WHAT'S SPACE GOT TO DO WITH IT?

DISTANCE AND AGRICULTURAL PRODUCTIVITY BEFORE THE RAILWAY AGE

George Grantham
McGill University
May, 2010

Abstract

This paper argues that the conventional Malthusian account of pre-modern economies as constrained by diminishing returns resulting from a fixed land supplied is flawed because it does not recognize the importance of systematic indivisibilities in the production and distribution of farm produce that supported increasing return to additional inputs when the demand price of produce warranted them. Those indivisibilities locked in low-intensity farming practices in places where the demand for produce was diffuse. Most of pre-industrial Europe was in that situation, so average agricultural productivity was low. It was only in regions where urban concentrations of consumers aggregated demand to a level capable of inducing extra investment to exploit latent returns to scale in farming and transportation that the productivity of traditional mixed farming achieved its full potential.

What's Space Got to Do with It? Distance and Agricultural Productivity Before the Railway Age

To most economists the defining characteristic of the pre-industrial economy was the fixed extent of Ricardo's 'original indestructible powers of the soil,' or what Von Thünen prosaically termed *der Boden en sich.* From that territorial inelasticity Ricardo deduced the principle of diminishing return, which together with Malthus's demographic hypothesis underpinned the classical proposition that in the absence of technological change, an economy converges to a steady state in which the a real wage is just sufficient to ensure reproduction of the labour force. Ricardo's proposition is a central element of recent unified growth theories that attempt to explain the early nineteenth-century transition from a land-constrained economy to one constrained by labour and capital by an equilibrium growth path shocked by accelerated technological change, population growth, and changing preferences toward work and saving.[1] The evidentiary basis for this stylization, which for Ricardo was plain economic logic, comes mainly from wage and price series showing a rise in nominal wages relative to the price of consumption goods following the Black Death in 1348 followed by declining real wages in the sixteenth and early seventeenth century when population was growing.[2] Hansen and Prescott's interpretation sums up the conventional wisdom.

> 'The behavior of the English economy from the second half of the thirteenth century to nearly 1800 is well described by the Malthusian model. ...During this period there was a large exogenous shock, the Black Death, which reduced population significantly below trend for an extended period of time. This dip ....was accompanied by an increase in the real wage. Once population began to recover, the real wage fell.[3]

A second piece of evidence for a land-constrained economy is the negative correlation between land rent and real wages. To quote Hansen and Prescott again, 'When population was falling in the first half of the sample, land rents fell. When population increased, land rents also increased.'[4]

A critical presumption of this stylized account is that the esscape from Malthus's trap required new agricultural technology. According to conventional wisdom, that new technology was embodied in

---

[1] E. g., Galor and Weil, 'Population, technology and growth'; Hansen and Prescott, 'Malthus to Solow'; Clark, *Farewell to alms.*
[2] For a review of these series, see Van Zanden, 'Wages and the standard of living'
[3] Hansen and Prescott, 'Malthus to Solow,' 1207.
[4] *Ibid.*

nitrogen-fixing forage legumes that between 1650 and 1800 that provided breathing space for the economy to expand through the initial phase of industrialization to 1840, when development of mineral fertilizers and the colonization of new farming territories overseas effectively eliminated the land constraint.[5] This land-augmenting innovation was supported by increases in farm size and consolidation of scattered holdings that raised the productivity of agricultural workers, thereby relieving the labour constraint on the expansion of non-agricultural production.[6] Agricultural innovation, then, was a necessary, though not sufficient condition for the great industrial transition.

Searching for an Agricultural Revolution

The problem with this account is none of the technical and institutional innovations it rests on were in fact new.[7] Eric Kerridge pointed out long ago that

> 'of the conventional criteria of the agricultural revolution, the spread of the Norfolk four-course system belongs to the realms of mythology; the supersession of oxen by horses is hardly better; the enclosure of common fields by Act of Parliament, a broken yardstick; the improvement of implements, inconsiderable and inconclusive; the replacement of bare fallow, unrealistic; developments in stock-breeding, over-rated; and drainage alone seems a valid criterion. The failure of historians to locate the agricultural revolution has thus arisen, in part at least, from mistaken notions of what form an agricultural revolution could have taken.'[8]

What Kerridge says about England was equally true of other partss of Europe. Clover, sainfoin, and alfalfa were widely cultivated in classical antiquity arouind the Mediterranean, and it is possible that under Roman rule they made their way northward together with the grapevine.[9] Although the forage legumes were abandoned in the early middle ages, they were replaced by pulses in the twelfth and thirteenth century by pulses, which were extensively sown advanced farming districts in northern France and England in arable rotations dominated by wheat.[10]

---

[5] Wrigley, 'Transition to an advanced organic economy'; Chorley, 'Agricultural revolution'; Overton, *Agricultural revolution;* Allen, 'Tracking the Agricultural Revolution'

[6] Allen, 'Two English agricultural revolutions'; Crafts, 'British economic growth'

[7] Grantham, 'In search of an agricultural revolution'

[8] Kerridge, *Agricultural revolution*, 39.

[9] Zohary and Heller, *The genus* Trifolium; Abrosoli, *The wild and the sown.* White clover is indigenous to northern Europe. Northward diffusion of red clover depended on the presence the long-tongued bumblebee as its specialized pollinator. Simmonds, *Evolution of crop plants,* 176-77.

[10] Campbell, 'Diffusion of vetches'; Fossier, *La terre et les hommes,* 427-429 ; Verhulst, 'Intensification et commercialisation.' The presence of vetch is recorded as early as 820 at Saint-Amand, but is absent from other Carolingian texts, which suggests that it had not yet acquired its role as an integral part of three-course rotations. Derville, *Agriculture du nord,* 52.

Nor were large compact farms novel. While the present state of research on Roman Gaul does not permit reconstitution of the large farms of northern Gaul, references in Carolingian polyptiques to fiscal domains that probably descended from them suggests their presence in antiquity. Many formed the core of the huge demesne farms of the thirteenth and early fourteenth centuries.[11] For example, around 1250 the Cistercian grange at Vaulerent, situated a couple of dozen kilometres east of Paris, contained 380 hectares (950 acres) and included plots ranging up to 80 hectares.[12] While it was probably Europe's largest farm, Vaulerent was not unique. Two of 51 Artesian holdings possessed by the bishop of Arras in the 1320s covered 280 and 367 hectares, respectively and a third had nearly 100.[13] Eighteenth-century English tenant farms were no larger.[14] Although medieval operations on this scale were exceptional (and would be for centuries), 40 to 75 hectare farms were common in the districts of 'high farming' that provisioned large cities. As in the early industrial era, large compact holdings were the most efficient way of growing tradable surpluses.[15] That efficiency rested on the labour saved by making extensive use of horses in cultivation.[16] High yields were obtained by plowing the land intensively and by sowing a significant proportion of the 'fallow' in nitrogen-fixing pulses. These practices were common in districts possessing good commercial outlets for grain, and foreshadowed the key features of the seventeenth- and eighteenth-century agricultural revolution.

Probably the most astonishing feature of these farms is that their productivity was probably as high as high as that of progressive farms in the eighteenth and early nineteenth century. To be sure, the average yield in 1300 was probably in the neighborhood of 10 hectolitres per hectare (approximately 12 bushels per acre),[17] but in districts of high farming yields commonly exceeded that average by 50 to 100 percent.[18] In 1281-1282 the Abbey of Saint-Denis' demesne farm on the outskirts of Paris at Gennevilliers reported wheat yields of 21 to 25 hectolitres.[19] Normal yields at Vaulerent probably exceeded 20

[11] Magnou-Nortier, 'Trois approches de la question du manse'
[12] Higounet, *Grange de Vaulerent,* 32-37.
[13] Derville, *Agriculture du nord,* 153, 161 ; Richard, 'Thierry d'Hireçon'.
[14] Allen, *Enclosure and the yeoman,* 215-216
[15] Fourquin, *Campagnes parisiennes,* 97; Derville, *Agriculture du nord,* 73.
[16] Contamine, 'Le cheval dans l'économie rurale'
[17] Slicher van Bath, 'Yield of different crops;' Wrigley, 'Transition to an advanced organic economy;' Campbell and Overton, 'Statistics of production'.
[18] For a compilation of yields in northern France, see Béaur, 'From the North Sea to Berry'
[19] Fourquin, 'Les débuts du fermage,' 30.

hectolitres, since the initial lease in 1315 stipulated that the tenants owed no rent if they yield fell below 15 hectolitres.[20] Campbell's ventilation of English manorial accounts reveals that demesne farmers in southern England commonly made yields of 17 to 18 hectolitres.[21] The highest yields are reported from Artois and districts adjoining Flanders, where yields of 25 hectolitres were common and at least one location possibly reached 35 hectolitres, which is near the upper bound for traditional varieties of wheat.[22] The evidence on labour productivity is naturally thinner, as there was no reason to record it. The rising share of the urban populations of Flanders and Tuscany between 1100 and 1300 nevertheless implies a significant improvement.[23] Karakacili's painstaking analysis of the corvée labour accounts from manors belonging to Ramsay Abbey provides the only direct estimate of labour inputs for wheat under medieval conditions. Her study indicates that on well-managed operations labour productivity in the early fourteenth century was as high as in the late eighteenth.[24] For what it is worth, Clark's imputation of productivity trends from agricultural wages and prices is consistent with that finding.[25]

That yields and labour productivity on some farms in the thirteenth century might have equalled that of late eighteenth-century England suggests that from a purely technological standpoint, the Malthusian trap was not binding, which implies the medieval and early modern economy could have supported a larger population and higher levels of specialization than it actually did.[26] When Slicher van Bath uncovered evidence of high cereal yields in the Low Countries antedating the introduction of clover and other legumes, it came as a shock. 'We are so used to connecting the yields in the early modern period with the New Husbandry that it is a novel view to state the contrary.'[27] But if high yields were accessible before the agricultural revolution why was the technology that supported them not more widely exploited? If the knowledge were a free or almost free good, why didn't the best practices diffuse more quickly and more widely? More significantly, why after having exploited techniques of advanced organic husbandry

[20] Since the farmers had to cover outlays and provide a cushion for risk, the expected yield would have been at least 33 percent higher. Higounet, *Grange de Vaulerent,* 52.
[21] Campbell, *English seigniorial agriculture.*
[22] Richard, 'Thierry d'Hireçon, agriculteur artésien' ; Derville, *Agriculture du nord,* 157-60. Morineau, 'Les Taques d'Onnaing '; Derville, 'Dîmes, rendements,' 1418-1419. The upper bound was due to increased susceptibility to lodging in plants subject to heavy dressings of organic manure..
[23] Persson, 'Labour productivity'
[24] Karakacili, 'English agrarian labor productivity'
[25] Clark, 'Long march of history,' and more generally, *Farewell to alms.*
[26] For estimates, see Grantham, 'Divisions of labour'
[27] Slicher van Bath, 'Rise of intensive husbandry,' 142.

for two hundred years did farmers subsequently abandon them? For, the exceptional instances of high productivity in the early fourteenth century were no longer to be found a hundred years later.[28] Marxist historians attribute that failure to the persistence of 'feudal' social and economic structures.[29] But the chronology does not hold. The most progressive farms in the thirteenth century were under the direct administration of 'feudal' religious establishments and survived the late medieval crash as 'capitalist' leaseholds which, in spite of their 'modern' organizational form, abandoned the advanced organic husbandry.[30] Recovery was indeed associated with 'capitalism', but it was the capitalism of the urbanizing Low Countries, not the countryside, that brought it on.[31]

Distance and the Land Constraint

To get a handle on why the spread of highly productive forms of traditional husbandry was so uneven and impermanent, we need to reconsider the land constraint. To classical economists, that constraint stems from the fixed supply of land. Yet the relevant area is in fact not fixed, but can be altered by improvement and neglect, and by changes in relative prices that make worthless land valuable and valuable land worthless. Nothing, however, can alter the distance between two points, which as Marshall cryptically observed, is 'the foundation of much that is most interesting and most difficult in economic science.'[32] Adam Smith showed how distance influenced the extent of the market for commodities differing in bulk and perishability.[33] Following up that insight, Von Thünen demonstrated how it affects the spatial pattern of agricultural production. Postulating a homogeneous agricultural region within which labour and capital are perfectly mobile and produce sold at a central point, Von Thünen reasoned that t farmers' optimizing responses to commodity-specific production and transport costs would generate a series of concentric rings of specialized production.[34] Since the spatial sorting is an efficient allocation of the mobile inputs, factor productivity is everywhere the same. A person uninformed of this proposition, however, would tend to suppose that the inner rings are more productive because they produce more output

[28] Campbell and Overton, 'A new perspective'; Campbell and Overton, 'Statistics of production'; Morineau, 'Taques d'Onnaing.'
[29] Brenner, 'Agrarian class structure'; Bois, *Crisis of feudalism.*
[30] Grantham, 'French agriculture, 1250-1500'
[31] Tits-Dieuaide, 'Évolution des techniques agricoles'; Vandervalle, 'Stabilité et perfection'; Van Bavel, 'Elements in the transition of the rural economy'
[32] Marshall, *Principles of economics*, 121. For an analytical treatment of these intriguing difficulties, see Fujita, Krugman, and Venables, *Spatial Economy.*
[33] Smith, *Wealthy of Nations,* chapter 10, and the 'Digression on Silver.'
[34] Von Thünen, *Isolated state*

per hectare. This was the view of eighteenth-century reformers, whose association of intensive mixed husbandry with agricultural progress has inspired the conventional wisdom that departures from 'advanced organic' agriculture were a sign of backwardness. Yet early nineteenth-century observers in France reported that in peripheral districts where grain yields were abysmally low (and to judge from the height of conscripts the inhabitants were undernourished), when it came to livestock husbandry the peasants were on the technological frontier.[35] How could they be so progressive in one branch of mixed farming and so backward in the other? Von Thünen's paradigm provides a partial answer. Their cash crop was not grain, which was costly to transport, but cattle that transported themselves to their markets.

Economic historians have frequently noted theositive spatial correlation between urbanization, degrees of commercialization, and agricultural productivity.[36] The causal links supporting that correlation, however, are far from obvious. In particular, they are not fully described by an aggregate production function with urbanization as one of its arguments. This is not because urbanization had no effect on productivity. The difficulty is that the link between urbanization and agricultural productivity was a product of a changing balance between centripetal forces originating in urban demand for farm produce and the centrifugal attraction of a land-intensive production function. The centripetal force raised productivity, the centrifugal force depressed it. The remainder of this essay is devoted to defending this hypothesis. The defence is organized in four parts. The first takes up the question whether the urban population was independent of agricultural productivity in the urban hinterland. The second analyzes factors tending to raise total factor productivity in agriculture around major cities. The third analyzes how dispersion tended to depress it. The final section briefly considers whether early modern increases in agricultural productivity are attributable to exogenous improvement in transportation. The main conclusion of this examination is that the primary exogenous factor affecting agricultural productivity in the pre-modern world was urban demand.

