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Energy availability from livestock and agricultural productivity in Europe, c.1800-1913: a new comparison

Abstract

We explore the proposition that an important reason for English supremacy in agricultural productivity in the early 19th century was their relatively high energy availability from draught animals compared to France. We compare draught animal power in several European countries and show that this proposition did not hold at the time, neither in relation to France nor to the European average. At a much later point in time, towards the end of the 19th century, England and Wales however had relatively high amounts of draughts animals per agricultural worker. They also had low number of workers and animals per hectare, which indicates that they enjoyed an overall high efficiency of muscle power, rather than an abundance of such power. Thus the idea of animals substituting agricultural workers does not hold even at this later point in time. The article is based on extensive, new data collection on draught power in different countries of Europe. We take increasing size of animals over time into account in our modelling and widen the analysis to muscle energy productivity of the agricultural sector to check the 'substitution hypothesis'.

Keywords: draught animals, energy, England, Europe,

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1. Introduction

In two similar pieces published in 1988 and 1991, one as part of his seminal book on the Industrial Revolution, *Continuity, chance and change,* Tony Wrigley drew attention to the possibility that high energy inputs accounted for England's peculiarly high labour productivity in agriculture during the early nineteenth century. It is well-known that high levels of labour productivity were inextricably linked to the ability of English society to keep a low proportion of its population working in agriculture, thus permitting the rapid expansion of the industrial and service sectors without the danger of too rapid rises in agricultural prices and declining living standards. If increasing energy inputs were an essential component of high agricultural productivity, these inputs could not come from humans if labour productivity was also to rise. Without radical technical change, it would be likely that any gains from increased human labour inputs would be cancelled out by the food necessary to fuel those longer or harder hours of work. The answer to this conundrum was the increased use of draught animals. He backed this supposition up with comparison using English and French data, but observed that the paper was 'largely speculative', and expressed the hope that it would 'provoke a search for new material'.[1]

In the years that have since passed, that expressed hope has unfortunately not born fruit.[2] Indeed, much remains to be done more generally in the comparative study of European agriculture: the desire expressed by O'Brien and Prados de la Escosura in 1992, that, 'In order to measure and to explain the gap in levels of per caput income and output per worker across European countries, a larger and more secure database is required', has not been answered in regard to draught animal power.[3] This paper however seeks to take up Wrigley's challenge and compare the relationship between the energy input from draught animals and humans with agricultural productivity in England and Wales and seven other Western European countries: France, the Netherlands, Sweden, Germany, Italy, Portugal, and Spain. By extending the comparison to several

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[1] Wrigley, E.A., *Continuity, chance and change. The character of the industrial revolution in England* (Cambridge, 1988); Wrigley, E.A., 'Energy availability and agricultural productivity', in Campbell, B.M.S. & Overton, M., *Land, labour and livestock* (1991), pp.323-39.

[2] Although Patrick O'Brien has backed Wrigley's management on the assumption that late nineteenth century differences in draught animal stocking rates were reflected in earlier centuries. O'Brien, P.K., 'Path dependency, or why Britain became an industrialized and urbanized economy long before France', *Economic History Review,* XLIX (1996), pp.213-249.

[3] O'Brien, P.K., L.Prados de la Escosura, L., 'Agricultural productivity and European industrialization, 1890-1980', *Economic History Review* XLV (1992), p.514.

Western European countries we are able to see whether England and Wales stand out as exceptional. The period covered runs from 1815 to 1914. This begins in an era when reasonably reliable statistical data first become available, and ends when unusual wartime conditions, and a rapid expansion in the use of tractors occurred. It also covers the classic period of 'agricultural revolution' that saw dramatic productivity improvements in all European states, though with rather different chronologies and rates.

It is worth from the outset emphasising two points:

1. Wrigley's argument related to labour productivity, not agricultural output or land productivity more generally, and this is also the primary concern of this paper. However, the analysis is expanded to encompass the more general 'muscle productivity' of the agricultural sector, including inputs from both humans and animals.
2. This paper addresses the relationship between energy from livestock for the agricultural sector and the labour inputs, not the energy from livestock supplied to any other sector of the economy.

Our main research question is, to what extent were changing energy inputs a significant variable in determining levels of agricultural labour productivity in the period of 'traditional energy carriers', (i.e. before agriculture was motorized)? More specifically: did England and Wales achieve its high level of agricultural productivity as a result of high amounts of draught animals used there? The first part of this paper will examine this question utilising roughly the same methods as those applied by Wrigley, largely based on simple numbers of animals. However, animals of the same species varied in size across Europe and larger animals can provide more muscle power than smaller ones. Knowing that England and Wales had relatively large beasts, we therefore must modify our results by taking the size of the animals in different countries into account, to explore whether this gives England and Wales or indeed other countries a more prominent position than the sheer numbers do. Expert breeding affected the size development of beasts in some countries and led to a convergence in size with the leaders in north-west Europe. This is accounted for in our modelling.

It is then investigated whether the energy inputs that fuelled muscle power were used more efficiently over time in relation to output from the agricultural sector. One reason to expect an increase in energy productivity (value added/energy inputs) in the agricultural sector is that expert breeding and technical change could permit the improved and more efficient application of power. The *size* of the animals and thus the amount of fodder they consumed and work they could individually perform increased; and as more expert breeding and technical change could permit the improved and more efficient application of power, or in other words *final energy consumption* became a larger proportion of energy inputs: actually performed work in the agricultural economy became a larger proportion of the basic energy input that came from fodder. There are other potential reasons for a change in energy productivity, such as changes in output mix (structural change in the composition of produced goods), changes in the input mix (substitution between different factors of production) and overall productivity increases which may have unintended effects on muscle energy.[4] Of course, agriculture was subject to many changes during this period, such as major reconfiguration of land-holding structures, changes in cropping regimes and general output, increased mechanization of many kinds, and from the late nineteenth century the extensive use of chemical fertilisers, which may have affected energy productivity.[5] We do not aim to separate out in detail the underlying causes for energy productivity changes in agriculture, but merely use the energy productivity measure as an aggregate indicator of overall muscle energy efficiency.

Section two of the paper will outline the principal methods used in gathering and analysing data. We have employed statistical data as far as is possible but a degree of interpolation and estimation was inevitable, given the scale and time period of our analysis. More detailed references as well as data sets for benchmark dates are provided in Appendix A. The third section presents the results of our comparative analysis, at this point using similar 'energy values' for livestock as those employed by Wrigley, to provide a consistent test of his analysis. As the temporal span on his work was much shorter, Wrigley did not account for changes either in animal size or the amount of work actually

[4] **** Stern, 2004; Brock and Taylor, 2004, Kander and Lindmark 2004 Need full refs.

[5] See for example Schremmer, E., 'Faktoren, die den Fortschritt in der deutschen Landwirtschaft im 19. Jahrhunder bestimmten', *Zeitschrift für Agrargeschichte and Agrarsoziologie* 36 (1988), p.47; Turner, M., "Agriculture, 1860-1914", in Floud, R., and Johnson, P. (eds), *The Cambridge Economic History of Modern Britain: Vol II, Economic Maturity, 1860-1939* (Cambridge, 2004), pp. 133-60; Clout, H.D., *The land of France 1815-1914,* (London, 1983), passim; Dovring, F., 'The transformation of European agriculture', in Habbakuk, H.J., & Postan, M.M., eds, *The Cambridge economic history of Europe, Vol. VI.II. The industrial revolution and after* (Cambridge, 1965), pp.604-72.

performed by them. The fourth section will thus consider the data available by which these changes may be estimated and incorporated into the analysis and the basis for these estimates are provided in Appendix B. It is demonstrated that at the end of the Napoleonic period, and in contrast to what has been supposed, the amount of energy from draught animals per worker in agriculture was not high in England and Wales in comparison to France. What is notable however is the ability of British agriculture to significantly increase this figure over the course of the nineteenth century, an achievement unmatched even by those countries that began from a considerably lower base. This development was not marked however until after 1870, in other words, it belongs to the restructuring of agriculture brought on by the price and cost pressures of the 'depression' period. Section four also demonstrates that that the energy productivity of draught animal use, and muscle energy use more generally, tended to rise across the period. However this was much more marked outside of the north-western regions; and England and Wales made barely any progress at all in this regard. Progress in the *value* of the sector was not simply, therefore, a function of increased energy inputs. England and Wales saw higher energy productivity than the rest of western Europe, which is an alternative way of expressing their generally higher efficiency in agriculture; but its European neighbours tended to reduce this gap over the century, though remaining far from closing it in most cases.

2. Methods

We present below new series for draught animals available for use in agriculture for all the countries concerned. The livestock series are based on a mixture of already available series, previously available data adjusted to improve accuracy, and material collected from printed statistical sources. However, almost inevitably, inconsistencies remain between series that are assembled from data collected using different premises. For example, they contain aggregates of different animals, in part because of genuine differences in agricultural practice (thus it is of no importance that donkeys or mules do not appear in the English series). Wrigley's schema did not embrace donkeys of mules, but they are of some significance in Mediterranean agriculture, including that of southern France. There is rather less data on the amount of work performed by these beasts, or what they consumed, than for horses and oxen. This is unimportant for England and Wales, or the Netherlands, where nearly all work was done by horses, but is probably significant elsewhere. Equally, not all series contain cows, although they were widely employed for draught purposes and outnumbered draught oxen in Germany as late as the beginning of the twentieth century. German statisticians, who provided the only data on draught cow use, considered in 1873 that cows provided 9.9% of draught power in agriculture, reckoning a cow, for these purposes, as a third of an ox.[6] For aggregating the number of animals we first use the principles outlined by Wrigley in 1988 and 1991 to calculate 'raw' data of livestock numbers, where one ox equals two-thirds of a horse (exactly the proportion also employed by contemporary German statisticians). Similar allowances are made for other animals: one mule is assumed to equal one horse, a donkey half a horse, and a cow one-third of an ox, i.e. two-ninths of a horse. This is done in order to provide a basic analysis of the relationship between livestock inputs, other factors of production such as land and labour, and the net value of agricultural output in the countries concerned.

A very important further problem is assessing how many of these animals out of the national herd were actually used in the agricultural sector. This disaggregation is rarely made although in some countries total numbers of beasts give a very misleading impression as to those available for draught use in agriculture. In England the number of horses employed on-farm is very clearly recorded from 1867. In estimates from the early nineteenth century times, it seems that agricultural horses made up around 60% of the total number of horses, less than half by 1870 and a mere third by the start of the twentieth century.[7] In 1852 72% were so employed in France, falling to 53% by 1890.[8] In the German states as a whole the first comprehensive statistics from 1873 suggest that 70% of horses were predominately used in agriculture, and a similar level in the 1890s.[9] The share in Sweden was also about 70% in the early nineteenth century, and declined slightly over the century. Similar estimates have to be taken for the proportion of oxen, mules and donkeys used for draught power in agriculture, although here the statistical data is rather sparse and less reliable. Many of these animals that dwelled on farms were certainly used in the transport sector, but we have no accurate measure of the extent of this use. The figures also need to be adjusted for the age at which horses and oxen generally started working, where the proportion of foals and calves is not explicitly

[6] Lengerke, A. von, *Landwirtschaftliche Statistik der deutschen Bundesstaaten* (Braunschweig, 1840), pp.108-165; *Statistik des deustchen Reiches,* Bd.VIII (1874), p.106.
[7] See Appendix A.
[8] See Appendix A.
[9] Prussian statistics from 1861 suggest that the proportion was a few per cent higher in that year. *Statistisches Jahrbuch des deutschen Reiches*, (1887).

recorded. For example, although in 1873 some 70% of all German horses were employed in agriculture, 81% of horses of a working age were so employed.[10]

We have worked with benchmarks dates related to the availability of data across countries. These are: 1815, 1840, 1850, 1860, 1870, 1880, 1890, 1900, and 1913. These benchmarks give a good chronological spread but are basically chosen because of the availability of comparable data across a range of countries.

