and agricultural productivity. Assuming a larger agricultural labor share increases labor productivity growth, but reduces yield growth. The net effect, counterintuitively, is less productivity advance

**Table 5: Real Agricultural Output and Productivity - Preferred Labor Assumptions**

| Period | Real Output (1860-9 = 100) | Real Output per Male Farm Worker (1860-9 = 100) | Real Output per Capita (1860-9 = 100) | Productivity (1860-9 = 100) |
|---|---|---|---|---|
| 1500-49 | **36.6** | 96.1 | 264 | **66.7** |
| 1550-9 | **25.7** | 57.2 | 159 | **45.9** |
| 1560-9 | **29.5** | 64.5 | 184 | **50.9** |
| 1570-9 | **35.4** | 72.1 | 202 | **57.1** |
| 1580-9 | **41.9** | 82.7 | 236 | **63.9** |
| 1590-9 | **30.9** | 52.7 | 148 | **46.6** |
| 1600-9 | **44.9** | 76.9 | 218 | **63.7** |
| 1610-9 | **44.6** | 72.6 | 201 | **62.0** |
| 1620-9 | **48.6** | 73.3 | 206 | **64.7** |
| 1630-9 | **43.1** | 62.6 | 176 | **57.7** |
| 1640-9 | **49.5** | 69.4 | 195 | **63.8** |
| 1650-9 | **52.5** | 73.0 | 200 | **66.5** |
| 1660-9 | **52.4** | 74.5 | 200 | **67.3** |
| 1670-9 | **53.7** | 79.4 | 210 | **69.7** |
| 1680-9 | **57.1** | 85.1 | 225 | **73.6** |
| 1690-9 | **48.8** | 73.5 | 193 | **65.0** |
| 1700-9 | **56.9** | 83.8 | 220 | **73.1** |
| 1710-9 | **55.8** | 81.1 | 209 | **71.6** |
| 1720-9 | **58.2** | 84.7 | 213 | **74.1** |
| 1730-9 | **63.9** | 95.3 | 238 | **80.9** |
| 1740-9 | **62.7** | 89.1 | 221 | **78.1** |
| 1750-9 | **64.9** | 88.5 | 221 | **79.1** |
| 1760-9 | **62.5** | 85.0 | 200 | **76.5** |
| 1770-9 | **60.9** | 82.5 | 186 | **74.7** |
| 1780-9 | **61.8** | 83.3 | 173 | **75.5** |
| 1790-9 | **60.1** | 80.7 | 154 | **73.6** |
| 1800-9 | **58.2** | 77.9 | 135 | **71.3** |
| 1810-9 | **67.9** | 84.6 | 139 | **78.8** |
| 1820-9 | **82.1** | 92.9 | 144 | **89.1** |
| 1830-9 | **86.9** | 93.9 | 132 | **91.8** |
| 1840-9 | **93.0** | 96.6 | 118 | **95.7** |
| 1850-9 | **99.4** | 97.2 | 112 | **98.6** |
| 1860-9 | **100.0** | 100.0 | 100 | **100.0** |
| 1870-9 | **111.8** | 118.4 | 98 | **112.1** |
| 1880-9 | **123.8** | 136.0 | 96 | **123.2** |
| 1890-9 | **129.2** | 154.7 | 90 | **132.7** |
| 1900-9 | **124.1** | 155.0 | 77 | **130.8** |
| 1910-2 | **112.0** | 137.2 | 65 | **119.3** |

Source: See the text.

**Figure 2: Net Output per Acre and per Male Farm Worker, Preferred Labor Estimates**



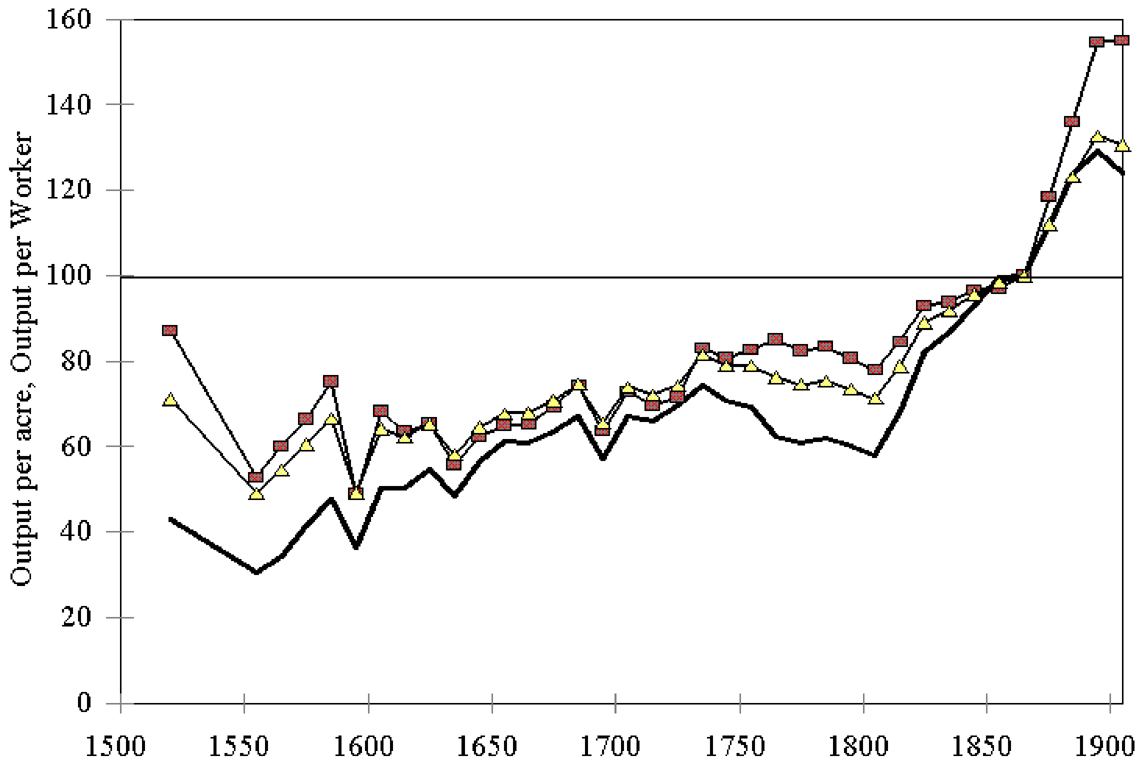

Source: Table 5.