Agricultural Productivity and City Size

To defend this proposition we must first establish that a city's population was not constrained *ex ante* by the productivity of its agricultural hinterland. I have investigated this question using a simple

[35] Mulliez, 'Du blé, "mal nécessaire"'; Le Roy Ladurie and Demonet, *Anthropologie du conscrit français*
[36] Most recently by Allen, 'Progress and poverty.'

accounting identity that exploits extant information on pre-modern crop yields, labour productivity, the proportion of land in subsistence crops, and per capita food consumption.[37] Imagine a self-sufficient district with a city situated at its center. For a given set of production and consumption parameters, we can compute the smallest self-sufficient territory capable of supplying steady-state subsistence for a city of specified size and its provisioning zone.[38] We can compare that territory with the smallest territory capable of covering the city's annual demographic deficit, on the assumption that rural population density is determined by the first exercise and the overall demographic balance by pre-determined urban and rural rates of natural increase.[39] If the food supply zone is smaller than the area of the demographic supply zone, the level of agricultural productivity cannot be a binding constraint on city size. The details of the construction are set out in Appendix A. Table A-1 shows the provisioning radii for urban agglomerations of 5,000 to 600,000 for yields ranging between eight and twenty hectoliters per hectare at an average labour input of 6 man days per hectoliter. An important implication of the computed radii is that at an average regional yield of 16 hectoliters, which was clearly within the capacity of traditional husbandry, the provisioning radius for cities up to 400,000 is less than 50 kilometers. This was approximately the outer limit for direct delivery by farmers using their own teams and wagons, beyond which they would have had to employ the services of middlemen.[40] The 50-kilometer radius thus defines the region of the urban effects considered in the following section.

How does this zone compare with the size of the demographic basin? De Vries has observed that no pre-industrial region succeeded in maintaining urbanization rates exceeding 35 percent.[41] The main reason was a highly negative rate of natural increase that exhausted the available rural demographic surplus. I have replicated his model of urban-rural demographic equilibrium for case in which the wholly agricultural rural population is determined by a labour input coefficient of 8 man days per hectolitre and a proportion of land in cereals of 12.5 percent. These parameters impart an upward bias to the provisioning space and the rural population as compared with the figures reported in Table A-1. Consider an implausibly low yield of 10 hectolitres. The provisioning space for a town of 10,000 would be 984 square

[37] The following discussion is drawn from Grantham, 'Espaces privilégiés.'
[38] The exercise assumes that input and consumption coefficients are fixed. Allowing substitution on both sides of the market would of course strengthen the conclusions offered below.
[39] On the parameters determining the demographic space, see Devries, *European urbanization*, 221-233.
[40] Grantham, 'Espaces privilégiées,' 712-714.
[41] Devries, *European urbanization*, 224-231

kilometres and contain a farming population of 9,587.[42] Using De Vries's estimates of pre-industrial urban and rural rates of natural decrease (-1.05 and 0.5 percent, respectively), the combined rural and urban population generates an annual demographic deficit of 52 persons or -0.5 percent, which implies that while the territory is self-sufficient in food, it is not self-sufficient in people. For yields greater than 12 hectolitres, the demographic constraint dominates the subsistence constraint for all plausible urban and rural rates of natural increase. From a technological perspective, it was not low agricultural productivity that set the upper bound to the size of urban agglomerations, but a negative urban natural rate of increase.[43] Most cities could procure subsistence from their immediate hinterland. What that hinterland could not supply were enough immigrants to offset the demographic deficit. It is curious, though perhaps only coincidental, that the resolution of the demographic problem through improved housings, sewage systems and water supply occurred simultaneously with improvements in transport eliminating many of the agricultural rents of proximity.

Adam Smith was possibly the first economists to notice that urbanization and improved farming seemed to go together.

> 'Compare the cultivation of lands in the neighborhood of any considerable town, with that of those which lie at some distance from it, and you will easily satisfy yourself how much the country is benefitted by the commerce of the town.[44]

He hedged this observation by restricting it to 'considerable' towns, the space of effective urban demand for produce in small agglomerations being too contracted to confer agricultural benefits from proximity. This is probably why the weak statistical correlation between agricultural productivity and urban growth in a small sample of early modern French provincial towns is so weak.[45] It also explains why average productivity was so low in the eighteenth century. As of 1800 only 10 percent of Europe's population resided in towns greater than 10,000 and only three percent in cities exceeding 100,000.[46] The bulk of Europe's agricultural production was situated in low-productive places.

Agglomeration and Agricultural Productivity

---

[42] I assume a full-time rural manufacturing population of zero.
[43] The negative urban natural rate of increase reflects both low fertility due to low marriage rates and an unbalanced ex ratio, and high mortality. For a review of the evidence and the arguments, see Devries, *European urbanization,* Chapter 9.
[44] Smith, *Wealth of Nations,* 357.
[45] Hoffman, *Growth in a traditional society,* 173-75.
[46] Devries, *European urbanization,* 36-48.

We must now investigate how urbanization raised agricultural productivity. Before turning to those consequences, however, we need briefly to consider the economic causes of pre-industrial urbanization. Prior to the industrial revolution physical concentration of people for economic purposes was a product of economies of scale in trade, finance, government administration, and certain branches of handicraft manufacturing involving close coordination of skilled workers. Most of these economies are attributable to reductions in transaction cost achieved by market pooling of specialized inputs, financial instruments, and expensive equipment, which was facilitated by bringing people physically close together.[47] Such economies bulked large in a world characterized by costly transport and intermittent communications.[48] Pre-industrial urbanization thus differed fundamentally from its later industrial manifestations (often superimposed on older centers), which grew out of the low cost of producing goods at strategic nodes in high-volume transport networks and at sites possessing privileged access to coal or water power.[49] Pre-industrial towns were by contrast products of network economies, although once a city crossed a (high) threshold it attracted manufactures serving its own population. In the words an early modern historian, London 'fed on itself as much as it fed on the country.'[50]

The extent of early modern market network economies is clearly visible in the expanding zone of high urban potential in the North Sea core between 1600 and 1750.[51] Devries observes that

> 'Around 1600 a large-city-biased but very widespread urban growth suddenly gave way to an era in which many cities declined while growth came to be concentrated rigorously in a small number of northern cities. In the mid- to late-eighteenth century this pattern of growth yielded in favour of a small-city-biased growth.'[52]

Rooted in market externalities, the pre-modern mega-city was hostage to the extent of its market, and given the low average level of agricultural productivity an extensive market was also a spatially extended one. The European economy could therefore support few large cities. In the eighteenth century these came down to three major centers: Paris, London, and the Dutch Randstadt, each of which held agglomerated

---

[47] The classic exposition of these points is book IV of Marshall's *Principles.* For a succinct summary, see Krugman, *Geography and trade* For modern examples of these factors, see Scott, *Metropolis.* See also Sabel and Zeitlin, 'Historical alternatives to mass production.'
[48] Parker, 'Communication techniques and social organization'; Smith, 'Function of commercial centers'.
[49] Hoover, *Location of economic activity;* Parker, 'Europe-centered development'
[50] Patten, *English towns,* 184.
[51] Devries, *European urbanization,* 160-166.
[52] Devries, *European urbanization,* 107.

populations exceeding half a million.[53] It was here that the impact of urbanization on agricultural productivity was strongest. The exception was Naples, whose population in the late eighteenth century was probably 350 to 400 thousand, but whose hinterland remained agriculturally backward. Situated on the Mediterranean periphery of the early modern economy, its regional and international commercial functions were increasingly handled by foreigners. More importantly for agriculture was the fact that importation of foodstuffs from the surrounding countryside was in the hands of a monopsonistic cartel operating under municipal license that deprived local farmers the rents from their proximity to customers.[54] The positive effects of urbanization considered below thus rested on the ability of farmers to reap those rents.

The Rings of Von Thünen

In demonstrating how competition for the right to exploit particular sites causes systems of husbandry to segregate into distinct of bands centred on the point of final demand, Von Thünen purpose was to show that, contrary to the conventional wisdom of his day, there is no absolute 'best' system of farming. What is best depends on distance. That agronomical focus is usually overlooked, in part because the English translation of *Die isolierte Staat* omits the voluminous and frankly tedious material deployed in support of his contention, which was inspired by an agricultural accounting system devised by the German agronomist Albrecht Thaer, of whom Von Thünen wrote, 'Adam Smith taught me political economy, Thaer scientific farming.'[55] Thaer's place in the history of agricultural science rests on his humus theory of plant nutrition, according to which the quantity of an enigmatic life-giving substance he called 'humus' determines soil fertility.[56] He attempted to track the stocks and flows of 'humus' by measuring the quantity of plant and animal matter in the soil under different systems of cultivation, and organized this material in a double-entry accounting system that credited its sources and debiting the uses.[57] Not surprisingly, these exercises in 'Agricultural Statics' showed that intensive methods of cultivation generate the most 'humus,' from which it seemed to follow that systems of intensive husbandry were objectively the 'best.' Von

[53] Devries, *European urbanization,* 121-142.
[54] Marin, 'Naples: Capital of the Enlightenment'
[55] Von Thünen, *Isolated state*, 225. In 1803 Von Thünen visited the farm at Celle where Thaer conducted his experiments in comparative husbandry.
[56] Fussell, *Crop nutrition*; Franz and Haushofer, *Grosse Landwirte.*
[57]Thaer, *Grundsätze der rationellen Landwirtschaft* Despite its quantitative structure, Thaer's Agricultural Statics was scientifically useless; 'humus' has no natural unit. The notion of a fertility balance sheet was finally implemented by Liebig, whose new techniques of organic analysis made it possible to reformulate it in terms of measurable chemical elements. Partington, *History of chemistry*, vol. 3, 237-39. See also Krohn and Schafer, 'Origins and structure of agricultural chemistry".

Thünen challenged that proposition on the grounds that the economic viability of different husbandry systems endogenous to their distance from points of final demand. Using data from his estate in Mecklenburg, he found that while the local form of 'advanced' husbandry--a sequence of three years of grass ley alternating with four years of arable rotation--gave 19 percent more output per hectare, it cost 17 percent more to operate than the local three-course rotation, and was profitable only near the port of Rostock, where the higher cost of production was offset by lower cost of carriage. He concluded that 'improved farming enjoys no absolute advantage over three-field farming. The price of grain determines which of the two is the best in any given situation.'[58] Since transport cost determined the net price received by farmers , intensive systems were normally profitable only near cities.[59]

The significance of Von Thünen's finding for Malthus's trap is that agricultural output in the pre-industrial era was not inexorably limited by inelasticity of land supply. If Belgian husbandry could support twice as many persons per square kilometre as Mecklenburg's advanced system, which in turn maintained 20 percent more people than the traditional three-field system, from an agronomical perspective pre-modern agriculture could support significantly more people than it actually did, at levels of consumption that contemporaries would have found acceptable.[60] For the Von Thünen effect to operate, however, that population had to be spatially concentrated. Von Thünen's model nevertheless fails to capture the full extent of the effects of spatial concentration of demand on agricultural productivity. The formal model implies that total factor productivity is the same at every point in the featureless plain, when in fact it was higher in the vicinity of large towns.[61] We must now consider why that was so.

Thick Market Externalities

Elevated agricultural productivity in regions surrounding major cities stemmed mainly from positive externalities generated by the high liquidity of markets for agricultural inputs and output. The most obvious externality resulted from joint supply of urban transport services and stable manure, which provided farmers delivering food and forage to cities a means of procuring fertilizer without having to

[58] Von Thünen, *Isolated state*, 71.
[59] Von Thünen demonstrates this point by comparing the highly intensive Belgian system with the advanced up-and-down system of Mecklenburg.
[60] The calculations are carried out in the *Isolated State,* chapter 17.
[61] Hoffman, *Growth in a traditional society; Grantham,* 'Agricultural supply'

maintain animals specially dedicated to that purpose.[62] The exchange was occasioned by a dense population of horses employed in drawing urban cabs, omnibuses, and delivery vehicles and draft animals used in long-distance haulage temporarily lodged on the outskirts of town.[63] It was amplified by cheap backhaul in vehicles that had been used to deliver produce, which extended externality deep into the hinterland.[64] Moreover, drawing provisions from a wide perimeter, large cities concentrated nutrients. Indeed the Parisian catchment basin for farm produce generated enough fertilizer to turn the naturally mediocre soils of the *banlieu* into some of kingdom's most productive territory.[65] The Netherlands was perhaps an extreme case owing to the low cost of transport, though it is worth noting that the province of Groningen initially subsidized shippers to haul manure from cities in Holland.[66]

The thick urban market for horsepower also permitted farmers near cities to share the fixed cost of their draft animals with urban transporters. Agricultural demand for traction was highly seasonal, which meant that farmers had to hold excess animals during much of the year to cover the peaks. In isolated districts, huge teams of poorly nourished animals were hitched for the heavy work in spring, when the fallow was broken.[67] In the mid-1780s the French agronomist Gilbert observed farmers in Champagne

---

[62] For an example of an extremely profitable exchange in the huge eighteenth-century Parisian market, see Moriceau and Postel-Vinay, *Ferme, entreprise, famille,* 239-40.

[63] According to Lavoisier, Paris in 1789 housed 21,500 horses whose annual consumption would have amounted to nearly 80,000 tonnes of oats and hay, which would have come to almost half the weight of bread grains brought in to feed the city's 600,000 inhabitants. In 1874 the Paris agglomeration employed over 72,000 horses. Husson, *Les consommations de Paris,* 119-120; Martin, *Étude historique et statistique.* By 1636 London had 6,000 private and public coaches. Kerridge, *Agricultural revolution,* 179. On the growing use of horses in English transport to 1900, see Thompson, 'Nineteenth-century horse sense,' 65

[64] In the 1840s the trade from Rouen, an agglomeration of about 100,000, reached out 20 kilometres. Moll, *Excursion agricole,* 34-35. The Parisian trade extended beyond kilometres. Moriceau and Postel-Vinay, *Ferme, entreprise, famille,* 235-36.

[65] 'C'est dans l'Élection de Paris qu'on reconnaît surtout le pouvoir de l'art sur la nature; des terres sinon très-mauvaises, chargés de riches productions…dont il est facile de rendre raison. Les provisions qui, de tous les points de la France, viennent se consommer dans cette ville, sont rendues en engrais aux terres qui l'avoisinent.' Gilbert, *Traité des prairies artificielles*, 20.

[66] Devries and Van der Woude, *First modern economy,* 203.