3. Results

3.1 Horse equivalents: a new data set

With the data we have assembled we can establish levels and trends in the basic availability of draught power in the agricultural sector. Actual numbers of different kinds of animals (horses, oxen, cows, donkeys and mules) and the sources are provided in Appendix A. There was a continual and widespread debate throughout the continent regarding the relative merits of horses and oxen for agricultural use, but there is little doubt in the long-term as to what farmers preferred; the trend is universally towards increased use of horses.

As one would expect given the relative size of the countries, absolute numbers of draught animals, in horse equivalents, differ substantially in level among the countries, as seen in Figure 1. Germany and France started out as the leaders in numbers, but while the numbers grew in Germany they declined in France, the latter ending up at the same level as Italy before the First World War. England and Wales is at the lower end of the scale, but had rather more draught beasts than the Netherlands, Sweden and Portugal. Spain resembled France in showing a declining number of draught animals. In northern Europe animals numbers tended to peak just before the First World War, but they did not peak in Italy until the 1920s and Spain showed a twentieth century recovery in numbers to peak as late as the 1950s.

Figure 1

3. 2 Draught energy per hectare and per labourer

One way of taking the different size of the countries into account is by adjusting the draught animals for the 'agricultural' area. If we examine the draught power available per

[10] *Statistik des deustchen Reiches,* Bd.VIII (1874)

hectare used for agricultural purposes,[11] shown in Figure 2, we find that the Netherlands, and England and Wales, had a rather low stocking rate. France and Sweden had a relatively high one. These differences reflect in part the different structures of their agricultural economies, with the pastoral sector being of relatively high importance in Britain and the Netherlands. In the second half of the nineteenth century, Germany and Sweden all increased their stocking rate from an already relatively high level, while in other countries this proportion remained fairly static or fell. Thus the tendency to increase the input of draught energy per hectare was by no means a generalised European phenomenon[12]

Figure 2

Wrigley's argument focused on the energy put at the disposal of each worker in agriculture by draught animal power, rather than the stocking rate. Figure 3 indicates that during the period on which his work focused, England and Wales did not stand out in comparison to France, but these two countries, and Sweden, differed considerably from central Europe. It is important to note that in England, this high level of draught animal energy input per worker may have arisen considerably earlier, perhaps as early as the late seventeenth century. Overall horse numbers estimated for England by Gregory King in

[11] We have chosen to use data for *all* agricultural land (i.e. directly cultivated and recorded as for use as pasture) for two reasons. Firstly, this avoids as far as is possible inconsistencies in the categorisation of land use between countries. Secondly, we see no reason to narrow agricultural practice down to, for example, a focus on the arable sector or indeed any sub-sector that will produce biases towards the practices of any one country. We have not however, included rough pasture, as draught animals had no effective role in the extensive hill and mountain pastures usually grazed by sheep..

[12] Acreages are drawn from Hannerberg, D. Svenskt agrarsamhällen under 1200 år, Stockholm 1971. Holgersson , B. Cultivated Land in Sweden and ist growth 1840-1939, *Economy and History*, vol??p??? Lund 1974, Kander, A. (1998): Energy consumption and Forestry in Sweden 1800-1990, - Implications for CO2 emissions, licentiate thesis, p 121-123; Hoffmann, W.G., *Das Wachstum der deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts* (Berlin, 1955), p.****; Collins, E.J.T., ed., *The agrarian history of England and Wales. Vol VII, 1850-1914*, (Cambridge, 2001), p.1768-78; although data is not directly available for Italy at an early date, it seems likely that the cultivated area remained roughly static at around 17 million hectares in the late nineteenth century, but with growth to nearly 21 million hecates by 1907-9. This is based on statistics collected in the 1860s, and the agricultural area, with mountains removed, provided by Zamagni. Earlier estimates provide by Malanima include some areas devoted to wood production but do not seem to include pasture. Brown, S., 'On the statistical progress of the Kingdom of Italy', *Journal of the statistical society of London*, 29/2 (1866), p.218; Zamagni, V., *The economic history of Italy 1860-1990. Recovery after decline* (Oxford, 1993), p.55; Malanima, P., *L'economia italiana dalla crescita medievale alla crescita contemporanea* (Bologna, 2002), pp.121-2; O'Brien, P.K., & Toniolo, G., 'The poverty of Italy and the backwardness of agriculture before 1914', in Campbell, B.M.S., & Overton, M., eds, *Land, labour and livestock. Historical studies in European agricultural productivity* (1991), p.402. The earliest Spanish figure may well include wooded land, as this was included in a similar satistic at later dates and had to be deducted; Barciela López, C., Giráldez Rivero, J., Grupo De Estudios De Historia Rural, López Ortiz, I., 'Sector Agrario y Pesca', *Estadísticas Históricas de España, siglos XIX-XX*, forthcoming, Cuadro 4.18; Toutain, J.-C., *Le produit de l'agriculture francaise de 1700 à 1958* ****; Need Dutch and Portuguese sources.

1696 were not radically different to those that can be estimated from taxation figures in the 1810s, though at 700 000 working in agriculture in 1811 we have estimated a figure somewhat higher than King's half a million in this category.[13]

Figure 3 here

Perhaps more surprising is the high availability of draught power in Sweden and France, around two-fifths of which came from cattle. In France, in the earlier part of the period under consideration, horses were dominant north of a line between the Cotentin peninsula, touching the most northerly point of the Loire then running to the northern edge of Switzerland.[14] To the south, oxen, followed by mules and donkeys, predominated. There seem to be two reasons for this discrepancy with Wrigley's figures. Firstly, Wrigley appears to have underestimated French draught animal power, basing his estimates on back projecting late nineteenth century figures from O'Brien and Keyler. As can be seen draught animal power in France, unusually, was in decline after 1850. Secondly, he used a narrower definition of the labour force to include male labourers only. Our data uses estimates of all labour, both male and female although this is subject to the vagaries of census data, the recording of especially female labour, and the reality of multiple employments. Thus in the more specialised English agriculture, the labour force figures are more likely to accurately reflect actual agricultural employment, while in regions where labourers performed multiple tasks (such as Italy and many parts of Germany). The labour input to agriculture will be overstated by this method in regard to male employment, and labour productivity will appear lower than it really was.[15] The degree of female employment was dependent on the nature of agricultural tasks and opportunities for alternative work. This is an important qualification, as by the twentieth

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[13] King, G., 'The LCC Burns Journal', in Laslett, P., (ed.), *The earliest classics. Works by J.Graunt and G.King,* (1973), p.200. Indeed, given the evidence here, King's figure for agriculture appears much too low, and some of the horses he allocates to other sectors must have been employed on agricultural enterprises.

[14] See Clout, *op.cit.,* pp.102-3; Bouchet, G., *Le Cheval a Paris de 1850 á 1914* (Paris, 1993), p.43.

[15] See O'Brien and Prados de la Escosura, *op.cit.,* pp.516-7. These problems have been resolved by van Zanden by simply taking the entire agriculture-dependent population. Zanden, J.L. van, 'The first green revolution: the growth of production and productivity in European agriculture, 1870-1914', *Economic History Review,* XLIV (1991), pp.218-9. Sources on labour force: for Sweden, data provided by Schön, L. unpublished manuscript, which is an elaboration of Jungenfeldt:: Löneandelen…(need to check with Lennart); for Germany, Helling, G., 'Zur Entwicklung der Produktivität in der deutschen Landwirtschaft im 19. Jahrhundert', *Jahrbuch für Wirtschaftsgeschichte* 1 (1966), p.134; , *** check Tilly, Fremdling; England, from Lee, C.H., *British regional employment statistics 1841-1971* (Cambridge, 1979), pp.****; France, from Toutain, J.-C., *La population de la France de 1700 à 1959* (Paris, 19**), pp.161-3; check Paolo's ****, Ben's source ****; Mar ****.

century, women made up a majority of the agricultural labour force in some regions of Europe.

Overall, there is little evidence of very radical change at any point for most countries in the relation between livestock and human energy inputs. Exceptions are England and Wales in the mid-nineteenth century. This ratio tended to 'improve' in Germany, England and Wales, Sweden and Italy, but fell in France, Spain, and the Netherlands.

3.3 Does size matter?

The working horses in England were large by European standards. Here we investigate whether a modification for size can possibly alter the relative position of England and Wales, and other countries. The size calculations are explained in Appendix B.

Figure 4 here

The results show that England and Wales is still not remarkable by northern European standards at the beginning of the nineteenth century and indeed that France still has a little more energy available, as with the earlier result based on horse equivalents. However, in the long-term the English performance in increasing the draught power at the disposal of each labourer is very marked. Only Germany sustains a similar rate of growth over the nineteenth century, from a much lower base.

4. Substitution or efficiency?

We would like to examine two other possible implications of Wrigley's argument. Firstly, that the increased use of draught animals may increase overall energy inputs, but not provide for a smaller agricultural workforce; alternatively the animals may act as substitutes for human labour. In the English case, it is apparent that the male agricultural labour force was roughly static over a very long period of time reaching back into the seventeenth century, so there was no *direct substitution,* but livestock must have been taking an increasing share of energy inputs during the nineteenth century, and also expanding the overall energy available. To investigate these premises, we first examine the agricultural area per agricultural worker to see if that increased significantly. This can be compared with the agricultural area per draught animal. If both these ratios increase this indicates an economizing on muscle power in general. In section 4.3 we combine the two measures of energy into one and also take the value of output into account; we calculate the energy productivity. This is a final test of whether the benefits of increased draught animals use solely arise from substitution of animal for human energy, or if this is part of a more general trend towards increased energy efficiency.

4.1 Cultivated area per worker and per draught animals

England and Wales were clearly anomalous in the small size of the workforce relative to agricultural land, as shown in figure 5. In 1850, there were 6.2 ha per worker in British agriculture, as opposed to 4.2 ha in France or 3.7 ha in the Netherlands.[16] In fact, there is a very high degree of similarity in among all of the continental nations throughout the nineteenth century in this regard. In other words, variations in the ratio between draught animal power and the labour force are not caused by variations in the intensity of labour inputs to the land. However, from 1860, England and Wales' divergence from the rest of Europe became ever more pronounced.