## Table 6: Real Agricultural Output and Productivity - Alternative Labor Force Assumptions, 1500-1799

| Period | Real Output (1860-9 = 100) | Real Output per Male Farm Worker (1860-9 = 100) | Real Output per Capita (1860-9 = 100) | Productivity (1860-9 = 100) |
|---|---|---|---|---|
| 1500-49 | **43.2** | 87.1 | 311 | **71.2** |
| 1550-9 | **30.6** | 52.8 | 188 | **49.2** |
| 1560-9 | **34.4** | 60.0 | 214 | **54.5** |
| 1570-9 | **41.5** | 66.4 | 237 | **60.7** |
| 1580-9 | **47.7** | 75.1 | 268 | **66.7** |
| 1590-9 | **36.3** | 48.8 | 174 | **49.3** |
| 1600-9 | **50.2** | 68.2 | 243 | **64.3** |
| 1610-9 | **50.3** | 63.5 | 227 | **62.2** |
| 1620-9 | **54.8** | 65.3 | 233 | **65.2** |
| 1630-9 | **48.6** | 55.8 | 199 | **58.1** |
| 1640-9 | **56.5** | 62.3 | 222 | **64.6** |
| 1650-9 | **61.1** | 65.1 | 232 | **67.6** |
| 1660-9 | **61.0** | 65.3 | 233 | **67.9** |
| 1670-9 | **63.3** | 69.4 | 248 | **70.7** |
| 1680-9 | **67.1** | 74.2 | 265 | **74.5** |
| 1690-9 | **57.4** | 63.6 | 227 | **65.6** |
| 1700-9 | **67.2** | 72.9 | 260 | **73.9** |
| 1710-9 | **66.2** | 69.5 | 248 | **72.0** |
| 1720-9 | **69.6** | 71.5 | 255 | **74.3** |
| 1730-9 | **74.3** | 83.1 | 277 | **81.6** |
| 1740-9 | **70.7** | 80.6 | 249 | **79.0** |
| 1750-9 | **69.3** | 82.7 | 236 | **78.9** |
| 1760-9 | **62.5** | 85.0 | 200 | **76.4** |
| 1770-9 | **60.9** | 82.5 | 186 | **74.6** |
| 1780-9 | **61.8** | 83.3 | 173 | **75.4** |
| 1790-9 | **60.1** | 80.7 | 154 | **73.5** |

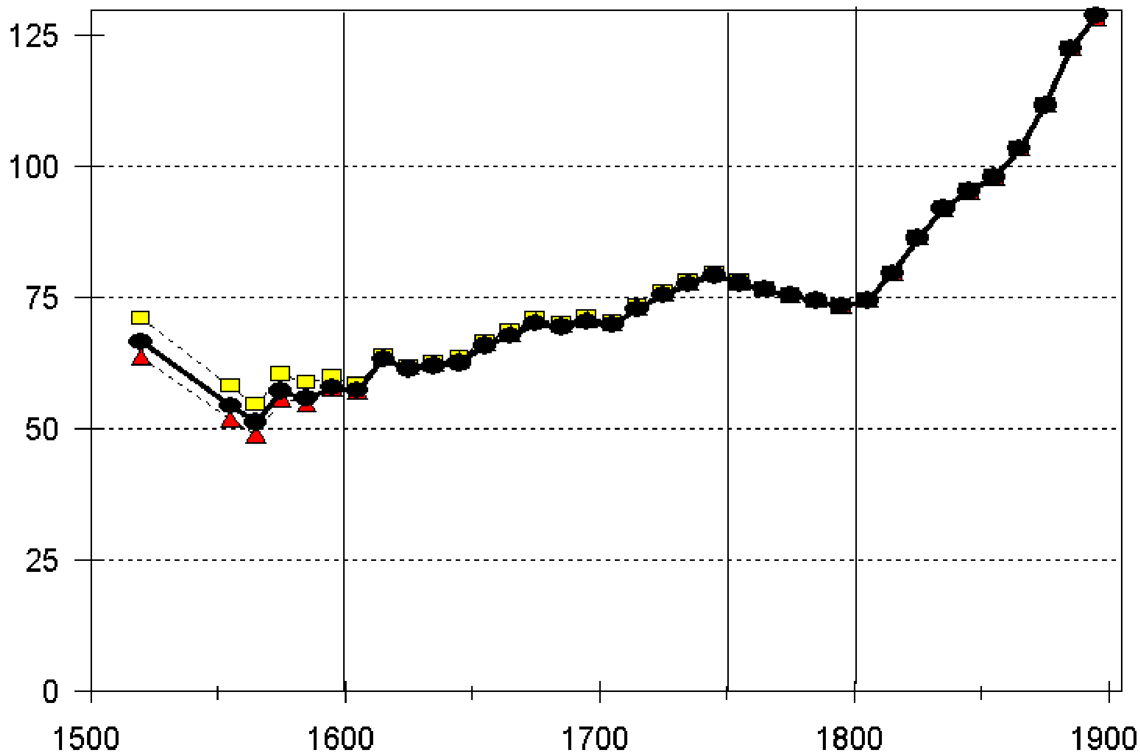
Source: See the text.

**Figure 3: Net Output per Acre and per Male Farm Worker, Alternative Assumptions about Labor Force**




Source: Table 6.

**Figure 4: Agricultural Productivity Under Different Assumptions**




Source: Tables 2, 5, 6.

than before because now also labor, which shows little rise in real costs, gets a larger weight in earlier years in calculating productivity. Thus now estimated productivity in the years 1500-49 is 71% of the level in 1860-9, as opposed to 67% on the preferred estimate. Figure 4 shows the estimated movement of productivity, calculated as a 30 year moving average, inferred by three different methods: first assuming the share of different inputs in costs remained constant at the 1860s levels throughout, second that only 55% of workers in agriculture in 1500-49, and lastly that 75% of workers were so employed. For most periods these assumptions make little difference to calculated productivity. Productivity under the preferred labor share estimates in general lies between productivity estimated by the other assumptions.

Figure 4 suggests that there are four distinct phases in productivity growth. The first, the sixteenth century, is one of stagnant productivity levels. As table 7 shows it is estimated that between 1525 and 1605 there a modest net decline in productivity.[4] But this overall result occurs at a time when labor productivity was falling quite significantly while land productivity was rising. This, I think, was just the predicted economic response of farmers to rising land values and declining labor costs created by population growth. There followed a long period of very modest but steady productivity advance from 1600 to 1750. This seems to be mainly driven by a growth in yields, since land productivity advances by more than twice as much as labor productivity. By the 1750 average output per acre increased 40% from its 1600 level. There follows a 50 year hiatus in productivity growth in the late eighteenth century where both yields and labor productivity decline modestly. After 1800 there is slow but sustained productivity growth, though by different primary means in the early and late nineteenth centuries.

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4 The benchmark dates chosen for table 7 were those outside periods of rapid price inflation since if rents did not adjust immediately these would be associated with lower productivity levels.