[67] 'Nécessairement le travail est en proportion des frais d'entretien; mais tout compte fait, il est impossible de blâmer d'une manière absolue un pareille économie du bétail, car elle a sa raison d'être dans un système qui n'est pas dénué de tout fondement. Dans ce système le travail n'est pas continu; ce n'est que par intermittence qu'on a besoin des attelages, et dans ce cas ils marchent passablement, pour peu qu'on leur donne quelque nourriture à l'écurie. Que la longue saison du chômage revienne, ils reprenne leur vie presque sauvage, et à coup sûr, très-économique.' Lecouteux, *Cours* 2, 118-119.

ploughing with eight horses and four oxen.[68] These mammoth teams, which required as many as three men to conduct, were common where the soil was stiff and fodder scarce. By contrast, farmers near Paris could meet seasonal peaks in traction requirements by renting horses from urban transporters or by purchasing and reselling them in the market.[69] From a farmer's standpoint, the exchange was pure gain, because it reduced the capital outlay needed to raise a given quantity of produce. The advantage ran both ways, since animals worn out in road haulage were restored by the ample rations and comparatively light work on farms.[70] The exchange magnified quality differences between draft animals employed in urban provisioning zones and animals employed outside them. Given the ease of transporting horses, price is a good index of their productivity. The French agricultural inquiry of 1852 indicates that horses employed within 50 kilometres of Paris were worth two to three times more than horses used by farmers more than 150 kilometres away.[71] That difference directly affected labour productivity. On the large farms encircling Paris teams of two to three horses conducted by a single ploughman worked 0.35 to 0.4 hectares per day; in peripheral departments it took two to three workers handling teams of eight to twelve animals needed four to five days to plough one hectare. The productivity differential was 267 percent.[72]

Input sharing near cities represented a true increase in total factor productivity. A similar positive correlation between urban proximity, thick markets, and agricultural productivity is also evident in forage crops. In the absence of an external outlet, farmers grew just fodder to feed their animals, and in the event of any surplus purchasing additional beasts to consume it on the spot.[73] As an intermediate input to bread cereals, hay and oats received the minimum input consistent with meeting on-farm demand. The presence

---

[68] 'J'ai vu très fréquemment en Champagne huit cheveaux & quatre bœufs attelés à une charrue, et conduits par trois personnes, quelle consommation de forces et de temps.' Gilbert, *Traité des prairies artificielles,* 88

[69] 'Il est même des cultivateurs qui, pressés par une accumulation des travaux à l'époque des semences, font l'acquisition des vieux chevaux qu'ils vendent quelques mois plus tard.' Lecouteux, *Agriculture de la Seine*, 125.

[70] Ce rétablissement est si bien apprécié aux environs de Paris, que plusieurs administrations confient, chaque année un certain nombre de chevaux fatigués à des fermiers qui les utilisent dans leurs cultures, les nourrissent à leurs frais, et les rendent aux administration dès qu'ils sont en état de reprendre leur service sur le pavé ou le macadam.' Lecouteux, *Cours d'agriculture* 2*,* 119.

[71] Based on a sample of 129 cantons in northern France drawn from manuscript returns of the *Enquête agricole de 1852.*

[72] Moriceau and Postel-Vinay, *Ferme, enterprise, famille,* 201-202. On labour inputs, see Grantham, 'Growth of labour productivity'

[73] 'On y proportion proportionne le nombre des bestiaux à l'abondance ou à la médiocrité des récoltes. Lorsqu'il y a excédent on conserve quelques approvisionnements pour l'année suivante, au cas que la récolte soit mauvaise.' 'Enquête sur les fourrages, 1813'. Archives Nationales F^{111} 494. Département de la Seine-et-Marne.

of a nearby outlet for these bulky low-value commodities – in rural areas a cavalry garrison or post house – gave farmers the incentive to devote more resources to their production. Natural meadows were irrigated, drained, and manured, and cleared of the stones and molehills that interfered with mowing; oats got an extra ploughing and occasional dressings of manure. The consequence was increased yields. Between the 1720s and the 1810s the yield of oats in England rose five times faster than that of wheat, clear evidence that new sources of demand were making the effort profitable.[74] The urban market for hay led farmers to sow forage legumes as substitute fodder for their own stock.[75] Since legumes fixed nitrogen in the soil, the practiced ultimately increased crop yields. Given the high cost of transporting hay and oats (which relative to their price were twice as cumbersome as wheat), these effects were also most pronounced in the vicinity of major cities. Unlike the shared input externalities, however, the gain in productivity was in large part due to fuller utilization of underemployed labour and capital locked up in the countryside.[76]

Cash Flow and Agricultural Capital

Working capital was the weak link of pre-modern farming. While landlords could finance buildings and improvements by taking out loans secured by a mortgage or by granting rent rebates to farmers making the investments for them, the working capital tied up in rent, seed, wages (or their equivalent in workers' subsistence), livestock and equipment was the tenant's responsibility. As Quesnay pointed out, the illiquidity of working capital with a turnaround time often exceeding a year made recourse to conventional bills of exchange and promissory notes employed in commerce virtually impossible.[77] As a consequence most farmers financed the advances out of personal and family reserves.[78] The difficulty of amassing those reserves constituted the chief entry barrier to large-scale farming. Not that farmers were

---

[74] 54 percent as compared with 11 percent. Turner, Becket and Afton, *Farm production in England,* 129, 158. See also Turner, 'Agricultural productivity.'

[75] 'On ne vend pas tant de sainfoin, de luzerne, dragée et autres foins, qui viennent de culture, qu'on vend de foin: on a coutume de les consommer à la maison, pour ménager les foins de prés, qui sont les seuls foins que l'on consomme à Paris.' Liger, *Maison rustique,* 814. 'Aux environs de Paris, les prés ne sont pas, comme ailleurs, une conséquence de l'exploitation, car ils ne concourent pas à l'alimentation des animaux de ferme, mais ils donnent une denrée commerciale, qui trouve dans la capitale une débuchée très lucrative.' Lecouteux, *Agriculture de la Seine*, 79-80

[76] On the potential supply of labour locked up in peasant households, see Devries, *Industrious revolution.*

[77] 'L'agriculture n'a pas, comme le Commerce, une ressource dans le crédit. Un marchand peut emprunter pour acheter de la marchandise, ou il peut l'acheter à crédit, parce qu'en peu de tems le profit & le fonds de l'achat lui rentrent : il peut faire le remboursement des sommes qu'il emprunte; mais le laboureur ne peut rentrer que le profit des avances qu'il a faites pour l'agriculture; le fonds reste pour soutenir la même entreprise de culture.' Quesnay, 'Fermiers,' *Œuvres économiques,* 181-82.

[78] Moriceau and Postel-Vinay, *Ferme, famille, entreprise,* 97-118, 129-140; Moriceau, *Fermiers de l'Île de France.*

entirely shut out from short-term credit. Landlords advanced seed, livestock, and implicitly the rent to sharecroppers in exchange for half of the crop, and from the Middle Ages rural people with cash on hand found remunerative employment for it by lending cattle and sheep on half shares to peasants.[79] And where farmers had land to pledge, they could access short-term credit.[80] On the whole, however, the traditional sources of credit were insufficient to cover advances for intensive husbandry, which Von Thünen reckoned to be two to three times greater than in traditional husbandry.[81] Most farmers had to rely on cash flow to finance advances, which meant that the pace of agricultural investment was critically influenced by the state of the markets for produce.[82]

There was thus economic logic in the Physiocrat's accusation that limiting free trade in grain prevented farmers from obtaining the capital they needed. Adam Smith agreed: 'The lands of no country' he wrote, 'can ever be completely cultivated and improved, till once the price of every produce, which human industry is obliged to raise upon them, has got so high as to pay for the expence of complete improvement and cultivation.'[83] Because most costs of cultivation were pre-determined, the market price of produce was critical to the financing of agricultural improvements. This was the point of Quesnay's *Tableau Économique,* which he devised to show how different patterns of demand and taxation affect the flow of funds to the 'productive' sector. Probably more important than the level of prices, however, was their variance. The theory of option pricing teaches us that the opportunity cost of an irreversible investment includes the value of avoiding possible negative shocks by delaying the investment. The higher the expected variance, the greater that cost and therefore the higher the expected return required to induce

---

[79] 'Ceux qui ont de l'argent comptant, pour le faire profiter & en tirer un bon revenu qui n'est point usuraire, peuvent se mêler du commerce des troupeaux à moitié; on y fait son compte en fort peu de tems: c'est le commerce le plus usité & où l'on gagne le plus à la campagne.' Liger*, Maison rustique*, 457. See also Fortunet, *Baux à cheptel;* Tricard, *Campagnes limousines,* 149-51. The leases were notarized to protect lenders from landlords seizing the stock in the event of the lessor's bankruptcy.

[80] Postel-Vinay, *La terre et l'argent,* 42-44. In 1648 the lessor of the 248 hectare farm of Choisy-aux-Boeufs borrowed 11,000 livres on a one-year note secured by hypothecating the tenant's landed property. Moriceau, *Fermiers,* 507-08.

[81] *Isolated state,* 85-86. The fixed capital estimates are 3046 and 1296 thalers.

[82] For some statistical evidence on this see Grantham, 'Measuring the unmeasurable' and more generally Meuvret, *Problème des subsistances, vol.1.*

[83] *Wealth of Nations,* 227.

the investment.[84] In then case of farmers' advances, much of the investment was irrecoverable in the event of a bad outcome. Thin markets for produce implied high price variance, which in turn deterred investment in extra cultivation, weeding, and livestock. Which unlike tje capital immobilized in barns and land improvements that could be financed with mortgages, were short-term outlays paid for by net cash flow.

Proximity to urban markets reduced the variability of farmer's cash flow in two ways. The short carriage distance and better transport facilities in the neighbourhood of cities supported greater diversification, cushioning the swings in proceeds from the sale of cereals, the traditional primary cash crop.[85] The sheer volume of produce passing through major urban markets reduced price variance by greater pooling of supplies subject to uncorrelated supply shocks and by supporting professional speculators whose operations tended to smooth temporal swings in grain prices.[86] None of this should be taken to imply that urban-oriented farming was risk-free. Many farmers provisioning the Paris market in the late seventeenth- and early eighteenth-century failed under the combined weight of harvest failures and low prices.[87] But the risks were nevertheless lower in urban provisioning zones.

One can get a crude sense of the effect of urban markets on price volatility from regional wheat prices in France in the second half of the eighteenth century. Table 1 lists the coefficient of price variation in 14 *généralités* in northern and central France expressed as a percentage of the variation in Paris.[88] Because the published prices average observations from several markets, the *généralité* coefficients understate the true variation relative to Paris. The table nevertheless indicates that price and presumably cash-flow variance was lower in urban provisioning zones than in the periphery. Price variability in the *généralité* of Paris was the same as in the city; in the généralité of Soisson, which was one ring further out and well-connected to the capital by water, it was only slightly higher. By contrast variability in the *généralité* of Amiens (the ancient province of Picardy) was significantly higher owing to the poor state of the roads. which the Prefect of Oise characterized as being so bad they deterred beggars from coming into

[84] Calculations for an irreversible investment s based on a trendless cash flow suggests that a 20 percent coefficient of variation doubles the required return relative to the risk-free supply price of capital. Dixit, 'Investment and hysteresis'
[85] For an example, see Moriceau and Postel-Vinay, *Ferme, entreprise, famille,* 238-39
[86] Kaplan, *Provisioning Paris*; Miller, *Mastering the market.*
[87] Moriceau, *Les fermiers de l'Île de France*, 585-89
[88] The *généralité* was the largest administrative jurisdiction for levying the royal land tax.

the province.[89] The region remained poorly endowed with roads well into the nineteenth century. [90] Flanders which was both urbanized and well endowed with water transport had the same variance as Paris. Lyon is a test case, since it lay in a region that was far from being a breadbasket. Nevertheless price deviations in Lyon and its primary provisioning zone in Burgundy were the same as in Paris. The regional gradient in price variation maintained itself into the nineteenth century. The standard deviation of monthly prices in first two decades in the *department* of Seine-et-Oise, Paris's inner provisioning ring, was 18 percent below that in the Haute-Marne, a typical peripheral *department.*[91] Proximity to cities, then, reduced investment risk.

[Insert table 1 here]

Positive Feedbacks

Perhaps the most unexpected way that urban-oriented intensive cultivation raised the productivity of both land and labour was through natural selection of crop varieties adapted to the looser and weed-free soils that resulted from repeated tillage. Modern experiments indicate that over 25 to 30 generations this selection effect can raise yields by as much as 25 percent.[92] The natural selection of livestock will be considered in the next section. Another by-product of intensified cultivation was faster ploughing and smaller plough teams, because well-tilled soils offered less resistance to the plough.[93] Yet because these conditions required the continuous input of labour and capital, the effect was reversible, which may partly account for the declining agricultural productivity in periods of economic contraction and de-urbanization. A less reversible consequence of investments induced by urban demand was the tendency for farms supplying cereals to large cities to grow larger and more compact. While urban demand for labour-intensive perishables supported clusters of small-scale labour-intensive fruit and vegetable farms,[94] the strong demand for grain provided an incentive to reduce labour costs in cereal production by increasing the size of farms and reducing the scattering of individual plots in open fields. While adjustments in farm lay-

[89] 'Les chemins vicinaux sont si mauvais dans ces contrées qu'ils éloignent jusqu'aux mendiants étrangers.'
[90] Lepetit, *Chemins de terre & voies d'eaux,* 55-57.
[91] Labrousse, *Prix du froment.* The seasonal deviations are calculated for a crop year beginning in September.
[92] Evans, *Crop evolution,* 293.
[93] Grantham, 'Growth in labour productivity.'
[94] Quellier, 'Growing peaches in Corbeil'

out were possible everywhere, it was only within the major urban provisioning zones that the investment made sense. In many cases the incentive was so strong that farmers arranged to exchange parcels of land among themselves in the rental market without notifying their landlords. [95] Farm size and plot size were therefore larger within the provisioning zones than outside them. Table 2 shows the variation in mean plot size for a sample of rural cantons drawn from five open-field *départements* in 1852. The average size within the Paris provisioning zone (the (Île de France and Beauce) were on average twice as large as those in the outlying districts of Champagne and Lorraine. The changes did not occur all at once, but over several generations the farming structure could rearrange itself endogenously in response to market opportunity.

[insert table 2 here]

We can now summarize the discussion to this point. Until the breakthroughs of the 1840s fundamentally altered the technological basis of mixed farming, the primary driver of agricultural productivity was spatial concentration of demand for farm produce. Agricultural improvement required investment, but as long as the transport of farm produce remained cumbersome and costly, concentration was effectively the sole means of aggregating demand for foodstuffs. The presence of deep markets for horses and fodder and the joint supply of urban transport and manure conferred a spatial advantage in total factor productivity on farms situated within a roughly 40 kilometer distance of large cities. Thick markets also reduced price variability, lowering the cost of investments in intensive farming. The consequence was higher productivity. I have elsewhere estimated per hectare vegetable-product supply elasticity for pre-railway France from cross-section data and find that controlling for proximity to cities it may have been as high as one. [96] This seems implausibly elevated, but Hoffman's indirect estimation of spatial patterns of productivity from rent and price data yields a similar relatively elastic relation.[97]

Spatial concentration of demand thus tended to raise supply elasticity. The same was true of bulky products like coal, where the development of large-scale mining and more efficient methods of transport and distribution responded to growth of demand in London and cities ringing the North Sea, which suggests

[95] Grantham, 'Persistence of open-field farming'; For an example, see Moriceau and Postel-Vinay, *Ferme, entreprise, famille,* 181-83.
[96] Grantham, 'Agricultural supply,' 60-61.
[97] Philip Hoffman, *Growth in a traditional society*, 171-72.

that the strongly positive supply response to increased demand was a general phenomenon that transcends agriculture.[98] To return once more to Adam Smith on how urban demand for meat and dairy products ultimately reduced their supply price:

> For some time before this practice becomes general, the scarcity must necessarily raise the price. After it has become general, new methods of feeding are commonly fallen upon, which enable the farmer to raise upon the same quantity of ground a much greater quantity of that particular animal food. The plenty not only obliges him to sell cheaper, but in consequence of these improvements he can afford to sell cheaper; for if he could not afford it, the plenty would not be of long continuance. It has been probably in this manner that the introduction of clover, turnips, carrots, cabbages, etc. has contributed to sink the common price of butcher's meat in the London market somewhat below what it was about the beginning of the last century.[99]

The history of agricultural productivity in the age of traditional husbandry thus turns on the history of urbanization and in lesser measure on the evolution of transport and distribution costs. The growth in agricultural productivity after 1650 was not a technological miracle permitting an 'escape from Malthus,' but a predictable consequence of growing urban demand for foodstuffs within the technological context of a traditional husbandry that remained essentially unchanged.