Figure 5 here

We have already seen that trends in the availability of draught power per hectare were divergent. However, in England and Wales, inputs per hectare from *both* labour and from draught animals were unusually low over the entire period, even though the stocking-rate here improved markedly in the second half of the century, as shown in Figure 6. This may have given rise to the contemporary perception that England had an unusually high stocking rate, when in fact it was marked by unusually low labour inputs. England may, of course, have had a high stocking rate on particular types of farms. In fact, these findings are entirely in line with medieval and early modern historians who have emphasised that a *low* stocking rate of draught animals can be taken as an indicator of agricultural progress.[17] Taken together these trends explain the relationship displayed already in Figures 1 and 2. England and Wales, and the Netherlands are clear leaders in being able to cultivate a large acreage per energy input in 1815, with France and Sweden trailing. By 1870 however these differences have narrowed very considerably. The more prevalent long-term trend is for increased inputs of energy per hectare, excepting France and Spain. However, France, the Netherlands and England have increasingly similar

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16 This reflects in part the persistence of small scale peasant agriculture and owner occupancy throughout much of Europe. See also O'Brien & Prados de la Escoursa, *op.cit.*; O'Brien, 'Path dependency'; van Zanden, 'Green revolution'; Clout, *France,* pp.36-8.

17 Campbell, B.M.S., *English seigniorial agriculture* (Cambridge, 2002), p.****.

energy inputs per hectare, with another group of Germany, Spain and Sweden at a somewhat higher level, while Italy retained a high and increasing level of energy inputs. Long-term changes in energy inputs per hectare were closely related to shifts towards energy inputs from draught animals rather than humans. Indeed, the countries that altered the intensity of energy inputs relatively little – Sweden, France and Spain – were barely able to shift the shares of the energy input that came from humans and draught animals respectively. Thus it is true that energy intensification in agriculture was marked by increased use of draught power.

Figure 6 here

4.2 Energy productivity

We have tested the overall energy productivity by examining the relationship between income to the agricultural sector, and labour and draught animal inputs. The value of output has been measured in constant prices from the years immediately preceding the First World War.[18] Energy productivity is the value added by each unit of energy input. The relationship is expressed in terms of French francs, to permit comparisons between countries. We recognise that there has been a lengthy debate as to the most appropriate way to make such comparisons, and that our method of using trading exchange rates will bias each country's results, both upwards and downwards. However, we do not consider this problem to be of an order of magnitude to fundamentally skew our estimates of levels of output or productivity.[19]

Figures 7 and 8 here

One possible implication of Wrigley's arguments is that increased use of draught power made much greater reserves of energy available to be utilised in agriculture, but that this could well have increased the energy input required per unit of value of agricultural output, or in other words, increased the 'energy intensity' and lowered energy productivity. Of course, taken simply in energy terms, one would expect increased use of animals to produce more usable calories to humans than had previously been the case

[18] Sources for incomes to agricultural sector: for Sweden, Schön, L(?): Jordbruk med binäringar; for Germany, Hoffmann, *op.cit.,* p.****; it should be noted that this includes forestry; England & Wales, from Perren, R., **** with the series then back-projected using Turner et al ****; Toutain cited in Levy-Lebouyer for France ****; need precise nat account reference for Netherlands ****; for Spain, Prados de la Escoura, ****; Italian ref from Paolo, ****.

[19] See the discussion in O'Brien and Prados de la Escosura, *op.cit.,*pp.519-525.

without them, or there would be no point in employing the animals unless one was trying to alter one's diet and forego calories thereby. One might expect however this move to be relatively easy because livestock can consume plant matter than humans cannot, and thus can raise the total energy input into the economy. We have assumed a constant rate of energy consumption by agricultural workers across time and space of 3000 kcal/day. It is of course unlikely that this would be the case, and is an important area for future research.

The results however are clear, as displayed in Figures 7 and 8. Energy productivity seems to rise in the very long-term, but much more markedly so before 1870. Indeed, the 'depression' period sees temporary declines in some countries. Because of the lack of integration of agricultural markets and exchange at the earlier date, we have not attempted to calculate these changes back to 1815 in terms of a standard unit of currency, but simply used an index based on the national value of output in each country's mown currency and calculated according to each country's own output in 1910-3 prices. These results do not invalidate Wrigley and O'Brien's suggestion of the importance of high energy inputs for agricultural success, but certainly complicate matters; it is perhaps not entirely surprising that the manner in which the animals are employed are more significant than their general availability. In other words, organisational and possible technological phenomena are more important than energy *per se*. Horses and oxen may of course be able to use technology to cultivate land far more efficiently than humans.

It is notable that both France and Germany are able to significantly augment their energy productivity over the nineteenth century, despite the fact that they enjoyed markedly variant trends energy inputs per labourer provided by draught animals, and indeed in the share of energy derived from human and animal sources. In other words, substitution of draught for human power was not necessarily a major factor in enhancing productivity. However, increased energy inputs from draught animals may have had an important influence in improving the labour productivity of German agriculture at particular periods. In Germany, we have examined trends in horse numbers across the nineteenth century for Baden and Württemberg in the south-west; Bavaria; the Rhineland; Westphalia; and several Prussian provinces, beginning in the 1810s. The southern region and Westphalia regions saw only modest increases between the Napoleonic age and the

1890s, ranging from only 6 to 27%.[20] The marked rise in German horse numbers after 1870 is almost entirely driven by Prussia, and within Prussia, by the East Elbian territories While all regions of Germany showed slow improvements in agricultural productivity across the century, both the highest levels of productivity, and steepest gains, were also concentrated in the east Elbian regions. Equally, though the East-Elbian share of the agricultural labour force remained virtually unchanged between 1880 and 1909, it increased its share of German root and cereal crop production from 33.5% to 43.4%. In this phase in German agricultural development, the greatest increases in net value added, and labour productivity, came in regions that easily had the highest ratio of draught animal power to human labour inputs, and also saw the largest – indeed, perhaps the only significant – increases in draught animal numbers.[21] We may have found here a model of development that does conform to that hinted at by Wrigley, but nationally, increased labour productivity and a reduced dependence on human labour (from 30% of muscle inputs in 1815 to 19% in 1913) went hand in hand with developments that also increased energy productivity. Draught animals, of course, come as an animal-and-technology package, and thus the increasing importance of draught power may reflect increasing capital intensity in agricultural production, which in turn improves energy efficiency, contributing to higher overall productivity.

England and Wales represents a rather different case. In the long-term, although total energy input was augmented, and came from expanding numbers of draught animals that reduced the share of human muscle input from 23% in 1815 to 10% by 1913, energy productivity remained static. As might be expected in this scenario, labour productivity and the ratio of draught to human power steadily increased. The agricultural labour force continually shrank after around 1860, the male agricultural labour force having possibly peaked as early as 1830,[22] and thus these trends may reflect a period of retrenchment during the depression and an increased setting to work of capital rather than labour intensive forms of investment. However this may only be true of the sector in a very general sense. If we examine trends in the use of horses between the early 1870s and mid-1890s, we find a very considerable variation in trends across counties, displayed in Map 1. Some south-eastern counties are in fact losing draught power, and the increases are highly concentrated in the most industrialised areas of the country: Lancashire,

[20] *Statistik des deustchen Reiches,* Bd.VIII (1874), p.128, passim.
[21] Graunt, O., ****
[22] Wrigley, ****

Cheshire, the West Riding of Yorkshire, Derbyshire, Staffordshire, Durham, and Somerset. Thus while labour shedding primarily occurred in the south and east, additional horsepower was being harnessed in the north and west. There is clearly a very distinct phenomenon occurring here that again we cannot generalise on national level.[23]

Map 1 here

It is also important to note the *levels* of energy productivity pertaining between 1880 and 1913. These were very low in Spain and Sweden; somewhat better in Italy and Germany; a little higher in England and Wales, and France, but clearly best in the Netherlands. The long-term French decline in the application of draught power, and indeed the total energy input, was nevertheless accompanied by a high level of energy productivity after rapid growth in the early years of the twentieth century. England however was the clear leader in *labour* productivity in this period, at a level perhaps double that found in the near continent, as shown in Table 1.[24]

Table 1. Labour Productivity in Agriculture (England & Wales = 100)

Year	*Sweden*	*Germany*	*England & Wales*	*Italy*	*Spain*	*Netherlands*	*France*
1880	37	47	100	26	33	51	50
1890	32	47	100	24	22	41	45
1900	29	48	100	22	16	38	34
1913	42	54	100	28	24	41	43

Source: see notes 15 and 17.

Indeed, French and Dutch labour productivity fell further behind that of England despite high levels of energy productivity, because English energy was increasingly being drawn from livestock. In regard to labour productivity, then, the 'backward' continent, even at this late date, tended to fall further behind the English hare. Mediterranean labour productivity lagged much further behind. We should also note that other comparisons tend to compare the United Kingdom as a whole with its continental neighbours; we have found that disaggregating England and Wales shows agricultural performance here to still have been very far advanced. That such large differences

[23] Parliamentary papers Vols. LXII, LXVIII, LXIX, ****; see also Collins, E.J.T., ed., *The agrarian history of England and Wales. Vol VII, 1850-1914*, (Cambridge, 2001), pp.1800-1805

[24] These calculation are made in 1913 French francs, rather than the more strictly accurate method of calculating PPP ratios.

persisted across the whole of western Europe, however, must reflect profoundly different ecological and thus plant growth conditions, which in part determine the structure of the agricultural economy, as they are not generally linked to the labour intensity of the agricultural sector, the sectoral breakdown of agricultural output, nor its relative dependence on muscle energy from humans or animals.[25] Nevertheless England and the Netherlands had clearly developed agricultural economies where labour *and* energy productivity were very high by the Napoleonic era, while France and Germany's gains in energy productivity were products of the long nineteenth century.

5 Concluding discussion

Let us recall our earlier observations. On the basis of the series assembled here, it seems that we must reject Wrigley's hypothesis that England and Wales had available an unusual amount of energy from draught livestock relative to the labour force in the early nineteenth century. If we factor estimates of changing animal size and use into the equation, these conclusions are not altered. Figure 2 demonstrates that there was a high degree of similarity between England and France in 1815. Rather, England and the Netherlands were marked by both high energy productivity, and a *low* draught animal input per hectare; and England had a low labour input too. Over the nineteenth century, we see quite mixed trends; in some areas a large enhancement in both energy input and energy productivity, in others, actual declines in the use of draught energy that accompanied efficiency improvements; and in others still, rises in input but persistently low energy productivity. For the most part, we see energy inputs per hectare rising, but a still faster rise in energy and labour productivity, especially in the 'trailing' countries. Clearly energy is essential to the agricultural economy: without it, quite simply, no work can be done. Equally, many of the tasks performed within European 'dry' agriculture, especially regarding the cultivation of cereals, such as ploughing and harrowing, generally employed draught animal power, and indeed animal power was relatively more important in the heavy-soiled regions of northern Europe and less important where aridity reduced the extent of cereal cropping in the south. The importance of muscle energy from livestock thus cannot be in dispute. However, it is clear that agricultural development over the long revolutionary period between the Napoleonic and the First World War was not generally the result of either increased energy inputs relative to the output measured by value, nor of a continuous rise in the proportion of energy supplied by livestock as

[25] On the breakdown of agricultural production in 1910, see O'Brien and Prados de la Escosura, *op.cit.,* .525.

opposed to human muscle energy. Trends across Europe are quite disparate, although a generally enhanced importance for draught animals is visible in some countries in the 'depression' period between 1870 and 1900, most markedly in England and Wales. It is likely too that production in terms of calories produced relative to calories input also became more efficient over the period as a whole – in contrast to the general pattern over the twentieth century, though this would bear further investigation.