**Table 7: Annual Growth Rates of Output, Output per Worker and Productivity – Preferred Labor Estimates**

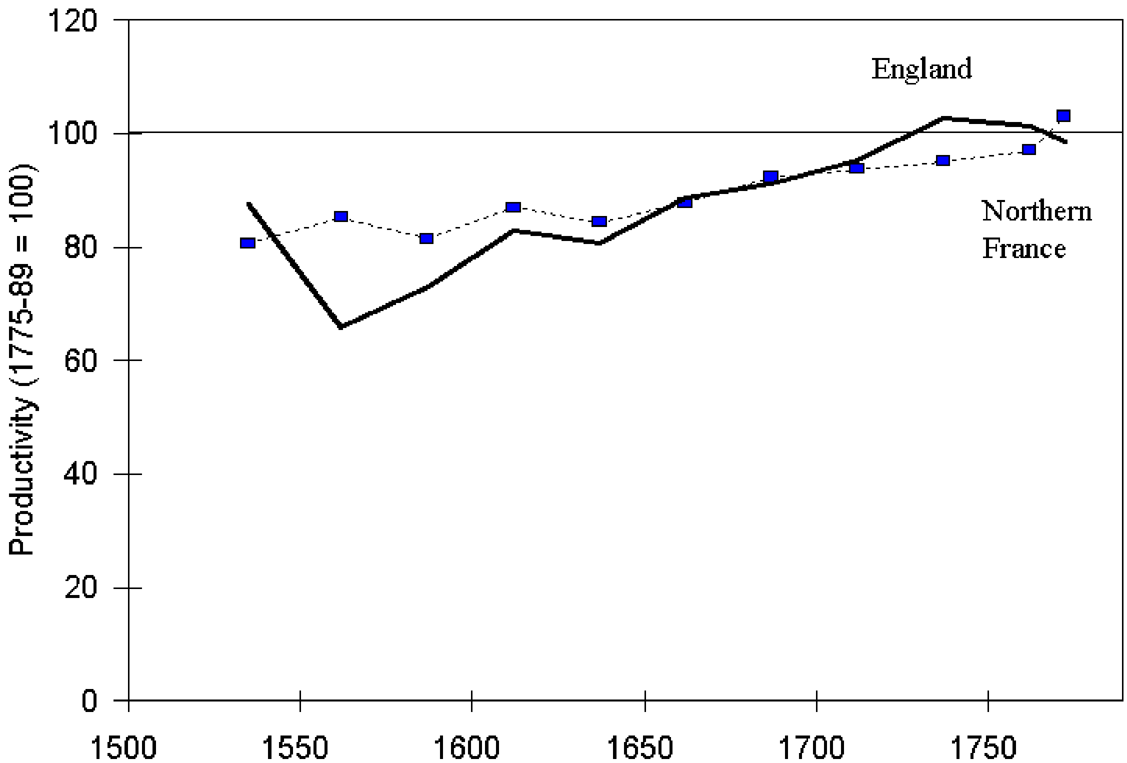
| Period | Productivity (%) | Net Output (%) | Net Output per Worker (%) |
|---|---|---|---|
| 1525-1605 | -0.06 | **0.31** | -0.32 |
| 1605-1745 | 0.15 | **0.24** | 0.11 |
| 1745-1795 | -0.12 | **-0.08** | -0.21 |
| 1795-1865 | 0.44 | **0.73** | 0.30 |
| 1865-1905 | 0.39 | 0.26 | **0.67** |

Source: Table 5.

Productivity rises mainly through yield growth before 1860. Labor productivity gains are more important after 1860. Thus the agrarian history of England in the years 1500 to 1912 really falls into two phases. In the first, 1500-1860, the primary driver of productivity growth in agriculture is gains in yields. In the second phase, in the late nineteenth century, labor productivity gains take over.

Philip Hoffman recently estimated total factor productivity in a similar way for a set of farms in the Paris Basin for the years 1520-1789 (with a constant set of input and output weights). Figure 5 shows the productivity movement on these farms compared to productivity movement for England, for 25 year periods, where 1775-89 is set to 100 in each country. Overall these farms in the Paris Basin show as much or more evidence of productivity growth in the years 1520-1789 as does England. Thus the conventional picture that in the eighteenth century France had a stagnating agricultural sector mired in the feudal past, while England had a vibrant commercial agricultural sector forging ahead, simply does not appear in this productivity comparison, at least when we compare Northern France to England. These two agricultural regions were both achieving modest and incremental productivity gains before 1790. There is nothing in the productivity series to suggest that after 1789 England would go on to triumph in the world of industry and commerce, and France would lag. Indeed the 40 years immediately before the French Revolution were characterized by relatively strong productivity growth in France and if anything a decline of productivity in England.