Structures of Dispersion

Spatial concentration of demand is only half the story. We must now consider the reverse side of the coin: how dispersion impeded agricultural improvement until the fall in transport costs in the late nineteenth century effectively made the Continent an urban zone.[100] Before we take up these impediments, we need first briefly to consider why traditional farming was so land-intensive.

Economic and Technological Sources of Dispersion

Richard Cantillon observed that a French family willing to live on vegetables and water could subsist on three acres.[101] As long as land was cultivated by hand, nothing prevented this condition from being general. At an expected yield of 20 hectolitres per hectare, a family cultivating two hectares of arable – about the maximum that could be handled by two adults—could grow enough wheat to support

---

[98] Chartres, 'Producers, crops, and markets'; On the medieval export of English coal to the Continent see Pelham, 'Medieval foreign trade, 321.

[99] Smith, Wealth of Nations, 225

[100] For a description of agricultural market integration in seventeenth- and eighteenth-century England, see Chartres, 'Producers, crops and markets'

[101] Cantillon, *Essay on the nature of commerce*, 19. He conceded that being accustomed to a higher standard of living, English families would probably require twice that area.

one additional family.[102] This seems to have been true from the beginning, since Neolithic farmers armed with digging sticks evidently obtained 20 hectolitre yields.[103] Manual cultivation was thus a viable technology, and it survived in many parts of Europe well into the nineteenth century, when it was given a new lease on life by the falling cost and improved quality of iron and steel employed in making spades, hoes, and sod forks.[104] At the start of that century the Prefect of Vaucluse reported that peasants producing 30 to 60 hectolitres on miniscule holdings cultivated by hand.[105] In the light of these yields nothing stood in the way of population densities exceeding 250 persons per square kilometre.[106] In 1800 the density of Europe's most populated region (Belgium) was only 100.

Pre-industrial Europe was thus a long way from Malthus's margin. Why, then, did contemporaries believe the continent lacked space to feed her multiplying numbers? The reason is that most food and raw materials were not produced by hand, but with ploughs. The plough was a land-using innovation. Substituting capital and land for labour, it raised the productivity of the latter at the cost of a lower yield. The consequence was increased land scarcity, , but it was scarcity conditional on farmers working the land with animals rather than with their own hands.

The reason why yields on ploughed land were lower than on land worked by hand is that the plough left soils infested with weeds, whereas hoes and spades all but eliminated them. The plough's signal advantage was its speed.[107] It took 50 days to spade one hectare; the plough took two and a half to five days. The actual differential in cultivating time was of course much smaller, because ploughed fields had to be worked three or four times, which meant putting them through a course of fallow that effectively doubled the land input of bread cereals relative to fields cultivated by hand. Despite that lavish expenditure

---

[102] At annual per capita consumption of 3.5 hectolitres and a net yield of 17 to 18 hectolitres per hectare.

[103] Reynolds, *Iron-age farm*: Reynolds, 'Crop yield potential,' Firmin, 'Archéologie agraire et expérimentation.'

[104] Coutin, 'Le labour à la bêche'; Fenton, 'Team cultivation'; David, 'Spade cultivation.' At the end of the eighteenth century, only one out of five to seven households in the Vivarais had ploughs. Molinier, *Stagnations et croissance*, 181. In 1800, 20 percent of the arable around Lille was cultivated by hand. Dieudonné, *Statistique du ... Nord,* 351.

[105] 'Combien de propriétaires recueillent depuis trente jusqu'à soixante hectolitres de grain, sans avoir seulement un âne. Ils ont travaillé ou fait travailler toutes leurs terres en culture à la main.' Séguin de Pazzi, *Mémoire statistique ... de Vaucluse,* 257.

[106] Half a square kilometer (50 hectares) under continuous cultivation would support 250 persons at a gross yield of 20 and net yield of 17 hectoliters per hectare.

[107] 'The plough works faster, but does not work the land as deeply, and often turns the soil in one piece without breaking the clots.' Duhamel du Monceau, *Éléments d'agriculture,* 148.

of land, a three- to four-fold increase in labour productivity more than offset an approximately 50 percent decline in yield.[108] Whereas a family cultivating two hectares by hand supported one additional household, a family employing a plough to work 20 hectares could support four to five.[109] The plough is an instrument of specialization. An economy consisting of subsistence farmers tilling the soil by hand could easily sustain levels of per capita food supply meeting pre-modern standards of consumption, but it could not support significant division of labour.

The scarcity of land was therefore conditional on the state of economic organization. Specialized states made greater demands on land because they required levels of agricultural labour productivity that could be achieved only employing ploughs to produce subsistence cereals. The spade could support a dense population, but the plough could maintain a specialized one. The plough enjoyed two further advantages over spades and hoes. Its employment was subject to economies of scale, which created an additional degree of freedom to raise productivity by increasing the size of farms. Animal drawn equipment was also more open to improvement. Although there were many distinct types of spade and hoe, the hand tools represented a dead-end technology whose limits had been attained in classical antiquity.[110] By contrast, ploughs, harrows, and other animal-drawn implements of cultivation were supported a wide range of improvement through greater specialization of form and the use of better materials.[111] Over the long-run these elements sustained significant increases in the productivity of animal-drawn equipment and are a reason why long-run supply of subsistence foodstuffs produced by land-intensive methods of cultivation turned out to be elastic.

---

[108] Aussi, quand le bon grain est accompagné de vesse, yvraie, & autres herbes nuisibles, non seulement le pain est rendu mal plaisant … mais aussi ne revient de moitié du bon bled & froment non meslé de ces herbes meschantes, tellement que trois charges de tel bled, après être criblé, ne reviennent à deux de grain pur & net.' Estienne et Liébaut, *L'agriculture et la maison rustique,* 299 bis. 'C'est souvent faute d'avoir bien sarclé, que l'on voit tant d'épis affamés & tant de grains maigres; encore le bled en est-il malsain, taché, désagréable au goût & fournit-il la moitié moins que du bled bien net.' Liger, *Maison rustique,* 570.

[109] Plowing input varied enormously, so the following calculation is merely illustrative. Assuming fields sown in wheat are ploughed three times at three days per hectare for horses and four to five days for oxen, a farmer plowing 160 days with oxen could cultivate 8 to 10 hectares of wheat in a biennial rotation. For a three-course rotation in which the spring field is cultivated once, a farmer plowing with horses could keep 13.3 hectares in wheat. As noted above, the maximum amount of land that a family could cultivate by hand was about two hectares.

[110] White, *Agricultural implements;* Manning, *Catologue of Romano-British tools;* Jacobi, *Ausgrabungen in Manching.*

[111] Comet, 'Technology and agricultural expansion'; Raepset, 'Development of farming implements'

The extensiveness of pre-modern farming was a phase in the evolution of agricultural technology that has reversed its direction in recent decades. The substitution of tractors for draft animals in field operations is perhaps the outstanding example of agriculture's diminishing land-intensity, though it is far from unique.[112] Mitigation of the epidemiological consequences of crowding has transformed pig, poultry, and dairy farming, just as raising crops indoors with artificial lighting and hydroponic delivery of nutrients is bringing further encroachments of the factory on open-air agriculture. In the wilder stretches of imagination, one can conceive skyscraper farms in which domesticated bacteria transform atmospheric carbon, nitrogen, and plant nutrients into food and fiber.[113] The land-intensity of traditional agriculture was a technological stage that, as Adam Smith quipped, made it cheaper to import claret from Bordeaux than produce wine from hothouse grapes in Scotland.[114]

Dispersion and Ecological Niches

With the exception of New World crops introduced towards the end of the sixteenth century the physical and biological *matériel* of European mixed husbandry remained virtually unchanged from the Roman era to the late eighteenth century.[115] While the ultimate source of the secular stasis in plants, animals, and systems of husbandry is to be found in the opacity of life processes to direct observation, their adaptability to the ecological and economic niches they colonized contributed to that stasis by impeding extensive exploitation of their genetic potential. With few exceptions—notably in horticulture, where 'sports' were propagated by grafting cuttings—that potential was not significantly improved upon by deliberate breeding. In the case of livestock, low reproduction rates and farmers' inability to distinguish phenotypic from genetic causes of variation frustrated attempts to breed superior animals.[116] Moreover, the stock was subject to

---

[112] Olmstead and Rhode, 'Reshaping the landscape,' pp. 664-65.

[113] Perhaps not so wild. The Belgian architect Vincent Caillebaut has proposed a translucent sail-shaped structure 600 meters high positioned in the East River as a support for growing rice, fruits and garden vegetables in hanging gardens. *Le Monde*, May 23, 2009.

[114] 'By means of glasses, hotbeds, and hotwalls, very good grapes can be raised in Scotland and very good wine too can be made of them at about thirty times the expence for which at least equally good can be brought from foreign countries.' Smith, *Wealth of nations,* 425.

[115] It was not until the eighteenth century that wheat varieties from Asia and North Africa began to make their way into Europe, and it was only in the nineteenth century that ransacking of the world's agricultural regions for promising genetic material began in earnest. Percival, *The Wheat plant;* C. R. Ball, 'History of American wheat improvement'; Walton, Varietal innovation'

[116] According to Russell 'There still remains considerable confusion about the genetic causes of physiological superiority [in animals], so that eighty years after the rediscovery of Mendel's work we

adverse selection when farmers gave in to the ever-present temptation to raise quick cash by selling off their best animals.[117] Race horses were a late exception, because thoroughbred racing generated performance-based pedigrees.[118] In the case of cereals, susceptibility to hybridization in open stands made it difficult to develop pure lines.[119] It took over a half century before the great seed collection built up by the Paris firm Vilmorin-Andrieux between 1785 and 1815 acquired enough genetic stability to warrant publication in the company's seed catalogue.[120] Given farmers' ignorance of Mendel's laws (not to mention the complex physiology of sexual reproduction in plants), it is hardly surprising that expression of the genetic potential of the original cultivars and domesticated animals was directed by natural selection.

That expression was assisted by an extensive menu of ecological niches and adaptive zones resulting from agricultural colonization of nearly every corner of Western Europe capable of supporting crops and livestock, which provided settings for thousands of natural experiments in plant and animal breeding under conditions of reproductive isolation. The specific mechanisms are obscure, but they clearly depended on reproducing from local stock. Farmers mated animals that seemed to offer better results, and held back their best seeds for sowing.[121] Such practices, which hardly rise to the level of deliberate breeding, privileged selection pressures of local soils and climate, and significantly, local patterns of demand for farm produce. Of the environmental factors, market forces seem to have been the most powerful.

Market-directed natural selection is most easily seen in the evolution of specialized cattle out of multi-purpose animals. The *braunvieh,* currently the most widely distributed dairy cow, originated in the

---

cannot be sure that the theory on which our current "scientific" decisions are based is the "correct" explanation.' Russell, *Like engendr'ing like,* 11.

[117] As late as the mid-nineteenth century breeders of Percherons fell into this trap, despite, or more likely because of their market premium. 'Pour l'appât du gain ils se desaisissirent trop facilement des bons animaux de race, pour les vendre aux autres régions, et les remplacèrent par des animaux d'autres pays, très inférieurs.' Musset, *L'élevation du cheval*, 125.

[118] Since registered horses were not permitted to race, racing registered animals produced pedigrees by default. *Like engend'ring like,* 93-94.

[119] Feldman and Sears, 'The wild gene resources of wheat;' On the general problem of breeding pure lines see Hayes and Garber, *Breeding crop plants.* .

[120] Meuvret, *Le probleme des subsistances* I, *Notes*, 136. See also Louis Vilmorin's obituary in the *Journal d'agriculture pratique* (1860), 295.

[121] 'On voit des cultivateurs employer les veillées de leur famille à trier, grain par grain, cinquante ou soixante livres de blé qu'ils sement séparément en bonne terre, pour faire leur blé de semence l'année suivante.' Dupin, *Mémoire statistique ... Deus Sèvres,* 240. On the genetics of mass selection, see Acquaah, *Principles of plant genetics.*

mountains of central Switzerland where milk from nutritious alpine grasses was turned into luxury cheese in monasteries keeping records of individual milk production to select cows for reproduction.[122] The dairy cattle of Holland and Flanders provide an even more striking case. Here, the strong urban demand for liquid milk and butter provided the foundation for the development of breeds that gave large volumes of milk from abundant rich feed. In the late sixteenth century the yield of Frisian cows was probably on the order of 1300 litres per year.[123] By 1600 Flemish cows were producing upwards of 3,000 litres.[124] To put these numbers of perspective, in 1618 Robert Loder's cows produced between 790 and 860 litres on an arguably well-managed operation.[125] Flemish and Dutch cows gave five to six times as much as milk as cows in most parts of rural Europe, where yields of 400 to 600 litres were normal.[126] Meat animals also exhibit market-induced selection. In the sixteenth and seventeenth century cattle reared on the steppes of southwest Russia were driven westward more than 1,000 kilometres to satisfy urban demand for meat in northern Italy and the Rhineland. Finished on the rich meadow grasses of Lombardy and Flanders, when slaughtered they weighed 450 to 500 kilograms, twice the size of local breeds with access to the same feed.[127] The vast extent of grassland in Eastern Europe occasioned this long-distance trade, but the outsized animals must have been a product of selective effects emanating from western markets. Similar selection effects are evident in the transformation of the English sheep in the twelfth and thirteenth century from animals kept mainly for milk and meat into producers of fine wool.[128]

Yet what the market gave it could also take away. The deteriorating weight and quality of the English wool clip in the later Middle Ages reflected collapsing demand for fine wool on the continent.[129]

---

[122] www.original-braunvieh.com/history.
[123] Devries, *Dutch rural economy in the golden age,* 143-44.
[124] Vanderwalle, 'Stabilité et perfection d'un système agricole ;' Aujollet, *La vache et ses produits,* 35-41.
[125] Cited by Devries, *Dutch rural economy,* 144.
[126] The average yield of dairy cows in the early fourteenth century on the well-managed manors of Peterborough Abbey was 450 to 600 litres. Biddick, *Other economy,* 94. In the 1830s, the lowest yields in Montfort (Sarthe) were 200 litres, the highest 800 litres. Statistique agricole 1836. Canton de Montfort. Archives Départementales, Sarthe M166 bis. On the mediocre state of the Scottish dairy before unification, see Adam Smith, *Wealth of nations,* 226-227.
[127] Blanchard, 'Continental cattle trades, 1400 – 1600.' At the end of the eighteenth century, the average weight of oxen fattened for market in the Limousin, where cattle were already partly raised for meat, was only 300 to 350 kilograms. Texier-Olivier, *Statistique ... de la Haute Vienne,* 349.
[128] Trow-Smith, *History of British livestock,* 77. Analysis of parchments made from English sheep indicates a significant increase in size. Perroy, *Le travail dans les régions du nord,* 16. On the fineness of English wool see Munro 'Spanish merino wools,' 432.
[129] Stephenson, 'Wool yields.'