Appendix A: Number of draught animals

This appendix provides information on the number of draught animals of various kinds that were used in agriculture and the sources and assumptions we have used for our estimates. Tables provide animal numbers in thousands for each country at benchmark dates.

Sweden

Year	*Horses*	*Oxen & Cows*	*Horse Equivalent*
1815	280	278	466
1840	293	319	507
1850	296	333	519
1860	299	352	535
1870	295	344	525
1880	320	378	573
1890	336	367	582
1900	367	348	600
1913	454	275	638

Horses

The total number of horses was reported annually during the nineteenth century by county agricultural societies for each parish and city within its area up until 1916. This information was not reliably updated and it did not tell what use the horses were put to. Large local investigations were performed in 1916, not least to gain information of the number of horses that could be mobilized in case of a Swedish involvement in the World War. The share for horses below 3 years was a rather stable 15-16%. For the year 1901, 4.4% of all horses were used in urban centres (more if only the share of adult horses is calculated).[26] This amount of horses clearly should be deducted from the total horse stock when we estimate the number of horses used for draught in the countryside. The local investigations of 1916 usefully divided the horses into two different uses: workhorses, and riding horses and carriage horses. On average 1916-1918 the workhorses amounted to 53% and the riding and carriage horses 4% of total horses.

[26] BiSOS series Q, Agriculture, 1901.

The procedure for reaching an estimate of agricultural workhorses has been the following:

1. Start with the total number of horses
2. Deduct young horses below 3 years, there is statistics for this, and normally the share is around 15-16%.
3. Deduct horses used in the cities, for transportation and industry. In 1901 this was 4.4%.
4. Deduct riding horses and carriage horses in the countryside. Only part of the 4% that were categorized as riding and carriage horses were used in the cities. Some indication of the proportion of heavy workhorses and light riding horses among the city horses is provided for a few cities in the local investigations. In Malmö 61% were heavy workhorses, but in Filipstad and Luleå there were only working horses. We thus assume that some 3% of the total were riding horses and carriage horses in the countryside.[27]
5. Deduct horses used for military purposes. They were around 2%.[28]
6. Deduct horses in the countryside that were mainly used for transportation and industry. The number of horses used for personal transportation during skjutsväsendet was only around 1 000 - 3 000 horses, i. e. less than 1%. However the total use of horse and oxen time for transportation and industry (work other than agricultural work) has been estimated to be 10% of adult working horses.[29]

In total 20% of the horses above three years were deducted because they were considered used for other work than agricultural.

Comment [e1]: I saw in the excel-file that this is what you did for Sweden, and actually I think it is all right!

Oxen and cows

Oxen and to some degree also cows were used as draught animals in Swedish agriculture. The cow was the poor man's oxen, especially preferred by poor crofters, since it could be used both for milk and for draught power, although the latter could be detrimental to the former. Often two cows were used in a pair, or one ox went in pair with one cow. Sometimes even the crofter's wife went in pair with the cow, mainly to direct the force, which was considered humiliating. This kind of combined harness for a cow and a

[27] ibid.
[28] Kocken, T (1939) Krigshästen från äldsta tider, in Trägårdh, C. et al (eds) *Hästen i Sverige*, Stockholm, Ribbing, O. (1939) Hästen i vår nuvarande armé, in *Hästen i Sverige*, Stockholm, Furugren, B. (1997) Arbetshästen och svensk hästavel, *Arbetshästen under 200 år,* (Eds) Liljewall and Myrdal, BTJ Tryck Lund.
[29] Krantz., O. (1986) Historiska Nationalräkenskaper för Sverige: Transporter och kommunikationer, 1800-1980, Studentlitteratur, Lund.

woman even had a special name: kärringaok.[30] The habit of using cows as draught animals increased along with the number of landless people over the course of the nineteenth century.[31]

Oxen were not used as draught animals their entire lives. This means that the total amount of oxen in the statistics must be reduced to account for those not actually working. One cost advantage with the ox compared to the horse was that the ox had its highest sales value when fattened for slaughter. In especially oxen rich parts of Sweden like Småland a special trade with oxen developed, with far reaching specialization, where some farms took care of the breeding, others took care of the training, others used the draught oxen, and yet other farms with rich fodder availability took care of the final fattening, and then the oxen were sent for slaughtering. On basis of the cycles in this trade we can say that below three years of age the ox was not yet tamed and ready for work. Then the ox worked for roughly four years and then was put to final fattening for 1.5 years and then eventually slaughtered.[32] On the basis of this information it seems reasonable to assume that 50% of all oxen (including the calves) were used for work. In other parts of the country with less specialization and fattening options it is however likely that the oxen worked longer before eventually being slaughtered, so a more reasonable assumption is that 60% of oxen all ages worked. Out of the adult oxen population, which is provided in the statistics, we have assumed that 80% of them worked in agriculture. For Swedish cows we assume the same proportion used for draft purpose as in Germany (see below).

[30] Sigvardsson, S (1991) : Oxen, Växjö: ToreSäll InfoMedia, p 21, 73
[31] Olaus Magnus, 1976, p 5.
[32] Sigvardsson, S. (1991), p 22., Peterson, G. Häst eller oxe, in Liljewall and Myrdal (eds), 1997, *Arbetshästen under 200 år*, , p 46-47.

Germany

Year	*Horses*	*Oxen & Cows*	*Horse Equivalent*
1815	1656	1924	2945
1840	1796	2143	3232
1850	1868	2095	3272
1860	2193	2178	3652
1870	2319	2122	3741
1880	2187	2080	3581
1890	2522	2164	3972
1900	2895	1970	4215
1913	3145	2210	4626

Horses

Surveys of horse numbers in the German states occurred intermittently from the 1810s onward. Nearly every state produced comprehensive surveys in the early 1860s, and from 1873 truly national surveys of livestock were conducted.[33] *These took place in 1883, 1892, 1900, and with increasingly regularity until becoming annual after 1912. It should also be noted that data on donkeys and mules also survives, but these were too insignificant in number to be included in the analysis. All of the national surveys provide data on horses either used 'predominately in agriculture', or from the 1890s, explicitly those used for the preparation of the soil.*[34] *In the case of the first category, statisticians acknowledged that this could only be an estimate of actual use, but they expressed the hope that the time spent by these horses doing non-agricultural tasks balanced out by non-agricultural horses that do occasional agricultural work.*[35] *After 1873 the time series is based on this data with interpolations for the missing years. The entire time series relates to the territory of the German Reich to within its 1873 borders (i.e., including Alsace-Lorraine).*

Before 1873 no direct data on horses working in agriculture exists, and estimates must be made of both the total number of horses, and then the numbers of these employed in agriculture. Contemporary statisticians noted problems with inconsistencies in the counting of livestock between different surveys, concerning, for example, whether very young animals were included, and what time of year the survey was taken in (winter surveys will produce a minimum for all species, and all national surveys were taken in December or early January). However, the spread of local surveys provides almost complete national coverage for the years around 1861, and have been homogenized into one data set placed in that year. Decadal, and sometimes for frequent, surveys of total horse numbers survive for all large German states beginning in the 1810s. These show a consistent upward trend with only a small standard deviation, and so a national trend has been back-projected from 1861 taking the arithmetic mean of the proportional change of horse numbers in these states (largely provinces of Prussia, Baden, Württemberg and

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33 *Statistik des deutschen Reiches*, Bd.VIII (1874)
34 *Statistisches Jahrbuch des deutschen Reiches* (1881, 1883, 1884, 1887, 1893, 1894, 1898, 1899, 1900, 1902, 1904, 1905, 1907, ****)
35 *Statistik des deutschen Reiches*, Bd.VIII (1874), p.105.

Bavaria) between the 1810s and 1861.[36] *This implies a rise in horse numbers of some 35% between 1815 and 1861. In 1873, 70% of all horses (including foals) were employed in agriculture; a very similar figure to the 69% found in the 1890s, although there was a slight dip in the intervening years. It has been assumed that this proportion remained constant over the nineteenth century, which implies in turn that over 80% of German horses over the age of three were used in agriculture. It is unlikely that this figure could have been very much higher, even in Napoleonic times.*[37]

Oxen and cows

Oxen numbers were recorded on a national basis from the survey of 1873 onward, and were also included in surveys of livestock by individual states reaching back to the 1810s (see above). However, there is far greater variation in local trend than is the case with horses, and lack of consistency in the years in when data was collected does not allow the back projection of a national trend with frequent benchmark dates. However, data from all major states in the 1810s has been aggregated into two regions, a 'northern' and 'southern', where the constituent units had similar oxen-holding characteristics. These two regions had similar oxen population sizes in 1873. A lineal trend was then back-projected between 1873 and the 1815 for each region, including those areas lacking data in the earlier period, and combined into a national trend. It appears that the oxen population at these two dates was very nearly identical, although this is a product of quite divergent trends with numbers falling in northern Germany and increasing in the south.

In 1873 statisticians tackling the problem of how to categorise their use assumed that all oxen over the age of two were used for draught purposes. This assumption is undoubtedly an exaggeration. Indeed, it was noted at the time that there was some variation in the proportion of oxen recorded as having been used for draught in the previous year. In the very small state of Brunswick, only 66% of oxen were used for draught purposes; in Baden, 83%. Here it has been assumed that 80% of oxen and steers over two years old were used for draught purposes.[38]

Cows had a fairly prominent role as draught animals in some regions, largely those with high numbers of smallholdings and industrial activity. In evaluating their power input, contemporary statisticians valued a cow at one third of an ox, taking into account size, speed and duration of work provided.[39] *The number of cows used for cultivation was recorded explicitly in 1873 and can be calculated indirectly from data provided in the 1890s. The proportion of total cows so employed was very stable between these two dates, shifting from 10.6% to 10.2%. It is assumed that before 1873 this proportion is constant (which possibly overstates their use, as smallholdings proliferated with partible inheritance in some regions of western Germany), and that after 1895 the proportion of total cattle made up by cows used for draught power declined at the same rate as the proportion of total cattle made up by oxen used for draught power (thus falling to 8.7% by 1914).*[40]

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[36] *ibid*., p.128, passim.
[37] *ibid.,* p.128, passim; *Statistisches Jahrbuch des deutschen Reiches* (1881, 1887, 1899).
[38] *Statistik des deutschen Reiches*, Bd.VIII (1874), pp.104-5.
[39] *ibid.,* p.106; Thaer, A.D., *The principles of agriculture,* trans. Shaw, W., & Johnson, C.W., (London, 1844 [1810-2]), pp.67-8.
[40] *Statistik des deutschen Reiches*, Bd.VIII (1874), p.128, passim; *Statistisches Jahrbuch des deutschen Reiches* (1899, 1905, 1915).