**Figure 5: Productivity Growth, England Compared to Northern France, 1520-1789**



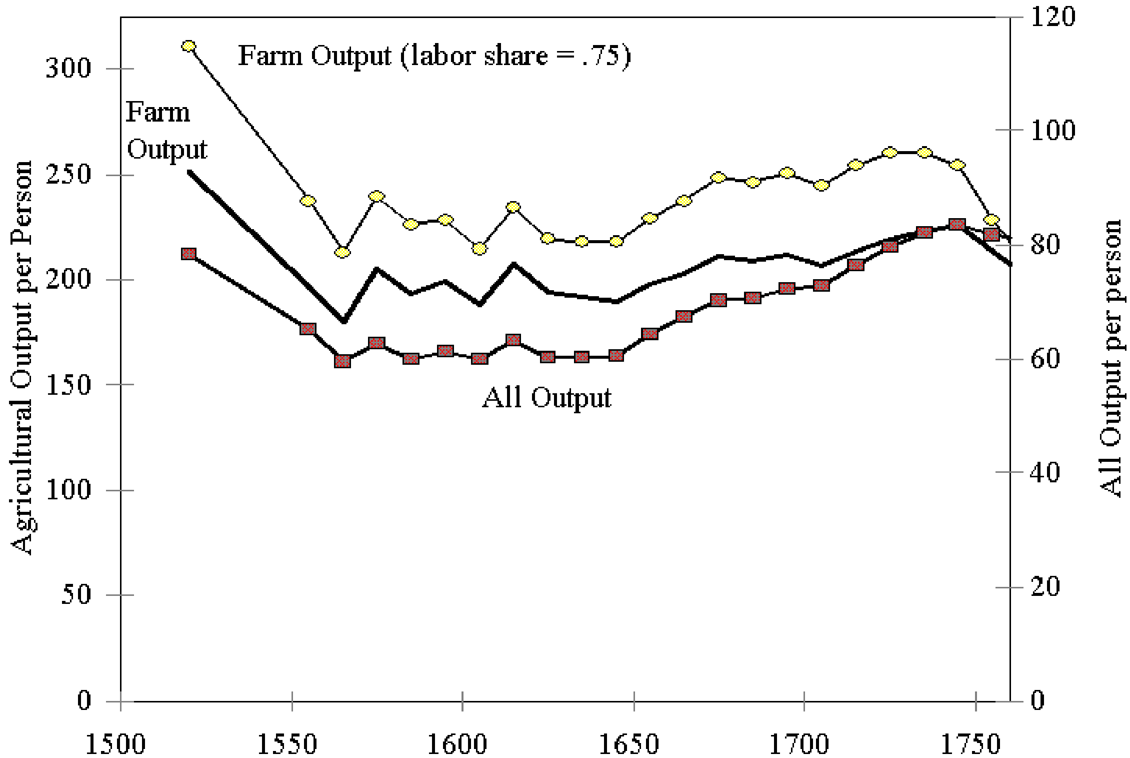

Notes: The average of each series is set to 100 for 1750-89.

Sources: Table 5. Hoffman (1996), p. 90.

**Labor and Land Productivity**

Calculating labor and land productivity above involves assumptions about the share of the population employed in agriculture before 1800 that are not directly verifiable. A check on the plausibility of the implied output per worker in agriculture and output per acre comes from looking at the implied level of agricultural output per head of the general population compared with estimated income per capita in England in these years. Figure 6 shows the implied agricultural output per person in England from 1500 to 1750-9 (calculated as a 30 year moving average), a period where England was largely self sufficient in food, compared with the estimated real income per person in the whole economy (again calculated as a 30 year moving average), under the both assumptions about the agricultural labor share. Under the preferred estimate of labor shares I find that agricultural output per head of population is surprisingly large in the years before 1750-9. Income per person seems to have been about the same in 1500-49 as in 1740-69. Yet agricultural output per person, assuming the same agricultural labor share in each period, is estimated to be about 15% larger in the earlier period. The alternative, more conventional assumption, however, produces an even larger deviation between earlier estimates of income per capita and estimated agricultural production. Thus in the years 1500-49 agricultural output per person would be about 50% greater than 1730-69 if three quarters of labor was then employed in agriculture. This is why I prefer to use a smaller labor share employed in agriculture for the years before 1750.

**Figure 6: Farm Output and GDP per head of the population under different assumptions**



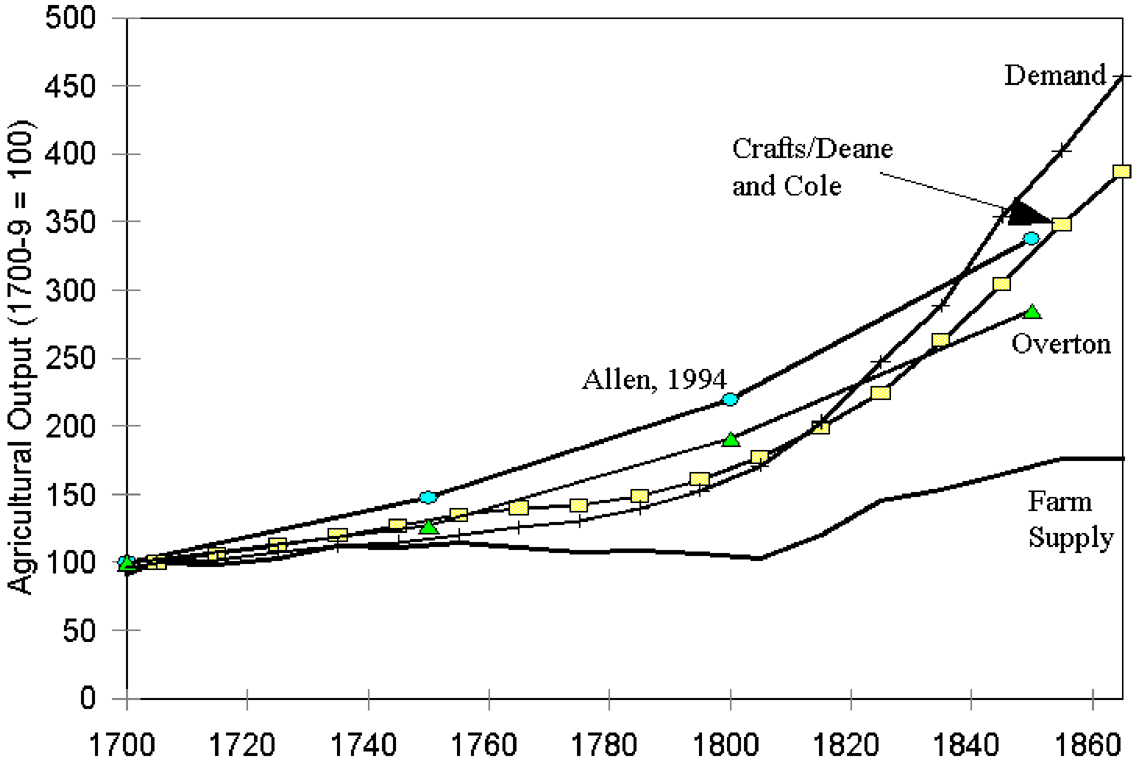

Source: Tables 5, 6. Clark (2001b).

## Net Farm Output, Food Demands, and the Industrial Revolution

The real output series produced here shows much slower growth than the conventionally accepted estimates of agricultural output growth for 1700-1869. Since these estimates underlie Crafts' calculation of output growth 1700-1860, if my revision is correct we need to substantially reduce the role of agriculture in economic growth in the Industrial Revolution England. Indeed we may need to reappraise the whole concept that the Industrial Revolution marked a significant break in growth rates between the old and the new worlds (see Clark (2001b)). Figure 7 shows my estimate of net farm output growth in England with 1700-9 set at 100. Also shown are the farm output estimates of Crafts for England for 1700-1831, and of Deane and Cole for Britain for 1831-1861/71: the series that underpin the standard Crafts account of growth in Industrial Revolution Britain. The estimates of Deane and Cole from 1831 on are derived in the same manner as here from factor payments. But the price series they used to convert nominal farm income into real farm output contained many imported agricultural items. These imported goods – tea, coffee, sugar, tobacco, rum, cinnamon, olive oil, pepper and logwood – were subject to very different price trends, and were also often heavily taxed in earlier years. Thus this price series moves very differently from the prices of domestic farm output. The estimates of Crafts for the years before 1831 are derived from consideration of the estimated consumption demand of the population. Figure 7 also shows recent estimates from Bob Allen in 1994 and Mark Overton in 1996 of farm output estimated from partial information on grain yields and animal sizes and stocks. The Crafts/Deane and Cole estimates and those of Bob Allen and Mark Overton from internal evidence on yields in agriculture correspond well. All of these estimates, however, are quite inconsistent with the evidence of real farm output presented in this paper.