By the middle of the fifteenth century sheep were reverting to their original status as dairy animals.[130] A similar economic contraction may explain the osteological evidence of declining size of livestock in the early Middle Ages.[131] Small grains exhibit analogous effects. In districts where the urban market induced agricultural intensification, traditional long-stemmed traditional wheat varieties evolved stiffer stalks to protect plants supporting heavier ears of grain from lodging.[132] The increased grain yield was thus gained at the cost of reduced straw quality.

Yet, while natural selection could expose the genetic potential of Europe's biological *materiel,* successful adaptation also impeded the diffusion of improved varieties competing with individuals better adapted to local conditions. The fodder constraint was the principal obstacle to the diffusion of superior livestock. Animals adapted to the supply and type of feed locally available, which meant that outside districts where forage was abundant they were selected for small size and the capacity to subsist on coarse rations.[133] The development of superior breeds thus depended almost entirely on the feeding regime, since farmers had no understanding of how inherited traits are transmitted in animals and as noted above, often the best beasts and bred the culls, magnifying the influence of the fodder constraint. The consequence was that attempts to introduce improved breeds without simultaneously improving the quality and quantity of forage resources commonly ended in failure.[134] One might expect the *Braunvieh* to prosper in the highlands of Auvergne, but cattle adapted to alpine limestone meadows were unproductive on the granitic soils of Aubrac.[135] Similar problems confronted farmers attempting to upgrade local stock by breeding

---

[130] Thirsk, *Alternative agriculture,* 9.
[131] Audoin-Rouzeau, 'Compter et mesurer les os animaux.'
[132]Traditional varieties of wheat were long-stemmed, which was an adaptation that evolved as a defense against weeds. They were therefore vulnerable to lodging when exposed to heavy doses of manure, because the uptake of nitrates dilates the cells, weakening the cell wall.
[133] 'L'espèce, en général est petite et faible, parce que les paturages n'étant pas abondant, le cultivateur est obligé de mettre beaucoup d'économie dans les fourrages.' Prefect to Ministre 1 May 1811. Archives Départementales, Haute-Marne. 185 M 4. 'L'espèce de Chevaux est généralement faible et aurait besoin d'être améliorée; celle des Boeufs et des vaches convient assez aux pâturages peu substantiels qui nourriraient difficilement de plus fortes espèces.' *Annuaire de la Mayenne*, (An 12), 140.
[134]The Prefect of Seine-et-Oise writes of the introduction of Swiss cattle to the experimental farm at Rambouillet, 'These animals, which found abundant and succulent feeding in the mountains of Helvetia, were out of place on barren wet terrain and had to be sustained on dry fodder; but their product did not cover half the expense and the effort was abandoned. Farmers replaced these beautiful but unfruitful cows with Norman beasts that had the greatest success.' *Mémoire statistique du Département de Seine-et-Oise*. An IX. Archives Nationales F^{20} 258. p. 237. For a similar example from Lorrain, see Marquis, *Mémoire statistique ... de la Meurthe,* 174.
[135] Crozes, *L'Aubrac*, 28.

them with imports.[136] The diffusion of improved livestock demanded complementary investments to increase the supply of fodder that farmers were understandably reluctant to undertake in the absence of a strong financial inducement.[137] One can infer the cost of such investments from the 100 to 200 percent rental premium on first-class natural meadows relative to first-class arable in unimproved districts of northern France.[138] In such circumstances, prudence counseled using local stock.. Finally, even in favourable ecological circumstances improved animals might fail to find purchasers; Breton peasants rejected *braunviehs* bred in the Vendée next door because its colour recalled an inferior local breed.[139]

The tight integration of arable and livestock husbandry in traditional agriculture posed further impediments to the diffusion of superior varieties. Here, too, the adaptability of traditional husbandry to an almost infinite geographical variation in physical and economic circumstances made it difficult to transpose individual elements of that husbandry to other districts without upsetting the local balance that reconciled competing, but also complementary demands of the pastoral and arable sectors. The most telling example was selection for stiff straw in wheat varieties giving high yields under heavy doses of manure. Fitzherbert describes one such variety.

> [T]here is another kind of wheat, which is called hole straw wheat, it hath the largest eare of al wheats, the boldest corne, and yieldeth the most, the finest, though not the whitest floure.... The straw is not hollow, but hath a strong pith throughout, by reason whereof in his growth no weather whatever can beare him downe, but will stand and prosper. His straw yieldeth as good thatch as reeds, a singular profit for the husbandman: and it is an excellent fuel to bake or brew with… Only cattell will not eate it, nor is it good for litter.[140]

In much of Europe, wheat straw was used as winter feed for draft animals, making it an essential intermediate input in arable cultivation. Attempts to introduce high-yielding varieties of wheat into regions lacking alternative sources of fodder were therefore blocked by the need to retain varieties giving a soft straw. High-yielding varieties of rye and oats faced similar obstacles. Rye straw was valued for plaiting,

---

[136] On a essayé de croiser les vaches du pays avec des taureaux venus de Suisse et de Flandre: mais le climat et les pâturages s'opposent au succès de cette spéculation. Les espèces qui en proviennent donnent si peu de lait, qu'on a été obligé d'y renoncer.' Chevard, *Histoire de Chartres,* 55-56

[137] This was the reason for the failure to introduce merino sheep to western France in the late eighteenth century. 'Il est probable que les cultivateurs … auraient difficilement consenti à changer leur mode de culture et d'assolement, pour procurer à des brébis la quantité de nourriture que la race des mérinos exigent.' Cavoleau, *Description ... de la Vendée,* 203.

[138] Data from canton agricultural statistics for 1852. The medium premium is 84 percent. For a description of the sample, see Grantham, 'Agricultural supply.'

[139] Cavoleau, *Description ... de la Vendée,* 180.

[140] Fitzherbert, *Boke of Husbandrie*, 23.

mattresses and binding sheaves which required suppleness; the soft straw of traditional strains of oats were used pack fragile objects like mirrors and plate glass.[141] Variations in the value of the joint product thus affected diffusion of superior varieties of the foodstuff. Near cities, the obstacles posed by stiff were lower, since straw not consumed on the farm found an outlet as litter for urban stables and mulch for market gardens.[142]

The mutual adaptation of plants, livestock, and methods of cultivation to ecological niches thus created a set of complementarities making it difficult to introduce superior breeds and plant varieties without changing other elements of the farming system. This was in large measure due to the non-specialized nature of farming outside the urban core, which tended to privileged non-specialized traits and joint products. It was this factor that as much as the stasis in agronomical knowledge that limited the improvement of the biological *materiel.* By the same token, changes in the structure of demand generated by urban growth could have a liberating effect on the evolution of crops and animals.

Dispersion and Stasis in Farm Implements

Pre-industrial stasis in farm tools and vehicles exhibits a combination of geographical speciation and impeded diffusion of better types that is analogous to the situation with respect to crops and livestock. This was particularly true of ploughs, where the range of terrain and crops induced typological proliferation going far beyond the basic division between implements that turn the topsoil to one side and those that throw it symmetrically about the furrow.[143]

> There be plowes of divers makynges in dyvers countreys, and in lyke wyse there be plowes of yren of diverse facyons. And that is bycause there be many maner of groundes and soyles. Some whyte cley, some redde cley, some gravell or chylturne, some sande, some meane erthe, some medled with marle, and in many places heeth-grounde, and one ploughe wyll not serve in all places. Wherefore it is necessarye, to have divers maners of plowes.[144]

---

[141] Liger, *Maison rustique* (ed. 1757), 814-815.

[142] "Quant aux fourrages ou *pailles*, celles de froment, si l'on ne peut pas consommer tout en litière & en fumier, se vendent à ceux qui en manquent pour la nourriture de toutes sortes de bestiaux, surtout dans les hivers longs; aux Grainiers, qui les vont chercher au loin pour les débiter; aux Maraichers & autres Jardiniers, qui ne font leurs couches à champignons que de pailles de froment." Liber, *Maison rustrique,* 814.

[143] On the typology of ploughs, see Haudricourt and Delamarre, *L'homme et la charrue.*

[144] *The Boke of hubondrie*, 9. The inventory English ploughs a century and half later was not much smaller. Kerridge, *Agricultural revolution,* 32-35.

However, what Darwin defined as the 'preservation of favourable variations and the rejection of injurious variations' did not operate with the same consistency in the mechanical world as it does in nature. Writing at the start of the nineteenth century, Tessier noted that

> Plough wrights everywhere seem to shape mouldboards as if by chance; in districts where large mouldboards are the rule, one rarely finds two the same, and I have frequently seen a particular farmer who one year possesses a plough that works with the greatest ease, in the following year has one that does less work and gives him and his team more fatigue.[145]

One reason was that farmers didn't care much as long as a plough worked adequately. Wheeled ploughs were especially forgiving, because defects in construction were mitigated by altering the position of the beam on the fore train.[146] Another reason was that wrights and smiths responsible for fabricating farm implements enjoyed local monopoly of manufacture, eliminating competitive pressure for sustained improvement. No doubt some craftsmen made excellent ploughs, but in the absence of strong pressure to do so, such men were rare.[147]

One might anticipate the sheer number of craftsmen to impart an upward drift in implement design. But local solutions to particular problems diffused slowly owing to the spatial dispersion of implement manufacture, which favored the transmission of local knowhow.

> 'sith there is no country but custome or experience hath instructed them, to make choice of what is most available, and he that will live in any Country may by free charter learne of his neighbors, and howsoever plough he made, or fashioned, so it be well-tempered, it may better be suffered.'[148]

Mechanical invention thus ran its course in geographic differentiation of types rather than in the development of widely diffused improvements.[149] An obvious way of achieving this was through

---

[145] Tessier, Thouin and Bosc, *Encyclopédie méthodique,* V, 103

[146] Une charrue à roues, telle mauvaise qu'elle soit, marche encore tant bien que mal, tandis qu'un araire mal construit ne va pas de tout.' Moll, *Manuel d'agriculture,* 61. 'La charrue la plus malfaite, dans ses pièces travaillantes, marche quand même avec un avant-train, tandis qu'un araire ne marche bien qu'autant que ses pièces sont parfaitement établies et que son règlement est précis.' Grandvoinnet, *Etudes pratiques et théoriques,* 27. But how so ever they be made, yf they be well tempered, and goo well, they maye be the better suffred.' Fitzherbert, *Boke of Husbondrie,* 10.

[147] 'Pour qu'elle ait en perfection toutes ces propriétés, il faut un ouvrier qui connaisse bien toutes les proportions et les dimensions convenables, qu'il sache en outre bien exécuter. Convenons-en, un tel homme est bien rare, surtout dans les campagnes.' Deslandes, *Élemens d'agriculture,* 104.

[148] *The Boke of Husbondrie* (1540), 4.

[149] A possible improvement can be seen in the changing design of scythe handles, which seem to have evolved in the Middle Ages from the straight pole of Roman times to the more efficient elongated S-shape. Comet 'Technology and agricultural expansion'

centralized production of models incorporating superior designs.[150] In principle nothing in the technology of pre-industrial methods of wood and iron-working posed an insuperable barrier to large-scale manufacture of farm equipment. Jigs and templates had long been employed in naval arsenals, and the early eighteenth-century patent application for the Rotherham plough envisaged assembling units from pieces shaped on moulds.[151] What blocked this solution was the monopoly of production conferred on local artisans by their spatial monopoly of repair services. Subjected to wide fluctuation in moisture and mechanical stress, wooden implements held together by mortise and tenon had continually to be adjusted and refitted, while shares and coulters abraded by sand and stones had to be repeatedly sharpened and forged anew. [152] Although most farmers could manage simple repairs,[153] complex joinery, special woods, and forged iron demanded specialists, and the urgency of repairs demanded them to be on the spot. Even when mass-produced implements succeeded in penetrating the countryside, their repair remained the province of local craftsmen, who were not always up to the task.[154]

The multi-faceted activity of the craftsmen who built and maintained farm equipment can be seen in the entries of a day book kept by a wheelwright outside Versailles in the 1770s and 1780s. [155] On July 10, 1778, he put in a half day mounting a large wagon, readjusting a plow, cutting a beam, framing a new plough, and repairing a cart; on August 28, he adjusted a farmer's plow and harrow and delivered three new plow beams; on October 9 and 10 he delivered a pair of wheels and a stable door. Most of his work consisted in repairing vehicles. Clients ran tabs settled in kind or in cash.[156] To break the monopoly held

---

[150] Brunt, 'Mechanical innovation.'

[151] 'Nor need they fit every plough to every share as now, by reason that each ploughwright having a ploughshare by him and fitting his ploughs to the said share, they'll naturally fit all other shares, tho' never so great a number of each be made at a distance from the other.' Cited in Marshall, 'Rotherham Plough,' 133.

[152] 'Les socs, les instruments aratoires exigent de fréquentes reparations.' Cambry, *Description .. de l'Oise,* 168 Using replicas of a medieval plough, Danish investigators wore out shares after ploughing two hectares and the wooden implement broke apart twice. Lerche, 'Ridged fields.' In the eighteenth-century farmers renewed their plough shares three times a season. Woronoff, *Industrie sidérurgique,* 431. At the end of the nineteenth century shares employed in dry soils had to be re-forged every 2400 to 3000 meters. (Ringelman, *Culture mécanique* vol. 7, 145). The wooden 'ears' attached to ards in southern France had to be replaced every five months. Leure, *Guide des cultivateurs,* 126.

[153] 'Les anciennes charrues sont si simples, que la plupart des colons les construisent eux-mêmes.' Munier, *Observations concernant les amélioriations.*

[154] The introduction of Belgian swing plows in the 1820s was frustrated by inability of local wrights and blacksmiths to repair them. Dureau de la Malle, *Description du bocage percheron,* 98.

[155] Plancouard, *Les comptes d'un charron-forgeron.*

[156] From a farmer's account from the same region. 'Je dois au charron 55# pour 35 journées et 5 mines de blé.'Plancouard, *Comptes d'une ferme vexinoise,* 22.

by local wrights and smiths, industrial manufacturers not only had to supply better implements at competitive prices, they had to deliver replacement parts at short notice, something difficult to achieve even in the railway age.[157] The exception was scythes and sickles, light enough to stand the cost of long-distance transport, easy to repair in the field, and requiring steel-forging skills that were not readily exportable.[158]

The spatial fragmentation in manufacture of ploughs had its counterpart in the fragmentation of the know-how associated with their use. Ploughing was a skill that took took years to master and able ploughmen were highly remunerated.[159] Their skill, however, specific to the type of plough and soils in which it was acquired, and its value declined rapidly outside its district of origin.[160] In England ploughmen were typically recruited from within a dozen miles of where they worked.[161] Their site-specificity thus made them poor vectors of the diffusion, and impeded efforts to introduce improved ploughs requiring different skills to operate. Thus an attempt in the eighteenth century to introduce an improved plough from the Brie to farms in the Limousin failed in the face of labourers' refusal to abandon the local inefficient implement.[162] Again, the comparatively rapid substitution of the scythe for the sickle

---

[157] In the early twentieth century the shortest delay was one week. 'On voit que dans les circonstances les plus favorables, il y a 8 jours de délai. C'est un minimum. Il faut compter 10 à 15 jours pour les expéditions à distance moyenne, soit plus de trois semaines avec celui nécessaire à l'envoi.' Ringelmann, *Compte rendu,* 175

[158] Tresse, 'Développement de la fabrication des faux.' The skills needed to produce blades of adequate quality were difficult to replicate. 'On a tenté vainement d'en fabriquer dans les ateliers de la Haute Vienne; jamais on n'a pu leur donner la malléabilité de celles de la Germanie.' Texier-Olivier, *Statistique de la Haute-Vienne*, 335.