England and Wales

Year	*Horses*	*Horse Equivalent*
1815	700	700
1840	720	720
1850	812	812
1860	807	807
1870	802	802
1880	840	840
1890	892	892
1900	925	925
1913	808	808

From 1873 the annual Agricultural Statistics recorded numbers of on-farm horses used for agricultural purposes. Before this date, only some local surveys of total horse numbers in 1854, along with incomplete tax data from the 1810 and 20s, is available. Scrutiny of this data suggests that Collins' estimate of 700 000 horses being used in husbandry in 1810 is accurate. Some 737 000 horses and mules were taxed for use in husbandry in 1821. Assessors did however note in 1819 that distinguishing horses in husbandry was difficult and that many were used for multiple tasks. Scaling up data on total horse numbers from thirteen counties for 1854 and assuming the proportion of the total employed in agriculture is the same as that estimated by Thompson for 1870 suggests that some 812 000 horses were employed in agriculture in that year. Intervening years before 1873 have been interpolated from these estimates. [41]

A few oxen were employed for draught power in the early nineteenth century, and debate persisted as to the relative merits of oxen and horses as providers of draught power. Burke records oxen as being the main providers of draught power in four western English counties early in the century, in an area that in the late 1860s held a tenth of the stock of English agricultural horses. Horses soon superseded these oxen. A survey of contemporary literature (especially the Reports to the Board of Agriculture) suggests that otherwise oxen input to total draught muscle power was negligible. They have not been included in our analysis. [42]

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41 Thompson, F.M.L., 'Nineteenth-century horse sense', *Economic History Review* 29 (1976), pp.60-81; Mingay, G.E., ed., *The agrarian history of England and Wales. Vol VI: 1750-1850,* (Cambridge, 1989), p.****; Collins, E.J.T., ed., *The agrarian history of England and Wales. Vol VII, 1850-1914,* (Cambridge, 2001), pp.1779-1806; Collins, E.J.T., 'Power availability and agricultural productivity in England and Wales, 1840-1939', in Bavel, B. van, & Thoen, E., eds, *Land productivity and agro-systems in the North Sea area, Middle Ages – 20th century. Elements for comparison* (Turnhout, 1999), pp.209-225; *Parliamentary Papers* 1805.LX, pp.721-2; 1816.I, pp.453-4; 1819.XV, pp.423-5; 1821.XVI, pp.323, 335; 1869.LXII, pp.52-60; 1870.LXVIII, pp.60-64; 1871, LXIX, pp.60-68; Mitchell, B.R., *International historical statistics: Europe 1750-1988* (London, 1988), p.365.

42 See Burke, J.F., *British husbandry; exhibiting the farming practice in various parts of the United Kingdom. Volume 1* (London, 1834), ****; Marshall, W., *Rural economy of the west of England. Volume 1* (London, 1970 [1796]), p.116, 238-9, 288, 293; for one example of the usage of oxen for ploughing and the debates on this subject, see Young, A., *General view of the agriculture of Oxfordshire* (London, 1813), pp.229, 287-90.

France

Year	Horses	Oxen	Donkeys	Mules	Horse Equivalents
1815	1560	1702	312	275	3078
1840	1778	1550	326	294	3218
1850	1816	1584	363	320	3317
1860	1715	1535	304	252	3096
1870	1499	1486	300	264	2857
1880	1431	1436	286	252	2740
1890	1322	1387	264	233	2571
1900	1539	1342	308	271	2811
1913	1708	535	288	154	2316

Horses, donkeys and mules

French agricultural statistics provide regular surveys of all livestock from 1867 onward. Before this date surveys were taken in the late 1830s, 1851 and 1862.[43] *Early in the century, total horse numbers have been derived taken from Montalivent, who made estimates in 1812. Some of these surveys (1851 and 1890) also provided estimates of horses employed for draught power in agriculture, when the proportion of total adult horses employed in agriculture was 72% and 53% respectively. In the 1840s, Mounier considered around two-thirds of horses reaching working age (over three) to have been used for husbandry. For the earliest dates, numerous agronomists provided estimates of the numbers of horses working in agriculture in the eighteenth and early nineteenth century, although the principles underlying these estimates are not always clear. We have used the estimate of Lavoisier (1791) despite its early date, on the assumption that numbers remained relatively static over the Revolutionary period. Lavoisier made an estimate of the horses employed to cultivate in certain acreages in different regions of France and scaled these up to a national estimate on the basis of land surveys. This gives an estimate of 76% of adult horses being used in agriculture (assuming that, as in 1840, around 13% of the horse population were foals), a figure consistent with what might be expected from later trends in this figure, as well as comparable estimates for other nations.*[44] *For intervening years the trends in the proportion of total horses working in agriculture has been lineally interpolated. Between 1890 and 1914 the proportion of total adult horses in agriculture is assumed to have remained static.*

The number of donkeys in toto*, and mules employed in agriculture, is recorded in surveys of 1840, 1862 and 1914.*[45] *It has been assumed that 80% of donkeys were used for draught power in agriculture. As the figure for the total number of donkeys*

[43] Gayot, E., *Atlas statistique de la production des chevaux en France. Documents pour servir a l'histoire naturelle-agricole des races chevalines du pays* (Paris, 1851); Royer, C.E., *Notes économiques sur l'administration des richesses et al statistique agricole de la France* (Paris, 1843); *Parliamentary papers*, 1866.LXX, p.241; Toutain, J.-C., *Le produit de l'agriculture française de 1700 à 1958: I. Estimation du produit au XVIIIe siècle* (Paris, 1961), p.154.
[44] Monier, M.L., *De l'agriculture en France d'après les document officials* (Paris, 1846), p.354; Lavoisier, *Statistique agricole et projets réformes* (Paris, [1791]), p.132.
[45] See note 19.

approximates steadily to around 25% of the number of horses employed in agriculture, donkey numbers for intervening years have been calculated on this basis. For years where no data for mules is available, it has been calculated that total mule numbers are equivalent to 22% of the number of horses working in agriculture, the proportion found in years with comparable data; and that 80% of those mules are employed for draught power. This presumes that nearly all adult mules and donkeys were employed in some way in agriculture, though many in the south would have also been used for transport.

Oxen

Oxen numbers were recorded in the surveys noted above, and previous estimates of oxen working in agriculture have been provided by J.-C. Toutain for 1850, 1890 and 1913.[46] *These appear to be reliable and have been followed here. For intervening benchmark dates numbers have simply been linearly interpolated. For the start of the nineteenth century, we have employed estimates collected by Chaptal on the basis of local statistical surveys.*[47] *Although his figure for working oxen is significantly lower than that provided by other agronomists of the revolutionary period, it is far more in line with all later estimates and on what seems likely on the basis of cross-national comparison.*

Italy

Year	Horses	Oxen	Mules	Donkeys	Horse Equivalents
1860	401	1351	236	472	1399
1870	384	1376	226	452	1377
1880	453	1452	267	666	1592
1890	480	1660	282	564	1693
1900	516	1762	303	607	1810
1913	669	2038	393	787	2237

Horses, mules and donkeys

National statistics provide figures for total numbers of horses, mules and donkeys from 1861 onwards. These have been adjusted by deducting 15% for foals, and a further 20% for horses used in non-agricultural purposes. It has further been assumed that 80% of donkeys and mules are used for draught power in agriculture.

Oxen and cows

The numbers of oxen have been calculated on the basis of national statistics from 1930 that record 29% of all bovine animals being employed for draught power across the period. Each bovine animal is treated as two-thirds of an ox for 'horse equivalent'

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[46] See note 19.

[47] Chaptal, J., *De l'industrie française* (Paris, 1819), ****.

and energy calculations. This rests on the assumption that roughly half of draught cattle are oxen, and half are cows, and that a cow is equivalent to a third of an ox. The beasts were both extensively used and might be yoked together.[48]

<u>Spain</u>

Year	Horses	Oxen	Mules	Donkeys	Horse Equivalents
1870	435	928	861	1038	2055
1880	360	886	792	958	1866
1890	284	843	767	878	1719
1900	322	801	741	798	1686
1913	378	847	709	694	1696

<u>Horses, mules and donkeys</u>

National statistics provide figures for total numbers of horses from surveys conducted in 1865, 1880, 1890, 1900, and 1910. A deduction of 15% from the number of was made to account for foals, although in the statistics collected this proportion has varied historically between 21% and 10%. It is assumed that 85% of the adult horses are used for agricultural draught work, thus a little higher proportion than in Sweden and Germany. Data on mules and donkeys was collected in 1865 and 1910, with intervening benchmark years linearly interpolated. It is assumed that 80% of mules and donkeys are used for draught power.[49]

<u>Oxen and cows</u>

Data was collected from the national statistical surveys mentioned above. These figures assume that 40% of all bovine animals were employed for draught power. This is based on the actual number of working animals as a proportion of all bovines recorded in 1965.[50] *As with Italy, each bovine animal is treated as two-thirds of an ox for 'horse equivalent' and energy calculations. This rests on the assumption that roughly half of draught cattle are oxen, and half are cows, and that a cow is equivalent to a third of an ox.*

<u>Portugal</u>

Year	Horses	Mules	Donkeys	Oxen	Cows	Horse Equivalents
1870	40	21	128	249	107	293

<u>Horses, mules and donkeys</u>

[48] Colman, H., The agriculture and rural economy of France, Belgium, Holland and Switzerland; from personal observation (London, 1848), p.273; Pallavicini, A., Del cavallo in Italia (Napoli, 1867), pp.30-45.
[49] Barciela López, C., Giráldez Rivero, J., Grupo De Estudios De Historia Rural, López Ortiz, I., 'Sector Agrario y Pesca', *Estadísticas Históricas de España, siglos XIX-XX*, forthcoming, Cuadro 4.25.
[50] ****

Data for 1850 specify number of mules, horses and donkeys.[51] *For 1870 government statistics give fairly detailed accounts on animals for all different purpose in Portugal.*[52] *No statistics are available for our other benchmark dates for Portugal. Since the 1870 data is obviously much better specified than the 1850 data, and things are not likely to have changed much between these two points in time, we simply employ the 1870 data.*

Oxen and cows

For 1850 only the total number of bovine animals is provided, but 1870 the number of working cows is given in the statistics.

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[51] Justino, D., (1988), A formação do espaço económico nacional. Portugal 1810-1913. Vol I . Quadro 2.1, p.57; Relatório do Ministério dos Negócios do reino apresentdo às Câmaras legislativas em 30 de Junho de 1852, Dec. 29. -for 1851; AHMOP, DGCAM, Ra, 3S, Mç 9; **** what do these sources mean?

[52] Ministério das Obras Públicas, Comércio e Indústria- Recenseamento geral dos gados no Continente em Portugal, 1870, Imprensa Nacional 1875.