Thus while farm net output in 1860-9, for example, on my estimates is a mere 77% higher than in

**Figure 7: Alternative Estimates of Farm Product Demand and Supply in England/Britain, 1700-1860.**




Sources: Allen (1994), p. 102, Crafts (1985), p. 42, Deane and Cole (1962), pp. 166-70, Overton (1996), p. 75.

1700-9, on the Crafts/Deane and Cole account it is 286% higher. There is a similar mismatch for output circa 1850. I show a gain to then of 70% from 1700-9, while Allen (1994) shows a gain of 238%, and Overton shows a 185% gain.

Recent evidence on grain yields in England from 1720 to 1914 from farm accounts by Michael Turner, John Beckett and Bethany Afton supports the income based estimates explored here. Figure 8 thus shows my estimates of farm net output compared to estimated net grain yield per sown acre, averaged across wheat, barley and oats, from Turner, Beckett and Afton (2001). Grain yields per acre show none of the sharp increases that would be necessary to help explain the assumed gains in total farm output. Indeed net grain yields per sown acre increase more slowly than my estimates of total net output per acre.

This leaves me with a problem to resolve, however. Also shown in figure 7 is an estimate of total demand in England for agricultural output estimated from the equation

$$D = aNy^{0.6}$$

where $N$ is the population of England and Wales and $y$ is an estimate of real income per capita, and $a$ is a constant.[5] Figure 7 seemingly implies that by the 1860s domestic farm output would supply only 39% of the food demanded by an English population that had grown nearly fourfold, and whose income per person had increased by 32% since 1700.

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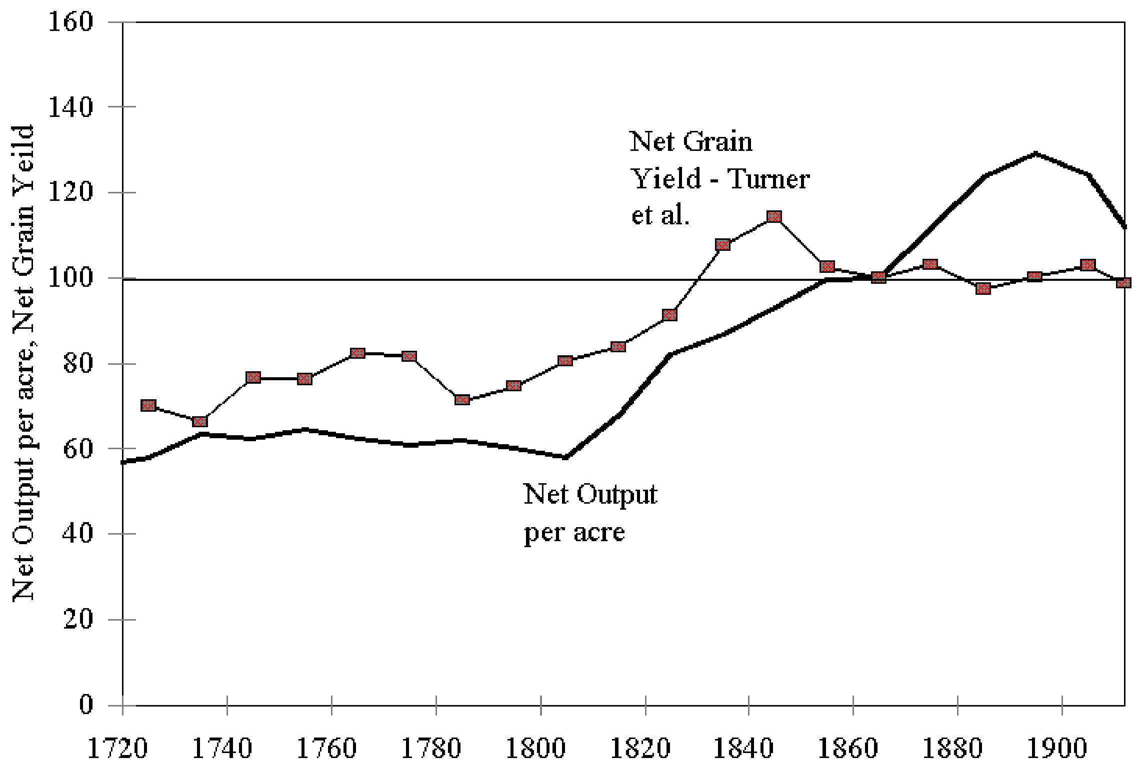
5 The income elasticity of demand for agricultural output is estimated from Clark, Huberman and Lindert (1995). That income elasticity is for food alone, while we shall see that agricultural supplied also heat, energy, construction materials and clothing fiber. But real incomes rose so little in these years (32%) that the precise elasticity is not important. Robert Allen has recently pointed out that to correctly estimate food demand we should also take into account changes in the relatives prices of agriculture and other products (Allen (1999)). For this period, however, food prices do not move particularly differently from a general consumption price index in England, so that the distortion induced by only considering income will be modest.

**Figure 8: Net Farm Output and Net Grain Yields per Sown Acre, 1720-1914**




Note: Net grain yields per acre are set to 100 in 1860-9. They are derived from Turner et al. (2001) up to the 1880s, thereafter from the official agricultural statistics, by assuming a sowing rate of 2.5 bushels per acre for wheat, and 4 bushels per acre for barley and oats throughout.

Sources: Table 5. Turner et al. (2001). Mitchell (1988).

This mismatch between the food demands from the British population in the Industrial Revolution period, and the evidence on food supply from domestic agriculture has already been explored in Clark, Huberman and Lindert (1995). If the output series derived in this paper is to be plausible then we have to bridge the gap between farm output in the lower curve and food demand in the upper curve. The first important element is food imports. Unfortunately after 1830 we only have trade statistics for the United Kingdom, which incorporates also Scotland and Ireland. Ireland was a net exporter of food to England after 1830. We thus have to make some assumption about how food imports to the United Kingdom were allocated. What I assume here is that Scotland and Ireland were on balance self-sufficient in food and raw materials, so that all imports of these to the United Kingdom went to England and Wales. In the 1860s food imports were on average £80 m. so that they were 70% of domestic net farm output. In 1700-9 food imports were on balance £1.7 m. in 1860-9 prices (see table 8).[6] But this still means that if we assume that English agriculture in all years produced exclusively food, total food availability per person in 1700-9 would have been £12.9 (in 1860s prices), compared to only £9.7 in 1860-9, whereas based on rising real incomes we would expect consumption to be about £15.3 in 1860-9 given its earlier level.