[159] A ploughman for one of the largest farms in France related that it took ten years to learn the craft. 'C'était un métier de petits trucs. Celui qui n'avait pas observé, celui qui n'avait pas retenu, ne devenais jamais charretier.' Mavré, *Chevaux de trait,* 24. Heuzé comments on the difficulty of drawing ploughmen from the ranks of ordinary day labourers, who make 'des charretiers temporaires et souvent très-inhabiles dans la conduite des chevaux ou des boeufs. Heuzé, *Les assolements,* 170.

[160] 'Ce n'est qu'à la suite d'une pratique de quelques années qu'on acquiert l'habilité nécessaire pour être appelé un bon laboureur. On doit de toute nécessité faire au même temps attention à la largeur, à la profondeur et à la direction qu'on donne à la raie, et par conséquence faire mouvoir la manche en haut ou en bas, à droite ou à gauche, et veiller à la marche des chevaux. Tel est habile dans le lieu où il est accoutumé d'opérer, ou avec les animaux qu'il connoit, qui ne fais qu'un mauvais labour dans un autre canton, dont la nature de la terre est différente, ou avec des animaux nouvellement achetées.' Tessier, *Encyclopédie méthodique*. V. (1813), 111.

[161] The median distance between successive employers for a sample of seventeenth- and eighteenth-century farm servants was four to five kilometers in Sussex and Hertfordshire and ten kilometers in Yorkshire. Fewer than ten percent travelled more than 15 kilometres. Kussmaul, 'Ambiguous mobility.'

[162] 'Quelques cultivateurs on tenté d'introduire cette charrue…mais l'attachement des gens du pays aux anciennes routines, les a forcés d'y renoncer.' Cochon de Laparent, *Description générale ... de la Vienne,* 65.

in the nineteenth century provides an illuminating contrast with the tools of tillage; scythes were owned by migrant workers.[163]

As in the case of crops and livestock, improvements in farm implements were stimulated by events originating outside the agricultural sector. The original improvements to the scythe seem to have occurred in Flanders, where heavy crops and seasonal labour shortages led to the development of the *pik* – a short-handled scythe – and the early adoption of the scythe to harvest wheat and rye.[164] The same region was also the site of the development of the light swing plough, one of the models of the Dutch plough introduced to England in the seventeenth century and improved iron Belgian ploughs of the early nineteenth. The farming districts that provisioned Paris with grain developed the plough with a reversible share, which accelerated the work and permitted fields not requiring extra drainage to be ploughed flat rather than worked up into ridges and furrows. Improvement in farm vehicles seems to have originated in the transport sector.[165] In Flanders, the superior skill of rural smiths and wrights may have been acquired meeting the demand for vehicles and fortifications generated by near continuous warfare.[166] On their own, rural districts possessed little indigenous capacity to improve the stock of farm equipment. Well into the nineteenth century, farmers throughout much of western France ploughed with a primitive implement that had a simple plank for a mouldboard and at the cost of a huge load on the draft animals turned the soil to a depth of two to three inches while leaving half the sod untouched.[167] This patently defective implement survived in remote corners of western France down to the beginning of the twentieth century.[168]

Transport and Productivity

While nothing alters the distance between two points, the economic significance of that distance depends on the cost of transporting materials, people, and information across it. Had the cost of transporting farm produce been trivial, the geographical pattern of agricultural specialization would have

---

[163] Grantham, 'La faucille et la faux.'
[164] Comet, 'Technology and agricultural expansion'
[165] Eric Kerridge, *Agricultural revolution* (1967), 36.
[166]'Les forgerons, charrons, ont été exercés à les construire, en sorte que, de proche en proche, ces instruments ont passés des des travaux publics dans les fermes, et sont devenus après une expérience aussi longue que heureuse, les seuls en usage en Flandre française.' Cordier, *Mémoire sur l'agriculture,* 193.
[167] 'Il n'y a guère que la moitié du terrain de labourée, parce qu'il reste à chaque sillon des bandes de terre assez large, que le soc n'atteint pas, et qui ne sont ouvertes que par un second labour aussi pénible que le premier, et ces labours ne pénètre qu'à deux ou trios pouces. Sub-Prefect of Mayenne, 30 Pluviôse An 10 A.D. Mayenne 7M 242. For descriptions of a similar ploughs, see Texier-Olivier, *Statistique de la Haute Vienne,* 333, and Jamet, *Cours d'agriculture,* 41, 69.
[168] 'Machines agricoles dans la Mayenne,' in Ringelmann, *Compte rendu,* 191.

reflected the location of natural endowments, and the aggregate demand for produce would have reflected the productivity and income of consumers independently of their location.[169] In such an economy effective market demand for produce would be in accordance with Say's Law. In the presence of high transport costs that connection is partly severed, because as Von Thünen pointed out, as distance increases between producer and consumer, transport costs absorb an increasing share of the demand price. Transportation improvement was thus a possible cause of pre-modern agricultural improvement. The logic is transparent. By raising the net price (and price elasticity) of farm produce, falling transport cost induces spatial extension of investments that increase agricultural productivity. The proposition is supported by the evidence from regional comparisons and simultaneous improvement in transportation and agricultural productivity in northwest Europe after 1650. As with population growth, however, the analytical problem is how to identify lines of causation. Just as in farming, the technology of land and inland water transport was laid down in the Late Iron Age and classical antiquity, and as in agriculture, its productivity fluctuated with the state of demand.[170] The underlying dynamics are therefore similar to those governing the productivity of traditional husbandry: in that variations in intensity of demand caused spatial and temporal variation in the exploitation of the latent potential of a static technology. The one (major) difference was that road and river improvements are public goods, and therefore posed distinct institutional problems of finance affecting their historical development. Nevertheless, the parallel with agricultural history is striking.

Our primary enquiry concerns the spatial correlations between agricultural productivity and the performance of pre-industrial transport systems. Regions situated in proximity to major towns and cities obviously benefited from the density of good land transport provided by a hub and spoke road configuration and by investments in bridges, pavement, and waterways induced by the high volume of traffic generated by the need to supply a large urban population. In early nineteenth-century France the density of primary (and presumably surfaced) highways in the first ring of the Parisian provisioning zone was 50 percent greater than in the second ring of *départements* and nearly 100 percent greater than in the

[169] Cf., Latham and Neale, 'International market for wheat and rice'
[170] Appendix B gives an inadequate summary of the evidence for this statement.

third.[171] Paving the roads close to Paris after 1650 Paris produced significant improvements in the rolling stock utilized by farmers to deliver produce, which raised its on-farm price.[172] The crucial factor was the value/bulk ratio. On good roads, four to six horses could haul two tonnes; drawing barges, a dozen could haul 20 to 40 tonnes. Bulky farm produce thus preferred waterways to roads for large shipments over long distances.[173] London drew the greater part of its grain not via the upper Thames, but from ports on the Kentish and East Anglian coast.[174] A map of the provenance of grain sold in Nantes in the late eighteenth century shows a string of small ports on the Loire and up and down the Atlantic coast, but hardly any towns in the city's immediate hinterland. By contrast, the origins of manufactured articles sold there are distributed according to the contemporary economic geography of northern France.[175] Paris was something of an exception as an inland port situated at the confluence of several rivers draining an extensive and productive basin. The city originally drew most of its produce by water, but local road improvement in the eighteenth century led to the grain and flour trade to take the highways.[176] Unlike that of Nantes, the Parisian provisioning zone was geographically compact, which magnified the impact of urban demand on agricultural productivity. .

Inland waterway had their own difficulties in circuitous routes, tolls, low water, freeze-ups, monopolistic shipping cartels, and leaky boats.[177] The main obstacle to their intensive use for long-distance shipments of farm produce, however, was the difficulty of massing 20 to 40 tonnes of grain in one place. In lesser, measure, the same was true of gathering one- to two tonnes to fill a wagon. We come here to the principal cause of joint stasis in agriculture and transportation outside the urban core. Low-cost transport of farm produce required exploiting latent scale economies in shipping and storing cereals. But exploiting those economies meant accumulating sufficient produce at one point to cover the fixed cost of loading and

---

[171] In 1820 improved road density in Seinet-et-Oise, which encircles Paris, was 1.27 km per km^2; the average density in the next ring of départements (Oise, Aisne, Seine-et-Marne, Loiret, and Eure-et-Loir) was 0.82; in the next ring (Aube, Yonne, Marne, and Eure) it was 0.67. Lepetit, *Chemins de terre,* 50-51.
[172] Moriceau, *Fermiers,* 292-93.
[173] 'Lorsque la petite rivière d'Étampes étoit navigable, & qu'on entretenoit les écluses, prescque toute la négoce des blés de Beausse se faisoit par cette ville; d'où ils arrivoient au Port de la Tournelle à Paris, sur de petits bateaux de dix muids de blé chacun. Savaray des Brulons, *Le Parfait négociant,* 7
[174] Campbell et al, *A medieval capital*, 60-61.
[175] Daudin, *Commerce et prospérité*, 62.
[176] Kaplan, *Provisioning Paris,* 103-107.
[177] Billaçois, 'La batellerie de la Loire'; Meuvret, *Le commerce des grains.* Baltic grain was notoriously inferior owing to water damage, and in France demagogues commonly charged that grain imported by the government to feed the people in times of shortages were in fact part of a plot to poison them. Kaplan, *Bread and politics.*

unloading and maintaining draft animals that consumed fodder even when they were not working. Failure to exploit those economies perpetuated high transport costs, which deterred farmers' investments in more productive forms of agriculture. In turn, low productivity limited the surpluses whose carriage could have sustained more efficient road and water transport.

A major obstacle to massing surpluses for efficient shipping stemmed from the slow release of grain into trade. Farmers in northern Europe commonly commenced harvesting early to insure the crop against damage from summer storms and to reduce the seasonal labour shortage by spreading the work over a longer season.[178] Grain harvested in these conditions could not be threshed at once, because it was not mature and had to be left in the sheaf to ripen. It was for that reason that 'old' grain sold at a premium.[179] Farmers who could afford to wait did not begin to thresh before December, and if possible delayed the operation until the end of winter. In Tusser's doggerel,

> 'Such wheate as ye keepe, for the baker to buy,
> Unthreshed until March, in the sheaf let it lie.
> Least moissures take it, if sooner ye thresh it,
> Although by oft turning ye seeme to refresh it.'[180]

The Rules of Robert Groseteste enjoins reeves from threshing oats before Christmas.[181] It was simple prudence to keep cereals in the sheaf as long as possible, as the loose stacks protected the crop from mildew and germination while obviating the cost of stirring threshed grain every two or three weeks to keep it from spoiling. It was only the spring hatch of insects in the straw that finally forced farmers to thresh the lot. There was an even more pressing reason for delaying threshing. Just as grain improved in the sheaf, so straw preserved its palatability in the grain, and straw was a critical component of winter feed for livestock, which meant that the rate of threshing was governed not by the price dynamics of the market

---

[178] 'On scie le bled, même sur le verd, quand on craint de gros vents qui le feroient verser ou qui l'égreneroient.' Liger, *Maison rustique,* 577.

[179] Old grain was easier to mill, yielded more flour, and made better bread. Kaplan, *Provisioning Paris,* 50-51.

[180] Tusser, *Hundreth good pointes* ((1585 edition), V: verse 5. Estienne and Liébaut, advise farmers to let the grain ripen in the sheaf at least three months before threshing. *L'agriculture et la maison rustique,* 300. According to *The Rules of Robert* Grosseteste. 'Also do not permit that on any manor oats are threshed, anywhere, before Christmas, be it for fodder or for sale, before that date all should be bought if you can. Oschinsky, *Walter of Henley,* 307.

[181] Also, do not permit that on any manor oats are threshed, anywhere, before Christmas, be it for fodder or for sale, before that date all should be bought if you can. Oschinsky, *Walter of Henley,* 307.

for grain, but by on-farm demand for its joint product.[182] Threshing was controlled by the demand for straw as fodder because threshed straw dried out causing the animals to reject. The cost of delaying grain sales was usually lower than the cost of obtaining substitute feed for animals, which given its cost of transport would have had to be grown on the farm.[183] These constraints on the timing of threshing and therefore sales of grain put the notion that the release of grain was governed by the cost of inter-temporal smoothing in the market for grain in a new light.[184] What might be termed the user cost of creating inventories of threshed grain was extremely high, not so much because the cost of financing them was high, but because the opportunity cost in quality and straw was high.

These elements of traditional husbandry in northern Europe – in the south hard wheat varieties and a dry climate permitted immediate threshing—had important implications for the efficiency of the transport system for produce. To begin with, storing the crop in the sheaf ensured that grain remained dispersed on farms rather than concentrated in centralized granaries.[185] The slow rate of threshing on individual farms in turn caused that stock to come onto the market in thin trickles in small carts or on the backs of pack animals rather than in packets large enough to fill a barge or wagon.[186] Given the high marginal cost of carting and pack trains, distances travelled were normally short, which meant that the bulk of corn not consuimed on the farm was distributed locally. The dispersion and slow release of cereals into trade thus reinforced the segregation of metropolitan and local markets, the latter served by a host of small traders arbitraging small

---

[182] 'Le besoin de paille pour les bestiaux, la nécessité de se procurer de l'argent, ou l'avantage de la vente de chaque denrée, règlent et déterminent la quantité de gerbes que le fermier fait battre.' Masson de Saint-Amand, *Mémoire statistique*, 92. Corn is threshed 'à mesure de la consommation des pailles.' Dauchy, *Statistique de l'Aisne*, 9. 'La paille du froment est le fourrage qui convient aux chevaux.' Quesnay, 'Fermiers,'168. 'La paille de froment, battue & dépouillée de son grain, se donne par gerbes aux bestiaux, principalement aux chevaux, la nuit & le jour, outre leurs ordinaires d'avoine; & quand ils l'ont bien tirée au ratelier, ce qui en reste leur sert en litiere.' Liger, *Maison rustique,* 581.

[183] La paille se consomme dans le pays ainsi que le foin. S'il y a un vide, on se restreint dans la consommation; mais on n'est point dans l'usage d'en faire porter des Départments voisins. Les transports rendraient la denrée trop coûteuse.' Enquête sur les fourrages 1813. Département des Basses-Pyrénéees. Archives Nationales. F^{111} 494.

[184] Discussion of this issue has unfortunately turned on the question whether farmers were 'rational' rather than on the technological details of the specific case in hand.. See. McCloskey and Nash, 'Corn at interest'; Komlos and Landes, 'Anachronistic economics', McCloskey, 'Conditional economic history.'