Appendix B: Animal size and energy

The method of calculating draught animals in terms of horse-equivalents is rather crude, although employed by German statisticians in the nineteenth century. One ox equals two-thirds of a horse, one donkey is one-half of an ox, and one cow is one-third of an ox.[53] Animals are of the same size and power in different countries and do not change over time. This is certainly a simplification. We know for instance that England and Wales had relatively large working horses. Sidney in 1875 writes: 'It is in England that the cart-horse like every other kind of live stock valuable in agriculture, has attained the greatest average perfection, because the principles of breeding have been more carefully considered by our farmers than in any other country, and also because it is the country where, as compared with the rest of Europe the roads are good, the farmers are rich and the landowners lead the way in every stock-breeding improvement.' A similar testimony was given by a Pehrson, a Swede, about the same time.[54] Thus it may be that England actually had larger access to muscle power than the sheer numbers indicate. But it is also likely that other countries caught up with them over time due to imports of cold blooded working stallions and cross-breeding with their domestic smaller working horses. In south-western France and Spain, the asses were very tall compared to the British donkey, reaching a height of 14 hands (140 cm). The draught mules in Britain and Spain could reach a height of 16-17 hands and be very strong.[55] In southern Europe and the Mediterranean region the donkey and mule were favoured above the horse for agricultural work, and often were harnessed together with an ox. In these regions mules and donkeys may generally have been larger than their northern European counterparts that were not much used for draught power.[56] These kinds of problem call for an attempt to modify our results by taking actual fodder inputs to oxen, horses, mules and donkeys into account, and furthermore accounting for change over time and variation in space. An additional reason for doing so is that it enables aggregation of all muscle energy, both from humans and from draught animals. Human muscle energy applied to

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[53] *Statistik des deutschen Reiches*, VIII, (1874), p.105.

[54] Sidney, S. (1875) T*he book of the horse: saddle and harness, British and foreign*, Cassell Petter and Galpin, London, p 276; Pehrsson, O. (1873): *Om hästkulturen I Normandiet jemte några anteckningar under en resa på kontinenten och i England*, p 38.

[55] Sidney, S., op.cit., *pp 285-286*; Lefour, Inspectuer de l'agriculture, *Le cheval, l'ane at le mullet. Extérieur, races, élevage, entretien, utilisation, equitation, etc.* (Paris, 1872), p.166.

[56] Clutton-Brock, J. (1992): *Horse power: a history of the horse and the donkey in human societies*, Natural History Museum Publications, London, p 155.

agriculture could be calculated as the energy value of the food intake by the agricultural labourers.

From the human perspective draught animals can be regarded as living machines that convert chemical energy into motive energy. The chemical energy is the energy of the fodder they consume.[57] The motive energy is to a large extent employed for human purposes, for instance when the draught animals are harnessed to a plough or a carriage. All fodder consumed by the animal, as well as the energy needed for rest, is from the human perspective a necessary cost for the draught work of the animal. The fodder consumed in a workday is dependent on the size of the animal and how hard they worked. Fodder requirements for a day at rest are simply dependent on the size of the animal. To calculate the primary energy of the fodder consumed by draught animals there is thus a need for information on the numbers of draught animals, how many days they worked during one year and how much they ate when they worked and when they rested. It is very difficult to find reliable information on the number of workdays, so we refrain from taking number of workdays into account. Instead we apply the simple formula for primary energy consumption by draught animals of equation (1):

$E_i = H_{t_t} * Hf_t + C_t * Cf_t + D_t * Df_t$

Where:

(1)

E_t = primary energy of the fodder intake by draught animals (in year t)

H = number of horses and mules

C = number of cattle (oxen and sometimes also cows)

D = number of donkeys

Hf = average fodder intake by the horses

Cf = average fodder intake by the oxen

Df = average fodder intake by the donkeys

In order to aggregate all the fodder by animals it is necessary to have some way of estimating the energy content of the fodder. This is provided by agronomy handbooks and can be expressed in terms of fodder units. The fodder unit equals the digestible

57 Malanima, P., *Energia e crescita nell'Europa preindustriale* (Rome, 1996), pp.71-89.

energy content of 1 kg barley.[58] One kilogram of barley contains 2 800 Kcal useful energy and approximately 3 000 Kcal digestible energy. This means that we can go from fodder units to calories, and we choose the digestible energy content, i. e. 3 000 Kcal per fodder unit. Animals of different size require different amounts of fodder units. Swedish agronomist Hansson provides feed recommendations for oxen and horses weighing 500 kg, which are summarized in table B.1:[59]

Table B.1: Fodder units per day for oxen and horses (500 kg beasts)

	Ox (Fodder units per day)	*Horse (Fodder units per day)*
Subsistence feed	*3.3*	*4.5*
Easy work	*6.0*	*6-7*
Average work	*7.0*	*7-8.5*
Hard work	*8.0*	*8.5-10.0*
Very hard work	*9.0*	*10+*

We assume, as did several nineteenth century agronomists, that fodder requirements increase proportionally to weight of the animals, and that for simplicity they work averagely hard all days of the year, which gives us the basis for our modelling shown in Table B.2.[60] In reality of course the animals rested, the number of rest days may have differed among our countries, and in addition the animals may have worked harder in some countries than in others during days they actually worked. Unfortunately we have nothing to back up such conjectures with, and we have not attempted to model this.

Table B.2 Fodder units per day in relation to size of the animal

Weight Ox per working day **Horse per working day**

[58] Hansson, N.(1928), *Husdjurens utfodring. Dess teoretiska grunder och ekonomiska genomförande*, Stockholm, pp. 25, 43.

[59] Hansson, N., *op.cit.*, p.235; Larsson, S.(1945): *Husdjurslära, del 2, Husdjurens utfodring och vård*, Stockholm, p 42. 30% of the gross energy in the fodder is not digestible; it simply passes through the body. The remaining 70% is called digestible energy. 61% of the gross energy is useful energy and 9% ends up as urine and methane. 1 kcal = 4190 joule.

[60] Hansson, N., *op.cit.*, pp.25, 43; Petit, P., *Nutrition et Production des animaux boeuf, cheval, mouton, porc*, (Paris, 1892), pp.182, 246; Oldenburg, F., *Anleitung zur Pferdezucht im landwirtschaftlichen Betriebe* (Berlin, 1901), p.129; Nobis, R., *Was hat der Landwirth zu beobachten und zu thun, um seine Pferde, Rinder, Schafe und Schweine gegen Krankheit zu schützen?* (Danzig, 1861), p.39.

270 kg	3.8	4.2
300 kg	4.2	4.7
350 kg	4.9	5.4
375 kg	5.2	5.8
400 kg	5.6	6.2
450 kg	6.3	7.0
500 kg	7.0	7.8
550 kg	7.7	8.4
600 kg		9
700 kg		10.9
750 kg		11.6
800 kg		12.5

It has not been possible to find much information on fodder for donkeys or mules. We have thus simply assumed that mules consume as much fodder as their relatives the horses in those countries, and that one donkey consumes three-quarters of the fodder for one horse in southern Europe. In order to estimate the actual amount of fodder units consumed by the draught animals of each country we need some information about the average size of the beasts and of the size development over time. We have not, however attempted to account for further influences, such as the maintenance of 'training horses' that were not fully employed in commercial agriculture until a relatively advanced age, or the lesser work performed by pregnant mares.[61] Below, we discuss the sources from each country that have formed the basis for our modelling of size development. These comprise a mixture of occasional estimates of weight of horses, statistical data on animal size collected by government survey, and fodder inputs either described or recommended by agronomists, or recorded by some transport companies. It should be stressed that information is scarce and that our estimates must remain conjectural.

England and Wales

The cold-blooded English horses were of four primary types. The London Dray-horse (used solely in breweries and thus not treated here), the Shire horse, the Clydesdale and the Suffolk Punch. The bulkiest and heaviest was the Shire, standing at least 16 hands high (160 cm) and found in the shires where the strongest class of plough horses are

[61] Collins, E.J.T., 'Power availability and agricultural productivity in England and Wales, 1840-1939', in Bavel, B.J.P., & Thoen, E., (eds), *Land productivity and agro-systems in the North Sea area, Middle Ages – 20th century. Elements for comparison* (Turnhout, 1999), p.217; also Thaer, A.D., *The principles of agriculture,* trans. Shaw, W., & Johnson, C.W., (London, 1844 [1810-2]), pp.78-9.

required.[62] By the twentieth century the Shires were the most widespread draft horses of England, and could occasionally weigh as much as 1000 kg in 1915.[63] The Clydesdale is of Scotch and Dutch origin and stallions could weigh nearly a ton, but was still only 16 hands 1 inch high (163 cm). The average weight of Clydesdales that were exported to the United States was 900 kg.[64] The Suffolk Punch reached from 15 hands 3 inches to 16 hands, and was excellent for plough teams, but less suitable for transport or drawing timber. It was not all that heavy; according to the American Suffolk Horse Association it should weigh 680-725 kg. Occasionally the Suffolk Punch could reach well over three quarters of a ton.[65] The Suffolk Punch was more widely employed during the nineteenth century. In the early twentieth century English horses varied in size from about 500 kg to enormous beasts of a tonne that were generally used in urban breweries. Heavy agricultural horses weighed about 850 kg, lighter ones generally about 700 kg. According to authorities of the 1910s, size increases had been quite dramatic since about 1880, when stud-books had first been kept and horse breeding societies founded, but the power output had increased even more than the weight because of physiological changes. Chivers estimated that around 70% of agricultural horses were heavy horses in the early twentieth century, suggesting that the average weight for an adult draught horse was around 800 kg.[66] Judging by the fodder inputs gathered by Burke from a little less than a century earlier, agricultural draught horses weighed 5-600 kg, though colliery and dray horses could be much larger.[67]

Germany

There were several kinds of cold-blooded workhorses in Germany,[68] out of which the Reinisch-deutsche was the heaviest and tallest at around 170 cm. It could be used for work at the age 3 and was worn out at the age 14, resembling the Percheron and the Ardenner; others, such as the Schleswiger or Norische were smaller, lighter, or both.[69] Several agronomists provided details of the fodder intake of horses from the late eighteenth century onward, and it appears that the race of horse was never a strong consideration in this literature, or at least was not considered worthy of comment. These

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62 Sidney, S., *op.cit.*, p.268; see also Collins, *op.cit.,* p.216; Philip-Fox, C. (1987) *Horses in Harness*, Reiman Associates, Greendale, USA, p.154.
63 Hart, E. (1994) *Heavy horses - an anthology*, Alan Sutton Publishing Limited, Gloucestershire, pp.38, 43.
64 Sidney, *op.cit.,* p.269; Philip-Fox, C. *op.cit.*, p.154.
65 Sidney, *op.cit.*, p 270; Philip-Fox, C. *op.cit.*, p.152; Hart, E. *op.cit.,* p 5.
66 Collins, *op.cit.,* pp.216-7; Lewis, C.A., 'Irish horse breeding and the Irish draught horse, 1917-1978', *Agricultural History Review,* 31 (1983), p.37.
67 Burke, J.F., *British husbandry; exhibiting the farming practice in various parts of the United Kingdom. Volume 1* (London, 1834), pp.127, 139-142.
68 Papavassiliou, F. *Liebenswerte Riesen: die schönen Kaltblutpferde Europas*, Wiesbaden 1988.
69 Kruger, W. (1939) *Unser Pferd und seine Vorfahren*, Verlag von Julius Springer, Berlin, pp.52-7.

figures suggest weights of 5-600 kg for most of the century.[70] National statistics provide slaughter weights of horses from 1906, when live weights appear to be only a little over 400 kg, though probably for aged stock.[71] There is rather more direct data in the case of oxen. Slaughter weights of adult male cattle are provided by a number of sources across the century, and from 1883 there is comprehensive statistical data that was collected at state (*Land)* and a national level, when the national average for oxen and steers over two years of age was 466 kg. This figure varied from as little as 369 kg in Westphalia to 625 kg in Berlin (the latter doubtless largely consisting of cattle fattened for consumption).[72]

Comment [e2]: Do these sources actually mention weight, or just fodder amounts? If it is the latter I think it should be spelled out, and how you made the estimates from fodder to weight and the uncertainties in such assumptions depending on for instance how hard they worked.