Clark (1999a) suggests that this apparent puzzle is generated mainly by the mistaken assumption that the output of English agriculture even before 1770 was almost entirely food for human consumption. The assumption that English agriculture produced only food for humans is close to true by the 1860s, when this was at least 90% of English agricultural output. But that was possible in the 1860s and later because the demands of the population for heat, light, building materials, clothing fiber, bedding fiber, dyestuffs, and transport were largely met either

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[6] There were exports of wheat and barley, but these were very modest relative to agricultural

by imports or through mined coal. In the pre-industrial period domestic agriculture could not specialize on food production because it also had to supply all these other needs. Wood, turf and furze was needed for fuel and construction, wool and flax were required for clothing, tallow was needed for candles and soap, oats and hay were needed to feed horses for transport, and the horses themselves also had to be provided.

Domestic agricultural production of energy, for example, was replaced almost entirely by the coal industry by the 1860s. Thus coal used for domestic consumption is estimated for Britain in 1700 at as low as 0.2 tons per capita (Hatcher (1983, pps. 68, 409)). By the 1860s coal consumption per person in England and Wales was nearly 3.5 tons per year. Most of this was not consumed for domestic heating, but coal consumption per capita for domestic purposes was still at least 0.73 tons (Church (1983, p. 19) reports this figure for 1855). Even assuming an income elasticity of demand for energy of one, this still implies consumers in 1700 would be expected to consume at least the equivalent of 0.5 tons of coal per capita. Thus they would have to consume the equivalent of 0.3 tons of coal in the form of wood and turf. This implies that agriculture in 1700 should have been producing 2.3 million tons of firewood (dry weight), or about 175 million cubic feet (Clark (2002b)). Wood was also used for fuel in brick making, iron and steel, salt making and pottery making. Iron production in England in the early eighteenth century was a very modest 17,000 tons annually. Yet each ton seems to have required about 1,800 cubic feet of wood. That implies that 30.6 million cubic feet of firewood per year. Thus in total we expect the agricultural sector had to produce at least 200 million cubic feet of firewood per year circa 1700. The average reported annual yield of coppiced wood in recent years is 1.27 tons per acre

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output, and were counterbalanced by imports of sugar, wine, coffee and tea.

**Table 8: Agricultural Consumption per Person in England, 1700s, 1760, 1860s (at 1860s prices).**

| | 1700-9 | 1760-9 | 1860-9 |
|---|---|---|---|
| Population (millions) | 5.16 | 6.25 | 19.97 |
| English Farm net output (£ m. 1860-9) | 64.7 | 71.4 | 114.3 |
| Net Food Imports (£ m. 1860-9) | 1.7 | 3.2 | 79.8 |
| Net Raw Material Imports (£ m. 1860-9) | -2.1 | -4.6 | 61.4 |
| Domestic Coal Consumption (£ m. 1860-9) | 1.7 | 7.9 | 48.3 |
| Total Food, Energy and Raw Material Consumption (£ m. 1860-9) | 66.0 | 79.3 | 303.8 |
| Consumption per Person (£. 1860-9) | 12.8 | 12.7 | 15.2 |
| Predicted Consumption (£. 1860-9) | 12.8 | 13.3 | 15.1 |

Notes: Cotton, wool, flax, and silk retained for home consumption are estimated by subtracting the raw material content of textile exports estimated using figures given in Deane and Cole (1962). Coal prices were taken as the average of export prices for coal free on board and the price of best coals in London.

Sources: Coal production: Flynn (1984, p. 26) and Church (1986, pp. 19, 53, 85-97). Imports 1860-9: Parliamentary Papers (1870). Imports 1700-9 and 1760-9: Schumpeter (1960, tables XV, XVII). Exports 1700-9 and 1760-9: Schumpeter (1960, tables VII, IX, X, XII, XIII), Mitchell (1988), pp. 221-2).

of dried wood, or 92.5 cubic feet. To produce 200 million cubic feet of firewood annually through coppices in 1700 would thus require 2.16 million acres of land devoted to firewood and iron production.

The construction industry in the 1860s imported annually into England the equivalent of 6.9 cubic feet of timber per person.[7] Again even assuming a high income elasticity of one the average person in 1700 would consume nearly 5 cubic feet of construction timber, so that total demand would be about 27 m. cubic feet. Given that imports in 1700-9 supplied only about the equivalent of 1.5 m. cubic feet, that would imply an additional 1.75 million acres of woodland (Clark (2002b)). Thus about 4 million acres of land must have been devoted to wood and fuel production circa 1700, or 15 percent of the farmland area of England and Wales.

Table 8 shows estimated farm output per capita for 1700-9, 1760-9, and 1860-9 for England in the prices of the 1860s. Also shown in 1860s prices are supplies of domestically consumed coal, and imports of food and raw materials. Counting all of these sources of supply of food, raw materials and energy, despite the decline in domestic farm output per person to about half its level of the 1700s there is a nearly 20% increase in the supply of food, raw materials and energy per capita. The rise in consumption per capita is about what we would expect if the income elasticity of demand for food, raw materials and energy was about 0.6. As noted the 0.6 figure comes from budget studies on food demand for working class families in the 1860s in England (see Clark, Huberman and Lindert (1995)). This elasticity may well be higher once we include demand for energy and raw materials. On the other hand richer consumers had

[7] Assuming that UK imports of timber were consumed in England, Ireland and Scotland according to population except that the Irish consumed half as much per head because of lower incomes.

a lower demand elasticity for food. But as was noted the elasticity assumption is not crucial here since estimated income growth between 1760-9 and 1860-9 was so low.

An implication of the reconciliation here between food demand and farm net output is that up to one third of English farm output in 1700-9 had to be horses, food for horses, firewood, and raw materials.[8] This implication is not at present directly testable, but farm accounts from this period should show a larger share of income from sales of faggots, hay, oats, and timber if the output series derived here for English agriculture is to be correct.

Another implication is that Crafts and Harley have underestimated agricultural output circa 1700 and 1760 by about 54%. This in turn implies that they have underestimated national income before the Industrial Revolution by about 25%. Thus their already modest growth rates of output per capita between 1760 and 1860 of a mere .59% per year are too high. The true figure could be an output growth of as little as 0.30% per year (see Crafts and Harley (1992)).

## The Sources of Productivity Growth

Figure 2 suggests that productivity growth in the years 1500-1869 was driven mainly by growth in output per acre, while productivity growth in the late nineteenth century was dominated by growth in output per worker. 1860-9 in England marks the break between a pre-mechanization era where labor productivity was largely stagnant because labor inputs on many tasks such as threshing and harvesting were heavily dependent on outputs, and little influenced by yields, and a mechanization era where labor productivity could rise even though yields improved little. Thus already by 1700-49 labor productivity was at 86% of its level in 1860-9.