[185] Straw made up approximately 70 percent of the weight of a sheaf.

[186] 'On trouve 1,024 anes ou anesses appartenent à des meuniers, coquetiers, blatiers ou à quelques laboureurs qui s'en servent pour monture dans leur vieillesse pour aller aux marchés voinsins, ou pour se transporter à de petites distances. Ces animaux sont d'une très petite espèce dont il ne se fait presque aucun commerce.' Compte pour an 1814 concernant l'état de l'agriculture dans le département de Gers. A.N. F^{11}494-496.

price differentials for a return scarcely exceeding a day labourer's wage.[187] The spatial segmentation of grain markets was reinforced by the need to clean cereals intended for sale in metropolitan markets to a standard known as 'merchant quality' and purged of straw, weed seeds, mouse droppings, and dead insects that would otherwise cause it to be sold at a heavy discount. The operation was expensive enough to drive a significant cost and price wedge between grain marketed locally and grain entering into more extensive circuits of exchange.[188] Unless a farmer was located near a major trade route –usually a waterway—he usually avoided the cost of the operation, which made sense only if he had a large disposable surplus ready to sell in a metropolitan market. In principle, cleaning and aggregation of dispersed stocks could have been carried out by middlemen, but that involved incurring the cost of constructing and maintaining storage facilities and bearing significant price risk.[189] The contrast with the situation inside the main urban zones is revealing. Benefitting from large markets, alternative sources of fodder, good roads and good port facilities, farmers and middlemen could engage in the trade at its most efficient level.[190] Here, too, one observes the two opposing forces of agglomeration and dispersion that determined the average level of agricultural productivity over nation-wide space.l

The segmentation of the grain market directly affected the efficiency of rural road networks, because the low volume of traffic in the non-urban sector put little stress on the dense web of tracks that since the Celtic age had connected farms with villages and villages with market towns. The cobweb of connecting paths made it easy for carriers to detour bottlenecks and breaks, which removed the incentive to repair and improve them. Suited to pack animals and two-wheel carts, the often muddy and deeply rutted tracks were impassible to loaded wagons, and dampened any interest in improving the 'rolling stock.' It was a system of capillaries adapted to low-intensity movement of people and goods. The arteries were hardly better. Except where the route was confined by mountain gorges, carriers had a choice of routes between any two points. The roads typically followed the ridge line to avoid flooding, which meant steep

---

[187] '…le nom de blatiers est demeuré à certains petits marchands forains qui vont avec des chevaux ou des ânes chercher du bled dans les campagnes èloignées des grandes villes et des rivières, et l'amène à la somme dans les marchez.' Delamarre *Traité de la police* Cited in Meuvret, *Le commerce des céréales*, 102. On evidence of their illiteracy, see *Ibid.*, 104.

[188] Cleaning and screening were among the first agricultural operations to be mechanized. Meuvret, *Commerce des céréales,* 20-21.

[189] On these points, see Grantham, Espaces priviligiés,' 715-16.

[190] Kaplan, *Provisioning Paris*

pitches to avoid the cost of bridges and causeways on uneven terrain.[191] Even prominent routes were impassable to all but light loads carried by pack animals or ox cart.[192]

As in the Middle Ages, pressure to improve roads emanated from cities where the volume of trade warranted investment in paving and bridges. The map of English turnpikes between 1660 and 1800 shows an expanding radiation from London and a proliferation of scheduled shipping services tracking it.[193] The investment was induced by demand for faster and safer transport. A similar radiation characterized the roads leading to Paris, although the presence of water routes inhibited investments in what were otherwise natural routes. There were no good roads, for example, between the port of Rouen and Paris, and in the 1670s Colbert instructed the Intendant of Soisson not to spend state funds improving the road to Paris, but pave the road across the height of land connecting the Oise with the Scheldt and Flanders.[194] As in Roman times, military considerations had a crucial role in determining where the investment was made.. The British government had an interest in the Great North Road to Scotland, and the pike from London to Harwich in East Anglia, which for a time was England's most heavily used agricultural road, was initially constructed for strategic purposes.[195] In France, much of the investment in highways and bridges was on routes leading to the battlegrounds of Italy.

The poor state of local networks thus reinforced the isolation and self-sufficiency of rural districts outside the urban core.[196] Where paths were impassable to vehicular traffic and even at times to pack

---

[191] Cavaillès, *La route française*, 62.

[192] 'Le tempérament, et surtout l'ardeur naturelle du cheval, ne lui permettroient pas de voiturer avec succès les engrais et les récoltes, à travers d'horribles sentiers, presque tous défigurés par de profondes ornieres et par d'épouvantables ravines;...Il n'y a que le boeuf, par sa marche tranquilloe et sûre qui puisse parcourir ces aspérités et qui puisse charroyer d'immenses fardeaux dans des chemins å peine praticables pour les hommes même.' M.-L. Texier-Olivier, *Statistique .. de la Haute-Vienne*, 334.

[193] Albert, *The turnpike road system in England*; Chartres, 'Road carrying in England..

[194] À l'égard des ouvrages à faire dans l'étendue de votre généralité, vous devez observer que le chemin de Paris ne regarde que les coches et carrosses qui marchent ordinairement sur ce chemin, parce que, à l'égard des vins, blés et d'autres marchandises qui viennent à Paris, elles viennent par eau. Ainsi le chemin de Paris n'est point nécessaire pour la consommation des denrées et l'utilité du commerce. Mais, comme le chemin des voitures des vins de Champagne et Soissonnais pour la Flandre et beaucoup plus utile parce que c'est par ce moyen de ces vins que l'argent vient dans ces provinces, j'estime qu'il faut préférer les ouvrages à faire sur ce chemin, pour la facilité des voitures, à celui de Paris.' Cited in Cavaillès, *La route français*, 54-55.

[195] Albert, *Turnpike road system,* 16, 41.

[196] 'Le défaut de débouchés, et la difficulté des transport qu'on est obligé de faire à dos de mulets; ce qui dégoûte les cultivateurs, qui se contentent de récolter des grains pour leur subsistance, et s'inquiètent peu de la reproduction d'un superflu dont ils ont peine à trouver le débit, les transports étant trop coûteux.' Cochon de Laparent, *Description ... de la Vienne,* 71.

animals, farmers had no reason to increase production..[197] It is hardly any wonder, then, that in the early 1670s Madame de Sévigny bragged to her daughter that she had sold a piece of her estate in Brittany that only rendered corn.[198] The connection between low agricultural productivity and poor transport is a system externality rooted in the dispersion of agricultural production and markets for agricultural produce. As long as transport costs remained high, it was cheaper to locate the manufacture of non-luxury tradables in the countryside rather in the cities where food costs were high; but a dispersed population of rural manufacturers could not support a transport network that could move bulky produce efficiently.[199] And without such a network, the demand price of produce in most regions was too low to induce the kind of investments needed to exploit the full potential of traditional husbandry.

Conclusion

We are now in a position to sum up. Until the constraints on productivity embedded in the production function of traditional husbandry were relieved in the 1840s by innovations in agricultural machinery and concentrated mineral fertilizers, the possibilities for agricultural improvement resided in the responses to effective demand farm produce. Accordingly to conventional classical and neoclassical analysis rising for the products of the land inevitably resulted in rising real prices owing to the operation of the law of diminishing returns. Yields might rise, but only because the marginal return to additional capital and labour employed in producing foodstuffs was falling. This paper has argued that the conventional Malthusian account is flawed because it does not take into account systematic indivisibilities in production and distribution of farm produce that supported increasing return to additional inputs when the demand price of produce warranted them. Those indivisibilities were linked in a system of positive externalities to locked in low-intensity farming practices where demand for produce was diffuse. Most of pre-industrial Europe was in that situation, so average agricultural productivity was low. It was only in regions where the concentration of

[197] 'Dans une partie du department il est impossible de rien voiturer pendant dix mois de l'année autremont qu'à dos de mulets, il est même des cantons où les chemins sont impraticables toute l'année pour les voitures.' Cochon de Laparente, *Description …de la Vienne,* 71.
[198] 'Nous en avons vendu une petite où *il ne venait que du blé,* dont la vente me fait un fort grand plaisir.' *Lettres de Madame de Sévigné*. 21 juin (1671).
[199] As late as the 1760s cotton was transported from Liverpool to Manchester by pack trains. Albert, *Turnpike road system,* 8.

consumers aggregated demand to a level supporting extra investment and the exploitation of latent returns to scale that the productivity of traditional mixed farming achieved its full potential.

The dynamic element in the pre-modern history of agricultural productivity was therefore urbanization, the history of which depends in large part on factors that have little to do with the productivity of farming. What prevented the urban effect from being more widely diffused was high transport cost. Beginnng around the middle of the seventeenth century – somewhat earlier in the Low Countries – governments and private syndicates began to put resources into improving transport networks. As in farming, the technologies employed had been around for nearly two millennia. Urbanization, investments in agricultural improvement, and investments in roads and waterways were the basis of powerful positive feedbacks in productivity that held off the law of diminishing returns until the coming of the railway and the steamboat created a new definition of agricultural and economic space. By 1900 the telegraph, the railroad and the compound maritime steam engine had together created a virtual market aggregating demand for tradable foodstuff from the whole interconnecting world. By that time, the spatial influence of cities on agricultural productivity had ceased to matter.

Afterword

The empirical supports for this paper draws heavily on evidence drawn from the records of pre-industrial France, which are abundant, well-understood, and accessible. That dependence raises the question whether the mechanisms it describes were peculiar to France, which as a large and partly landlocked nation faced higher transport costs than England or the Low Countries, though not higher than in central Europe, where conditions were even less favourable to urban-based transport systems. I do not believe this to be the case for the following reasons. The English case is special because of England's abundance of drowned estuaries, which made the greater part of England's best corn-growing districts east of the Pennines accessible to waterrborne transport. Like the Low Countries, England exemplifies Adam Smith's point that regions blessed with good water transport were likely to develop productive farming at an early stage. England's precocious administrative unification and the island's immunity from conflicts both foreign and domestic (the continental conflicts usually reflecting foreign interference) significantly lowered the costs of long-distance trade in foodstuffs relative to the situation on the Continent. A test of this argument could be constructed from the history of agricultural change in Central Europe between 1400 and 1700. Down to the outbreak of

the Thirty Years War, the spine connecting northern Italy and the Low Countries was dotted with prosperous urban centers, some of which had populations approaching 50,000. The agricultural economy that supported this incipient urbanization was destroyed by three decades of devastating civil war during which armies literally lived off the countryside. Further east, the Ottomans and the Turkish nomads of the Russian steppes kept much of that part of the world in disarray through the first decade of the eighteenth century, with corresponding consequences for investment.[200] The history of agricultural productivity probably owes as much to the ebb and flow of political violence as it does to the technological and institutional factors commonly considered to be determining. When eighteenth-century writers like Hume and Smith talked about the security of property, they were thinking of these extreme cases. The history of agriculture, then, is also linked to the broader history of large-scale violence. The history of that connection remains to be written.

[200] Darwin, *After Tamerlane*

Appendix A
Estimation of Agricultural Supply Zone

Let C be total grain output in hectoliters, r the radius of the provisioning zone in kilometers,[201] γ is the proportion of land sown in bread cereals, and y and s the average yield and seeding rate, respectively. Total supply is computed as the mean regional yield (net of seed) times hectares sown:

$$C = 100\gamma\pi r^2 (y - s) \qquad \mathbf{1}$$

The rural population required to \produce that supply (farmers plus dependents) is given by

$$Z = 100\gamma\pi r^2 \mu y \qquad \mathbf{2}$$

where μ is adjusted man years of labour input per hectolitre.[202] If rural and urban people consume the same amount of grain per capita, regional self-sufficiency in corn is expressed by the identity:

$$C = X + Z = \frac{100\gamma\pi r^2 (y - s)}{\alpha} \qquad \mathbf{3}$$

where X is the urban population and α annualized per capita consumption. For a city of population X, one can compute the hypothetical radius of its provisioning zone for different combinations of yields, seeding rates, labour productivity, and per capita consumption. Table A-1 sets out provisioning radii for different yields in a region where the 21 percent of the land is sown in bread cereals and the average input of labour per hectoliter is 6 man days. These figures are representative of conditions in northern France in the seventeenth and eighteenth century.

[Insert Table A-1 here]

[201] A square kilometer contains 100 hectares

[202] To make units of labour input and rural per caput subsistence consumption commensurable, man days per hectare are transformed into man years, and the man years transformed into the equivalent agricultural population. I assume a work year of 250 days and use estimates of the contemporary age and sex structure and participation rates to compute the relevant rural population. The assumed participation rate transforming full-time labour equivalent labour input into an estimate of the agricultural population is 60 percent. The evidence for this ratio is drawn from Marchand and Thélot, *Deux siècles de travail en France*. For full details on the construction, see Grantham, 'Divisions of labour,' Appendices A and B.

Appendix B

Pre-Industrial Transport

The fundamental innovations in land transport were made by Celtic wheelwrights and blacksmiths, who developed the heavy wagon with pivoting front wheels, axles reinforced with iron bushings, iron-reinforced wheel hubs, iron tires, suspension systems and a braking system, all of which were required to transport heavy loads by land efficiently.[203] Subsequent research has established that Lefebvre des Noëttes' claim that the ancients lacked efficient means of harnessing horse traction is unfounded, having been based on a flawed reading of the iconographic evidence.[204] Current scholarship holds that Roman vehicles were as efficient as any constructed in Europe before the late seventeenth century.[205] Roman roads are of course legendary. In the early fourth century AD the Empire possessed 85,000 kilometer of main highways, most of them paved for speedy transit. Of lesser ways we are naturally less well-informed, but in the first century BC Celtic tracks were sufficiently well maintained to permit British tin unloaded at Mont Saint-Michel on the Breton coast to reach Marseilles in 30 days. [206] Caesar reports that the Celts constructed a bridge across the Rhone, which implies they built other bridges on the main transport routes. Maintaining these facilities was expensive, and with the collapse of government administration and the contraction of trade in the fifth and sixth centuries the roads and vehicles designed for them fell into disrepair and disuse. It is conjectured that the craft of making heavy wagons with pivoting front wheels may have been lost and had to be reinvented by medieval wheelwrights in the thirteenth century. Be that as it may, Roman land transport was as efficient as anything Europe possessed before the eighteenth century.

The same is true of water transport. Unger's account of classical shipbuilding suggests that the big Roman merchant ships were as efficient and seaworthy as medieval ships down to the early sixteenth century, and notes that 'the essential body of information about the performance of vessels in the water did

---

[203] Sandars, 'Wheel wrights and smiths'; Weller, 'Roman traction systems'
[204] Raepset, 'Archéologie et iconographie des attelages'; Amouretti, 'L'attelage dans l'antiquité'
[205] Weller, 'Roman traction systems'
[206] Muhly, *Copper and tin,* 473-74, citing the Greek historian Diodorus Siculus. Caesar reports that the Celts bridged the Rhone, which implies bridges across lesser streams on the principal trading routes.

not change over the millennium.'[207] From the standpoint of agriculture, however, it is inland waterways that matter the most. The Gauls enjoyed an active fluvial commerce.[208] Strabo marvelled at their network of rivers, so well disposed that one could pass from one Ocean to another at the cost of a short portage.[209] The Romans maintained an intense inland navigation, which like their roads subsequently atrophied from disuse and disrepair.