Comment [e3]: What is your assumption about the relation slaughter weight to live weight here?

France

The Percheron was to become the most prominent domestic cold-blooded breed of horse in France, though in practice many cross- and local hybrids predominated. Boulonnais, Poitevin, Breton and Comtois were specified in Lefour's work of 1872; the famous Ardenner tended to be used for transportation.[73] The Percheron originated in the provinces Beauce and Perche and was first mentioned in the early nineteenth century, after which it steadily gained in popularity. The demand grew faster than the supply and as a consequence some smaller horses from Brittany were crossed with these and sold as Percheron horses, and so the quality of the horse deteriorated and exports had almost ceased in the 1870s, but then recovered again.[74] By 1936 Pecherons in the United States, that imported considerable numbers from both the continent and Britain, could reach 16-17 hands for mares, and 16.5 -17 hands for stallions. Stallions weighed 900-1000 kg.[75] However, for the period under consideration agricultural horses were clearly much smaller than this. Both the extensive figures on weight and fodder intake provided by Parisian transport companies for their horses in the 1870s, and agronomist works up to as late as the 1890s, suggest weights ranging from 420 kg to 560 kg.[76] Estimates of horse

Comment [e4]: How were these weights reached? Actually suggested or is it something you have estimated based on fodder? You should not hide how you did the estimates, I think they are fine, but tell about them explicitly!

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[70] Hartmann, Georg, *Die Pferde und Maulthierzucht* (Stuttgart, 1777), pp.248-9; Thaer, *op.cit.,* pp.80-1; Reider, Jacob Ernst von, *Lehrbuch der deutschen Landwirtschaft nach eigenem Systeme* (Leipzig, 1933 [1819]), pp.281-3; Oldenburg, *op.cit.,* p.129; Nobis, *op.cit.,* pp.42-5; Löbe, W.**,** *Anleitung zum rationellen betriebe der Pferdezucht und Pferdehaltung* (Berlin, 1862), pp.49-53.
[71] *Statistisches Jahrbuch des deutschen Reiches* (1927), p.66.
[72] Busch, W., *Die Leistungssteigerung der deutschen Landwirtschaft seit 1800* (Berlin, 1941), p.41; Schremmer, E., 'Faktoren, die den Fortschritt in der deutschen Landwirtschaft im 19. Jahrhundert bestimmten', *Zeitschrift für Agrargeschichte und Agrarsoziologie* 36, (1988), p.52; *Statistisches Jahrbuch des deutschen Reiches,* 1889, p.21.
[73] Lefour, *op.cit.,* p.87.
[74] Pehrsson, O. (1873), *op.cit.,* p.16.
[75] Philip-Fox, C. (1987) *op.cit.,* p.152.
[76] Colman, H., *The agriculture and rural economy of France, Belgium, Holland and Switzerland; from personal observation* (London, 1848), p.277; Lefour, *op.cit.*, p.114; Bixio, M., *De l'alimentation des chevaux dans les grandes écuries industrielles, 5 ans d'expérience sur une cavalerie de 10.000 chevaux* (Paris, 1878); Lavalard, E., *Le cheval dan ses rapports avec l'economie rurale et les industries de transport. Vol.1* (Paris, 1888), pp.201-64; Petit, *op.cit.*, pp.246-8; Bouchet, Ghislaine, *Le Cheval a Paris de 1850 á 1914* (Paris, 1993), pp.204-13.

weight provided by Lavalard for the 1870s and early 1880s are only a little over 400 kg, but this is blamed on there being very many young animals after losses in the Franco-Prussian war.[77] As early as the 1840s extensive estimates were made of cattle weight, the averages being 413 kg (gross) and 245 kg (net), but regional variations were large, with more than double the weight in some regions as compared to others. In Eure-et-Loire net weight was 324 kg, in Cantal 320 kg, in Nord 318 kg and in Loire 315 kg. In the southern provinces cattle were very small indeed: Corsica 112 kg, Finistère 136 kg, Ille-et-Vilaine 147 kg; but also in Marne only 160 kg.[78]

Sweden

The breeding of horses and cattle, where domestic breeds were crossed with foreign kinds, became common during the nineteenth century in Sweden, which increased the size of the animals. The normal Swedish rural horse in the early nineteenth century was around 150 cm. The earliest breeding by means of imported stallions mainly benefited the army; the agricultural horses remained largely unaffected. Only from the mid-nineteenth century did demand for stronger working horses in agriculture grew and heavy cold-blooded horses were imported from abroad. The Norwegian horse, the Scottish Clydesdale, the English Shire, the French Percheron and the Austrian Pinzgauern were tried, but these initial cross-breeding attempts were generally not very successful.[79] Most successful was cross-breading with the Norwegian horse, which developed into a new kind: The North Swedish horse, which got its name in 1901. Breeding of Clydesdales continued for a while but never became widespread. Only with the import of the first Belgian Ardenner horse in the 1870s did a really successful cross-breading start, which eventually made the Swedish Ardenner horse the dominant country horse in most of Sweden. Around the turn of the century larger Ardenner horses were imported and affected the size development of Swedish agricultural horses: the average height was 165 cm in the 1920s, and they were substantially broader and stronger than the original Swedish agricultural horses. Horse breeding was mainly designed to provide strong working horses. Cattle-breeding was devoted to increased beef and milk

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[77] Lavalard, *op.cit.,* Vol 2, pp.28, 225.

[78] Royer, C.E., *Notes économiques sur l'administration des richesses et al statistique agricole de la France*,(Paris, 1843), pp.90-1. Ratios between gross and net (or live and dead weight) appear to have varied quite considerably in Europe. In England the standard was 14:8, but according to some authors might be 2:1. Turner, M., Beckett, J., & Afton, B., *Farm production in England 1700-1914* (Oxford, 2001), p.181; Kjelleström, J. (1896) *Vad är oxen värd? Och vad kostar köttet?,* p 11: Average animals leave 46-48% of their live weight, half-fat animals leave 48-52% of live weight as slaughter weight and really fat animals leave 52-60%.

[79] Dyrendahl, S. (1988) *Från arbetshäst till sport-och rekreationshäst*, Kungliga Skogs- och Lantbruksakademiens tidskrift, Supplement 20; Furugren, B. (1997) *Arbetshästen och svensk hästavel*, in (eds), Liljewall, B and J. Myrdal: *Arbetshästen under 200 år*, Nordiska museets förlag, BTJ Lund.

production. Cattle or horses are not likely to have grown stronger and bigger during the first half of the nineteenth century, when the horse was still smaller than an ox.[80] It seems reasonable in the Swedish case to believe that the size figures given Hansson´s book on fodder recommendation for 1920s were relevant then, and that means that we assume an average size for horses of 550 kg in 1913 and 500 kg for oxen. Additional support for this assumption is provided by Johansson's statement that the average body weight for fully-grown Ayrshire cows was 587 kg.[81]

The Netherlands

The Netherlands was very early in developing heavy cold-blooded horses, one of which was the Frisian. In the eighteenth century average height was around 150 cm, and probably rose during the late eighteenth and early nineteenth century boom years in agriculture. Later, the Frisian horse lost market share, largely to Belgian imports and Oldenburgian horses. The mountain Ardenner, as in France, was seen as a little small for heavy agricultural work. Although a specific breed and although they lost market share, the size evolution of Frisians is probably representative for the whole, and it is not clear that they developed much in height over the duration of the period under consideration.[82] Still the body mass of agricultural horses is likely to have increased just like in the other countries.

Comment [e5]: I am not sure the Frisian was a cold-blooded horse, are you? We could ask Ben! I rather got the impression that this was a slimmer warm blooded horse, but I may be wrong…

Comment [e6]: There were one kind of Ardenner that was not so big and strong, the mountain Ardenner, but there was another one that was bigger and better!

Portugal[83]

Slaughter weights from Portuguese cities around 1900 give the following figures for weights in kilograms:

Horses	Mules	Donkeys	Bovines
267	264	136	298

For cattle, data stretches somewhat further back in time:

	Porto	Lisboa

[80] Support for the idea that cattle, especially in the south, grew bigger from the mid 1850s is given by the price of milk and beef in relation to the price of cows, which clearly shows that the cows became more expensive in relation to beef or milk. This indicates more productive animals in terms of meat and milk, and thus larger animals. See Kander (2002), *Economic growth, energy consumption and CO_2 emissions in Sweden 1800-2000*, p.177; Furugren, B (1997) *op.cit.*, p.132.

[81] Johansson, Karl-Ivar, *De svenska nötkreatursrasernas kroppsutveckling och produktion*, meddelande Ulltuna nr 38, (Uppsala, 1928).

[82] ****

[83] ****

1870-1874		221,5
1875-1879		223,9
1880-1884		233,8
1885-1889	223,1	242,2
1890-1894	234,1	249,3
1895-1899	233,3	248,9
1900-1904	240,3	255
1905-1909	242,8	252,4

Net weights in Europe varied between half and two-thirds of live weight.[84] In Lisbon there was an increase in slaughter weight by 15 % over 30 years, and perhaps as much as 50% over the century.

European comparisons

We do not have sufficient data to allow a very complicated and detailed modelling. However, there appears to have been a relative ranking of horses. Based on data on height – though this very obviously does not allow a simple translation into weight - and breed, we have assumed that the Netherlands and England had horses of equivalent size. France and Germany showed similar size and trend; southern German horses were probably small, and equally southern French horses, that showed the greatest gains in numbers during the late nineteenth century, were also smaller than their northern counterparts. Sweden began with rather smaller horses in the early nineteenth century but caught up later. Portugal, Spain and Italy, were undoubtedly at a lower level, but we can make little more than educated guesses. Data is rather better for oxen, where France, Germany and Sweden appear to have had very similar sized animals; again, the Mediterranean and Iberian breeds were rather smaller. We have attempted to stay close to the actual weights provided in the text above for specific countries and dates, but have rounded these off for simplicity. It is impossible of course to make such estimates with great exactitude for particular years. To calculate the rest of our benchmarks, we simply use linear interpolation.

Table B.3 Assumed average weights of animals

[84] See note 24.