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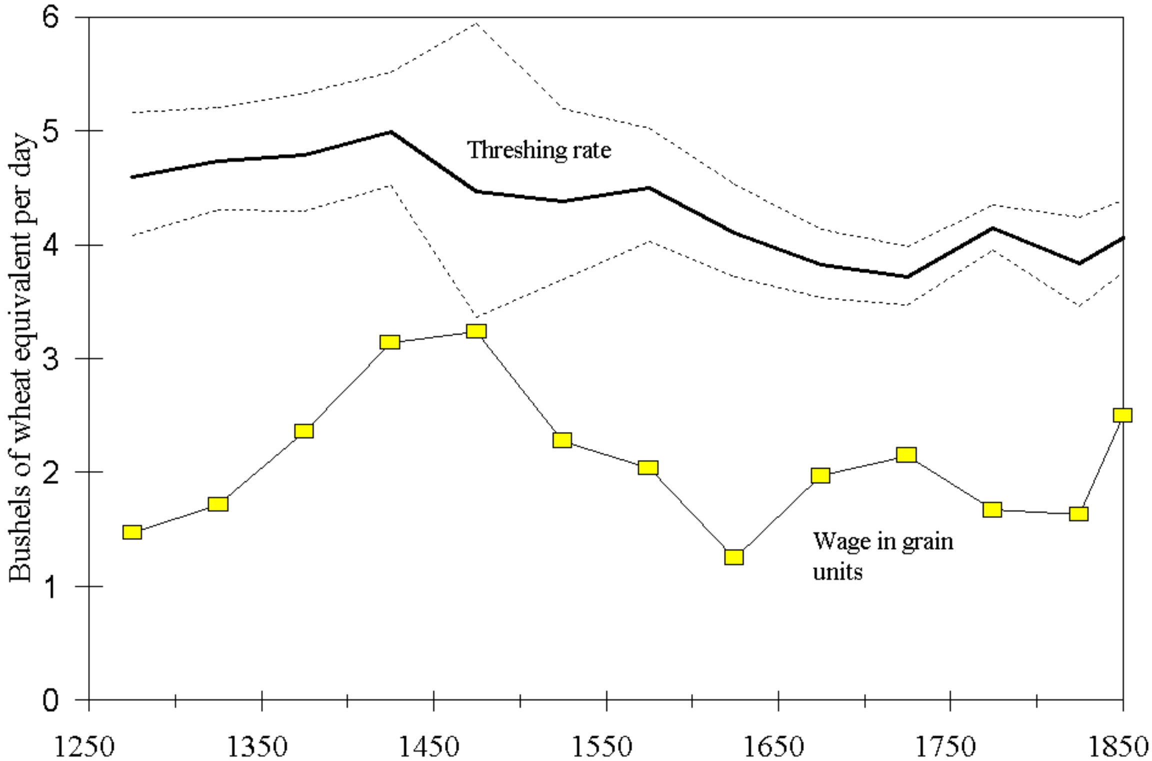
[8] Indeed that is why in the price index for agricultural output in the years before 1775 wood, tallow, hay, and wool is given a weight of 0.18 in forming the price index (compared to a weight of 0.06 in 1860-9).

This finding that output per worker increased little before 1860 is supported by evidence on labor productivity on specific tasks presented by Clark (1991a), and Clark and van der Werf (1999). Figure 9, for example, shows the estimated number of bushels threshed per day (expressed in terms of wheat) by English farm workers from 1260 to 1850. Surprisingly there is a modest decline in output per day on this task. Similarly table 9 shows that the implied number of days required to reap an acre of wheat, as well as Turner et al.'s estimate of wheat yields from farm accounts for the years 1560-1860. The second divided by the first gives the movement of task labor productivity in reaping wheat. This shows a gain of only about 15% from 1770 to 1860, even though wheat yields increase by nearly 40%.

In an interesting recent study, Eona Karakacili directly estimates labor productivity in arable agriculture on ten of the manors of Ramsey Abbey for a number of years in the interval 1279 to 1409. She finds a gross output per male worker/year of 222 bushels of wheat equivalent 1279-1348, and 186 bushels of wheat equivalent post 1357-1409 (Karakacili 2001, p. 200). It is a little hard to compare these gross arable output estimates directly to my net overall outputs, but as a rough correction I assume an average yield/seed ratio of 4:1 (Karakacili 2001, p. 218). In that case net output per male worker is 167 bushels pre plague and 140 bushels post plague. As Karakacili emphasizes, such labor productivities are higher than traditionally expected relative to the nineteenth century. They also imply an agricultural system, at least before 1350, that would have a much smaller share employed in agriculture than is traditionally assumed, and that was not at any kind of subsistence limit. In equivalent terms, for example, my estimate for 1860-9 is

**Figure 9: Labor Productivity in Grain Threshing**




Source: Clark and van der Werf (1999), figure 2.

**Table 9: Labor Productivity in Reaping Wheat**

| Years | Implied Days per Acre | Gross Yield per Acre (bu.) | Labor Productivity (bu./day) |
|---|---|---|---|
| 1768-71 | 2.59 | 20.8 | 8.0 |
| 1794-1810 | 2.90 | 20.0 | 6.9 |
| 1850 | 2.92 | 27.5 | 9.4 |
| 1860 | 3.07 | 28.6 | 9.3 |

Source: Clark (1991a), Turner et al. (2001), p. 129.

only 206 bushels per acre (at the relative prices of 1500-49). They thus support the story told here for post 1500.[9]

The relative unimportance of labor productivity gains in the years 1500 to 1860 is startling. For what is unusual about English agriculture compared to other European economies in 1860 was precisely the very high labor productivity of England. Thus in the mid nineteenth century output per acre in England was similar to output per acre in the Netherlands and Belgium, and only about 20% greater than output per acre in France and Ireland. But output per worker in England was double or more output per worker in all these other countries.[10] In particular output per worker in France is estimated at only 44% of its level in England in 1851. But this implies real output per male worker in England in 1700-49 already far exceeded output per worker in any other European economy in the 1850s. And even if 75% of the male labor force was in agriculture in the years before 1680 real output per worker in England in 1500 would be greater than in France in 1850. English exceptionalism in agriculture thus stems, as far as labor productivity is concerned, back to the middle ages.

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[9] There are some problems with these estimates, however, that suggest that while this is a promising innovation, these results must be treated cautiously. Because the estimates concentrate on the arable sector, to get true net outputs per worker we should deduct all fodder used for the work animals on the arable. Also the pre and post plague estimates are implicitly in conflict and suggest very different long run labor productivity trends. The drop in labor productivity after the Black Death contradicts basic economic reasoning so at least one of the estimates must be in error. No cultivator should adopt a technique on the arable post the plague that reduces both output per acre and per worker. If I compare the post plague estimates to 1500-49, the period most comparable in terms of the land-labor ratio and the real wage, I find a 50 percent labor productivity gain to 207 bushels per worker. But if I compare pre plague with the comparable period in terms of population 1600-49, there is no gain. So depending on whether I choose to believe the pre plague or post plague numbers I would get a very different impression about labor productivity trends. Only when this method is applied to other estates will we get an impression about whether it is robust to the vagaries of medieval estate accounting.

[10] See Clark (1991), Wrigley (1985), Allen (1988)

High English labor productivity in 1850 compared to other Western European countries has been taken to imply that there must have been substantial labor productivity growth in England sometime before 1860-9. Indeed there is a long history, starting with Marx, that emphasizes how in England the development of capitalist agriculture led to the expropriation of the independent peasantry, and the creation of a landless rural proletariat that were easily moved into the industrial sector. Thus there have been a series of articles recently estimating when labor productivity in English agriculture rose and seeking to explain its causes. Wrigley (1985) uses urbanization as a way to measure this (assuming constant food consumption per person) and finds that labor productivity in England nearly doubled between 1500 and 1800. Allen (1988) explores the role of larger British farm sizes in explaining this labor productivity growth and finds that farm size growth predicts a more than doubling of labor productivity in the south Midlands from 1600 to 1800. Patrick O'Brien concludes that "British families left the countryside, partly in response to better opportunities in towns or abroad, but essentially because the institutions of capitalist agriculture will not retain as much redundant labour" and that "the institutions and culture of peasant agriculture in France operated to restrain the outflow of people from countryside to towns and from agriculture to industry" (O'Brien (1996), p. 226, p. 228). Allen recently in this journal applies a more sophisticated variant of Wrigley's method over the years 1300, 1400, 1500, 1600, 1700, 1750 and 1800 which takes into account changes in food demand per capita also (Allen (2000)). This refined method still finds that labor productivity in agriculture roughly doubles from 1600 to 1800, while French labor productivity hardly increases at all, and that these were the years when the two economies diverged into a progressive England and stagnant France.

My evidence on farm output estimated from factor payments suggests, however, that the institutional changes in English agriculture between 1600 and 1800 – enclosure and the growth of the wage labor force in the countryside - had little effect on labor productivity. If England and France started out with the same agricultural labor productivity in 1600, and ended up with England at more than twice the level of France, then France must have seen a substantial decline in labor productivity over these years. Yet we see above that the evidence of Hoffman (1996) suggests that overall productivity growth in agriculture was similar in England and northern France in the years 1600 to 1789.

Further the observed gains in labor productivity between 1500 and 1860 may themselves be explained mainly as a consequence of yield growth. As Clark (1991a) explores, a rise in grain yields will itself lead to some increase in labor productivity. Indeed based on the estimates presented there the yield gains from 1500 to 1860 would easily explain any labor productivity gains. Even if these hypothetic calculations are incorrect it is clear that much of the observed gain in labor productivity between 1500 and 1860 would have to be attributed to yield gains, rather than to factors such as farm size, enclosure, or the creation of a landless rural proletariat.

Yield growth then seems to be the driving force in agricultural change between 1500 and 1860-9. The yields estimated per acre for 1500-39 are indeed low: the equivalent of 3.5 bushels of wheat per acre as net output. Clark (1991b) estimates for southern England in 1300-49 from manorial account records that net output per acre was the equivalent of 4.1 bushels per acre. Thus there is no sign of any gain in yields in the 200 years from 1300 to 1500, and indeed signs of some potential decline. Thereafter measured yields grow most rapidly in the late sixteenth century and early nineteenth century with a long period of stasis in between. The cause of these yield gains remains unclear.

**Conclusion: The Agricultural Revolution**

The concept of that an agricultural revolution, a counterpart to the Industrial Revolution, occurred in Britain sometime in the years 1560 to 1850 has long been the crucial organizing principle of English agrarian history. Thus at least eleven books have been written about English agriculture in these years which include "agricultural revolution" in their title. Most of the debate among agricultural historians has been about when in the long period 1560 to 1850 the agricultural revolution occurred, with the years 1550-1650, 1650-1750, and 1750-1850 each having their supporters.[11]

Yet if the rent and associated real output series derived above are correct it is not clear if we can usefully think of developments in English agriculture in the years 1500 to 1869 as representing any revolutionary change in technique. It is true that over these years English agricultural output seems to have tripled, and the measured total factor productivity of the system increased by about 50%. But this was achieved over a very long period with few abrupt changes so that the rate of growth of productivity per years was on average 0.15%. This would mean that even in any twenty year period farmers would be unable to discern, given the noise of year to year fluctuations, that productivity was actually increasing.

Further the measured doubling of productivity between 1500-39 and 1860-9 certainly overstates the true productivity gain, because it includes gains from more investment of capital in farmland as part of pure productivity growth. For the productivity measurement should property be done using only the site value of farmland. It implicitly assumes that each acre of farmland was the same in 1860-9 as in 1500-49. All farmland, however, was a bundle of raw land and various capital investments: housing, barns, fences, drainage, roads, soil amendments. After 1600 land became much more valuable relative to labor, and the value of land relative to labor continued to rise until 1800. If the cost of the capital invested in the land was proportionate to labor costs this would mean that after 1600 landowners would have an enhanced incentive to drain, reclaim, recycle animal waste, and build buildings. Thus, for example, about 10% of the rise in real rents from 1500-49 to 1860-9 was the result of common land being enclosed. Hence enclosure explains about 4% of the measured productivity increase. But I argue in Clark (1998b) that enclosure was mainly a capital investment induced by higher land rents relative to wages, with very little associated productivity gain. If the various other measures which resulted in higher land yields – increases in the pasture area, reduced fallow on the arable, higher arable crop yields – resulted in part from investing more capital in the form of maintaining increased stocks of organic matter in soil and returning more animal waste to the soil, then again my productivity measure based on rents will mismeasure some of these gains from intensified use of land as pure productivity gains.[12] The only way we could test to see how powerful these effects are would be to measure productivity using as a measure of land rents the site value of agricultural land. But no such measure is available.

Thus the extent to which the "agricultural revolution" of the years 1500 to 1869 was a revolution, in the sense of getting something for nothing through getting more output from the same set of inputs, or was just an intensification in the use of land, getting more output by using more inputs, is a matter still of conjecture.

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11 See, for example, Overton (1996) and Allen (1999). Overton supports a later agricultural revolution, Allen an earlier one.

12 See Clark (1992).

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