	Ox			Horse			Donkey
	1815	*1870*	*1914*	*1815*	*1870*	*1914*	
England	na	na	Na	500	700	800	na
Holland	na	na	Na	500	700	800	na
France	400	450	500	450	500	550	na
Germany	400	450	500	450	500	550	na
Sweden	400	450	500	400	450	550	na
Portugal	300	350	400	350	400	500	350
Spain	300	350	400	350	400	500	350
Italy	300	350	400	350	400	500	350

Figure 1 Horse equivalents

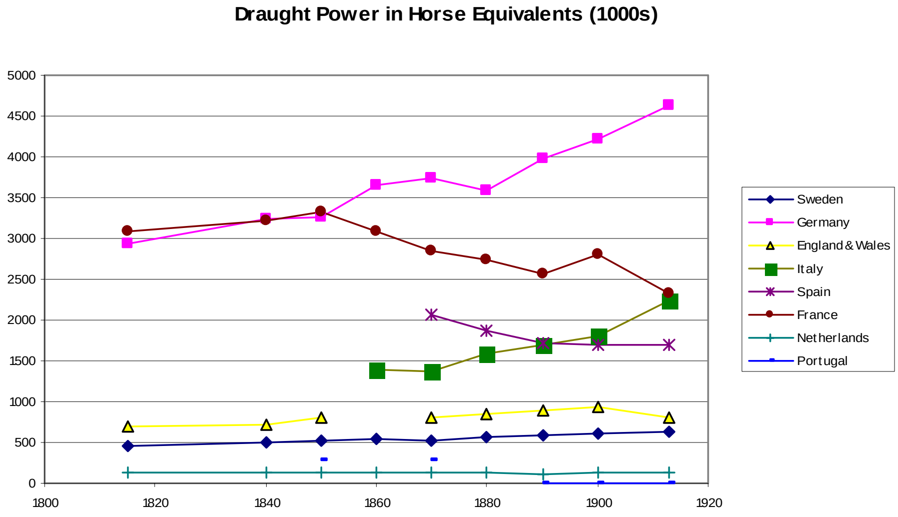


Figure 2 Horse equivalents per hectare

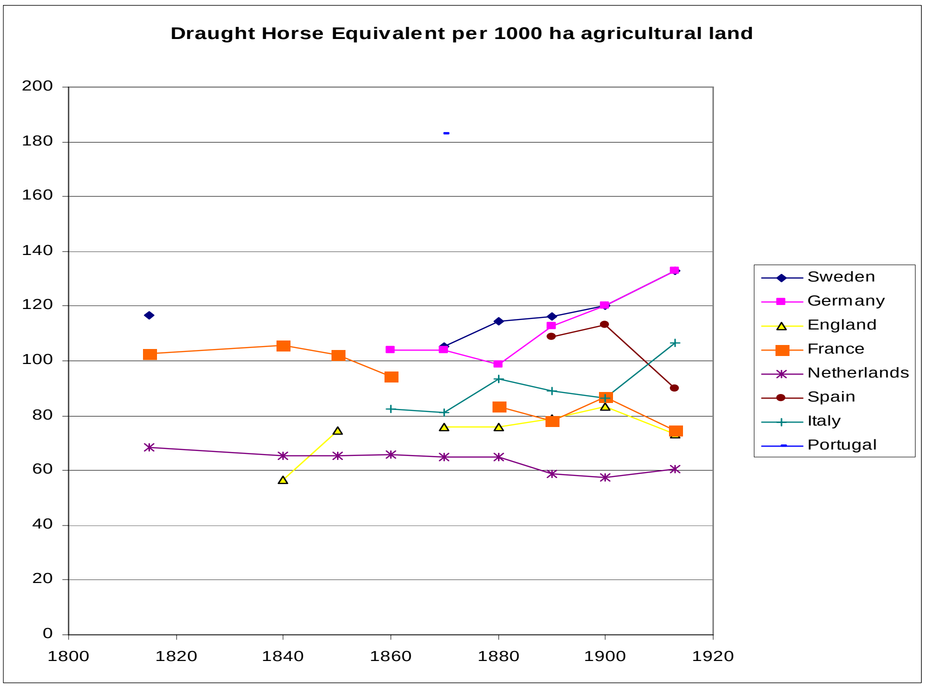


Figure 3 Horse equivalents per labourer

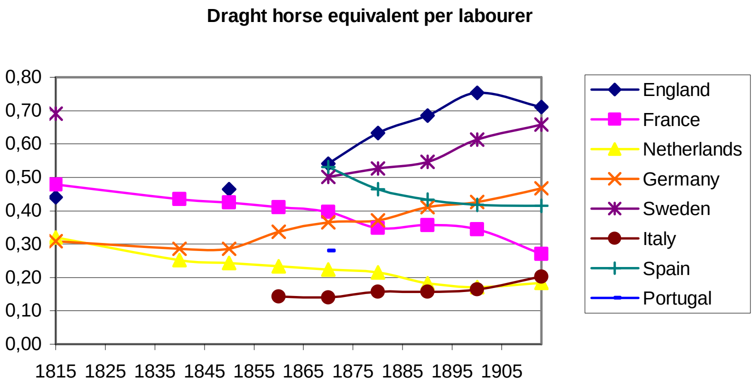
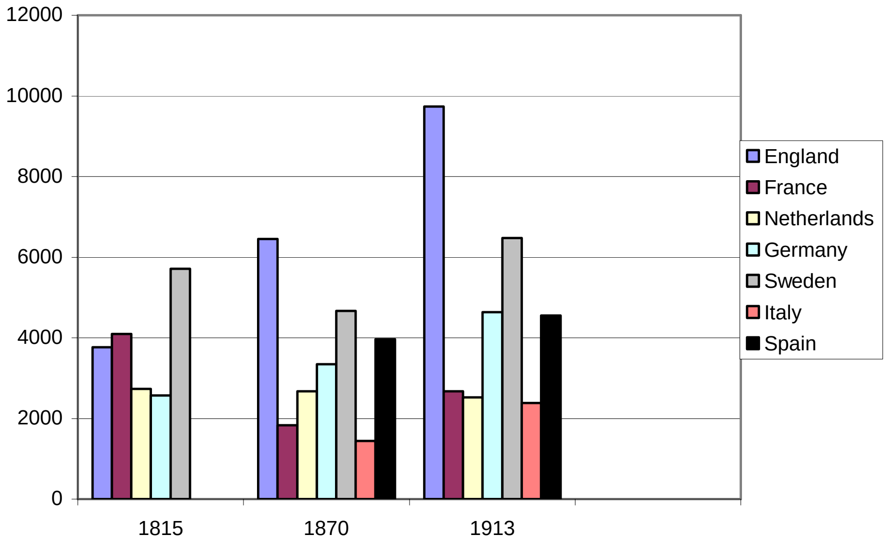


Figure 4 Draught energy per labourer, Gcal/labourer



Comment: When calculated according to changing animal fodder intake.

Figure 5 Hectare per worker

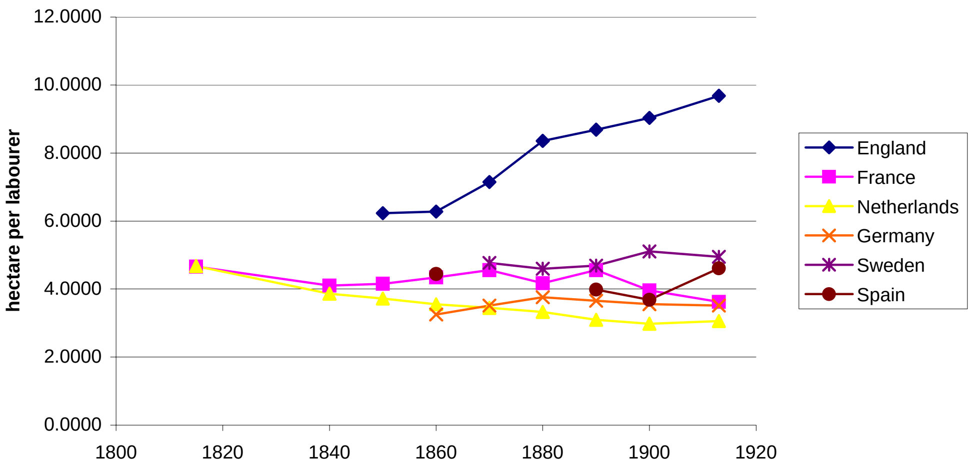
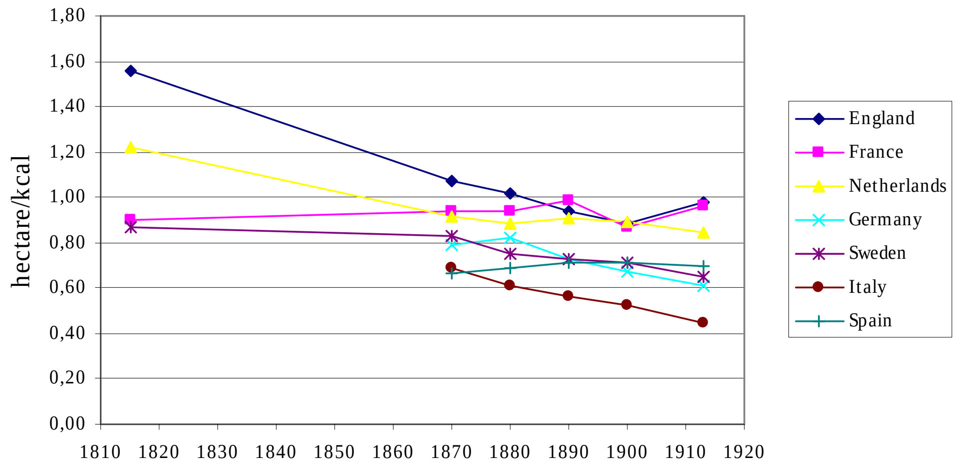


Figure 6 Cultivated Ha per kcal from humans and draught animals



Comment: both humans and draught animals are included

Figure 7. Muscle energy productivity

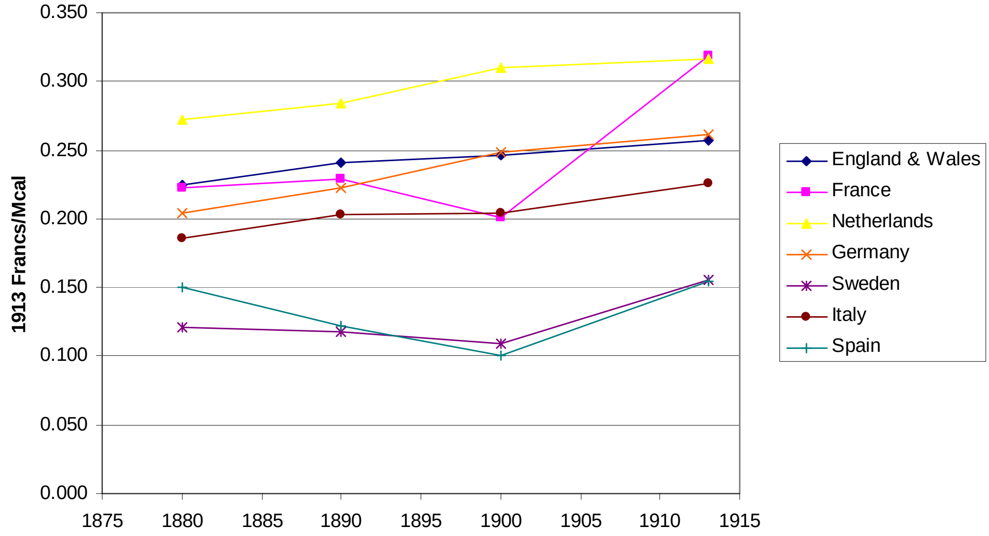


Figure 8. Muscle energy productivity index (1913=1)