The economic recovery of the twelfth and thirteenth centuries was accompanied by a revival in the transport network. By the end of the thirteenth century the efficiency of land transport was probably as great as it would be in the eighteenth century. A unique notarial register from Troyes dated July, 1296, contains seven contracts between merchants and professional transporters for shipments of cloth to French ports on the Mediterranean that stipulate the date of departure and the date of delivery.[210] The implied rate of travel through the difficult mountains of southern Auvergne is 26 to 32 kilometres per day. In 1837 the standard rate for scheduled hauling between Paris and Aix-en-Provence was 30 kilometres per day.[211] That the expected pace was not unusual can be inferred from Pegolotti's *La pratica della mercatura*, which states that haulers covered the 660 kilometres between La Rochelle and Nîmes, far from being a main thoroughfare, in 17 days.[212] They would not have moved more slowly in Roman times. These performances were a product of investment in roads and tracks financed by the users. In 1203 Blanche de Navarre, recent widow of the count of Champagne made a contracted with a group of entrepreneurs to pave the road between Troyes and Sezanne in exchange for the right to collect tolls for a determined number of years.[213] In England the number of bridges on main roads around 1300 was the same as it was in 1750, and to judge from the royal purveyance the cost of land transport was no higher.[214] Similar investments were put into inland waterways. On the much-traveled Loire, levies were erected to check flooding and deepen the main channel; the Seine was improved between Nogent and Troyes by Philip the Bel to facilitate

---

[207] Unger, *The ship in the medieval economy,* 24.
[208] Bonnard, *Navigation fluviale de la Gaule*
[209] Strabo, *Geography,* 4.1.14.
[210] Bautier, 'Les registres des foires de Champagne'
[211] Shippers avoided the easier route along the Rhone because it bordered the Empire, whereas the inland route between Le Puy with Nîmes lay entirely within the kingdom of France. By the seventeenth century the road had all but vanished, and locals believed its paving stones had been set by the Romans. Bautier, 'Rercherches sur les routes', 120-122
[212] Cited in Bautier, 'Routes de l'Europe médiévale,' 130.
[213] Bautier, 'La route française,' 82-83.
[214] Harrison, 'Bridges and economic development'; Masschaele, 'Transport costs in medieval England'

transport between Paris and the fairs of Champagne. As in land transport, these improvements were accompanied by a multiplication of tolls.[215] In the fifteenth century the Dukes of Burgundy improved the Smabre and constructed locks on the Senne opening up a direct inland water connection between Brussels and Antwerp. Charles VII's canalization of the Eure provided the landlocked city of Chartres with a port right in the middle of town.[216] The most intense investments were in urbanized Flanders. Thirty 30 kilometres from the sea, St-Omer canalized and deepened the Aa to admit ocean-going ships displacing as much as 150 tonnes.[217] Ypres financed the Ieperleet canal linking Bruges with St-Omer via Ypres, providing an alternative route from Bruges to northern France and eventually the occasion for war with Ghent.[218] The upper reaches of the Deûle were dredged to permit barges displacing 30 to 50 tonnes to carry grain from Artois to Lille. By 1300 the system of inland waterways connecting the Flemish towns with each other and with the grain-producing regions of the interior was better than it was under Napoleon.[219]

References

Acquaah, George, *Principles of plant genetics and breeding.* Oxford: Blackwell (2007).

Allen, Robert C., 'The growth of labor productivity in early modern English agriculture,' *Explorations in economic history* 25(1988) 117-146.

Allen, Robert C. 'The two English agricultural revolutions,1450-1850,' in Bruce M. S. Campbell and Mark Overton, eds., *Land, labour and livestock. Historical studies in European agricultural productivity.* Manchester: Manchester University Press. (1991), 236-55.

Campbell, Bruce M.S., James A. Galloway, Derek Keene, and Margaret Murphy, *A medieval capital and its grain supply.* London: Historical Geography Research Paper Series 30 (1993).

Allen, Robert C. *Enclosure and the yeoman.* Cambridge: CUP (1992).

Allen, Robert C., 'Tracking the agricultural revolution in England, *Economic history review* 52:2 (May 1999) pp. 209-35.

Allen, Robert. C., 'Progress and poverty in early modern Europe,' *Economic history review* 56 (2003), 403-443.

Albert, William, *The turnpike road system in England, 1663-1840.* Cambridge: CUP (1972)

Ambrosoli, Mauro, *The wild and the sown. Botany and agriculture in Western Europe: 1300-1850*. Cambridge: Cambridge University Press (1997).

---

[215] Bautier, 'Circulation fluviale, 24-25.
[216] *Ibid.* 25-26.
[217] Derville, 'Rivières et canaux'
[218] On the consequent conflict provoked by the city of Ghent, see Sortor, 'The Ieperleet affair.'
[219] Derville, 'Rivières et canaux'

Amouretti, Marie-Claire, 'L'attelage dans l'antiquité : le prestige d'une erreur scientifique,' *Annales ESC* 46 (1991), 219-32.

Audoin-Rouzeau, Frédéric, 'Compter et mesurer les os animaux. Pour une histoire de l'élevage et de l'alimentation de l'antiquité au temps modern,' *Histoire et mesure* 10 (1995), 277-312.

Aujollet, P. *La vache et ses produits.* Paris : Maison rustique (n.d.)

Ball, C. R., 'The history of American wheat improvement,' *Agricultural history* 4 (1930), 48-71.

Bautier, Robert-Henri, 'Les registres des foires de Champagne. À propos d'un feuillet récemment découvert,' in R.-H. Bautier, *Sur l'histoire économique de la France médiévale. La route, le fleuve, la foire.* Brookfield VT : Variorum (1991)

Bautier, Robert-Henri, 'Recherches sur les routes de l'Europe médiévale. I. De Paris et des foires de Champagnes à la Méditerannée par le Massif Central,' in R.-H. Bautier, *Sur l'histoire économique de la France médiévale. La route, le fleuve, la foire.* Brookfield VT : Variorum (1991)

Béaur, Gérard, 'From the North Sea to Berry and Lorraine: land productivity in Northern France, 13th – 19th centuries,' in Bas J. P. van Bavel and Erik Thoen, eds., *Land productivity and agro-systems in the North Sea area. Middle Ages – 20th century. Elements for comparison.* Turhout (Belgium): Brepols (1999), 136-167.

Biddick, Kathleen, *The other economy. Pastoral husbandry on a medieval estate.* Berkeley: University of California Press (1989)

Billaçois, François, 'La batellerie de la Loire au xviie siècle,' *Revue d'histoire moderne et contemporaine* 11 (1964), 173-75

Blanchard, Ian, 'The continental cattle trades, 1400 – 1600,' *Economic history review* 39 (1986), 427-60.

Bois, Guy, *The crisis of feudalism. Economy and society in eastern Normandy c. 1300-1500.* Cambridge: Cambridge University Press (1984)

Bonnard, Louis, *La navigation fluviale de la Gaule à l'époque gallo-romaine.* Paris : Alphonse Picard (1913)

Brenner, Robert, 'Agrarian class structure and economic development in pre-industrial Europe,' *Past & Present* 70 (1976), 30-75.

Brunt, Liam, 'Mechanical innovation in the Industrial Revolution : the case of plough design,' *Economic history review,* 56 (2003), 444-477.

Brunt, Liam, 'Mechanical innovation in the Industrial Revolution : the case of plough design,' *Economic history review,* 56 (2003), 444-477.

Cambry, Jacques, *Description du department de l'Oise.* Paris : P. Didot (An 11[1803])

Campbell, Bruce M. S., 'The diffusion of vetches in medieval England,' *Economic history review* 41 (1988), 193-208

Campbell, Bruce M. S. and Mark Overton, 'A new perspective on medieval and early modern agriculture: Six centuries of Norfolk farming, c. 1250 - c. 1850,' *Past & present* 141 (November 1993). pp. 38-105.

Campbell, Bruce M. S., and Mark Overton, 'Statistics of production and productivity in English agriculture, 1086-1871,' in Bas J.P. van Bavel and Erik Thoen, *Land productivity and agro-systems in the*

North Sea area. Middle Ages -20th century. Elements for Comparison. CORN Publication Series. Comparative Rural History of the North Sea Area 2. Turnhout (Belgium): Brepols (1999), 189-208.

Campbell, Bruce M. S., *English seigniorial agriculture 1250-1450.* Cambridge and New York: Cambridge University Press (2000).

Cantillon, Richard, *Essay on the nature of commerce in general* [c. 1734]. Trans. Henry Higgs. New Brunswick NJ and London: Transaction Publishers (2001).

Cavaillès, Henri, *La route française. Son histoire et sa fonction.* Paris : A. Colin (1946)

Cavoleau, Jean Alexandre, *Description du département de la Vendée et considérations générales sur la guerre civile de 1793, 1794, et 1795.* Paris (1818).

Chartres, 'Road carrying in England in the seventeenth century: myth and reality,' *Economic history review* 30 (1977), 73-94.

Chartres, John, 'Producers, crops and markets, 1600-1800,' in John Broad, ed., *A common agricultural heritage? Revising French and British rural divergence.* Exeter: British Agricultural Society (2009), 138-144.

Chevard, V., *Histoire de Chartres et de l'ancien pays chartrain, avec une description statistique du département d'Eure-et-Loir.* Chartres An X (1802).

Chorley, P. H., 'The agricultural revolution in northern Europe, 1750-1880: Nitrogen, legumes, and crop productivity,' *Economic history review* 34 (1981), 71-93.

Clark, Gregory, *A farewell to alms. A brief economic history of the world.* Princeton: Princeton University Press (2007)

Clark, Gregory, 'The long march of history': farm wages, population, and economic growth, England, 1250-1869,' *Economic history review* 60 (2007), 97-135.

Cochon de Laparent, *Description générale du département de la Vienne.* Paris : (An X [1802])

Comet, Georges, 'Technology and agricultural expansion in the middle ages: the example of France north of the Loire,' in in Grenville Astill and John Langdon, eds., *Medieval farming and technology. The impact of agricultural change in northwest Europe.* Leiden and New York: Brill (1997), 11-40.

Contamine, Philippe, 'Le cheval dans l'économie rurale d'après des archives de l'ordre de l'Hôpital,' in Elisabeth Mornet, ed. *Campagnes médiévales. L'homme et son espace. Études offertes à Robert Fossier.* Paris: Publications de la Sorbonne (1995), 163-79.

Cordier, Joseph-Louis, *Mémoire sur l'agriculture de la Flandre française*. Paris: P. Didot.

Coutin, Pierre, 'Le labour à la bêche en Limagne,' *Journal d'agriculture traditionelle et de botanique appliquée* 24 (1977), 86-09.

Crafts, N. F. R., 'British economic growth 1700-1850 : some difficulties of interpretation,' *Explorations in economic history* 24 (1987), 245-68.

Crozes, Daniel, *L'Aubrac. La belle aux yeux noir.* Rodez : Éd. du Rouergue (2006).

Darwin, [1]John , *After Tamerlane. The global history of Empire since 1405.* London: Penguin Books (2007).

Dauchy, Luc-Jacques, *Statistique du département de l'Aisne*. Paris (An X [1802])

Daudin, Guillaume, *Commerce et prosperité. La France au xviii^e siècle.* Paris : Presse Universitaire de Paris-Sorbonne (2005)

Johan David, 'Spade cultivation in Flanders,' *Tools and tillage* 5 (1984), 3-12.

Demonet, M., P. Dumont, et E. Le Roy Ladurie, 'Anthropologie de la jeunesse masculine en France au niveau d'une cartographie cantonale (1819-1830), *Annales, ESC* 31 (1976), 700-760.

Derville, Alain, 'Dîmes, rendements du blé et 'Révolution Agricole' dans le nord de la France au moyen âge,' *Annales, ESC* 42 (1987), 1411-1432.

Derville, Alain, *L'agriculture du nord au moyen age. Artois, Cambrésis, Flandre Wallonne.* Lille : Presses Universitaires du Septentrion (1999)

Derville, Alain, 'Rivières et canaux du Nord/Pas-de-Calais aux époques médiévales et modernes,' *Revue du nord* 72 (1980), 5-22.

De Vries, Jan, *The Dutch rural economy in the golden age 1500-1700.* New Haven: Yale University Press (1974)

De Vries, Jan, *European urbanization 1500-1800.* Cambridge MA : Harvard University Press (1984).

De Vries, Jan, *The industrious revolution. Consumer behavior and the household economy, 1650 to the present.* Cambridge: Cambridge University Press (2008).

De Vries, Jan, and Ad van der Woude, *The first modern economy. Success, failure, and perseverance of the Dutch economy, 1500-1815.* Cambridge: CUP (1997)

Deslandes (Conseiller general de la Sarthe), *Elemens d'agriculture.* Paris : Audot (1820).

Dieudonné, Christophe., Stat*istique du département du Nord* Douai : Marlier (An 12 [1804]).

Dixit, Avinesh, 'Investment and hysterisis,' *Journal of economic perspectives* 6 (1992), 107-32.

Duhamel du Monceau, *Éléments d'agriculture.* Paris : H.-L. Guérin et L.-F. Delatour (1762).

Dupin, Baron Claude Françoise Étienne, *Mémoire statistique du département des Deux Sèvres.* Paris (An 12 [1804]).

Dureau de la Malle, A., *Description du bocage percheron.* Paris: Fain (1823)

Estienne, Charles, and Jean Liébaut, *Agriculture et la maison rustique,* Lyon (1583)

Evans, L. T., *Crop evolution, adaptation, and yield*. Cambridge: CUP (1993)

Feldman, Moshe and Ernest R. Sears, 'The wild gene resources of wheat, *Scientific American* 244 (January 1981), 102-112

Fenton, Alexander, 'Team cultivation with the spade in Scotland,' *Journal d'agriculture traditionelle et de botanique appliquée* 24 (1977), p. 77-86

Firmin, Gérard, 'Archéologie agraire et expérimentation,' in Jean Guilaine, ed., *Pour une archéologie agraire.* Paris: Armand Colin (1991), pp. 279-30

Fitzherbert, John, *Fitzherbert's Booke of Husbandrie ... newlie corrected, amended and reduced into a more pleasing form of English than before.* London (1598).

Fortunet, F. *Charité ingénieuse et pauvre misère. Les baux à cheptel simple en Auxoisau xviii^e^ et au xix^e^ siècle.* Dijon : Publications du Centre recherches historiques (1985).

Fossier, Robert, *La terre et les hommes en Picardie jusqu'à la fin du xiii^e^ siècle.* Paris : B. Nauwelaerts (1968).

Fourquin, Guy, *Les campagnes parisiennes à la fin du moyen âge.* Paris : PUF (1964)

Fourquin, Guy, 'Les débuts du fermage: l'exemple de Saint-Denis,' *Etudes rurales* 22-23-24 (July-December, 1966), 7-81.

Franz, Gunter and Heinz Haushofer, *Grosse Landwirte.* Frankfurt : DLG Verlag (1970)

Galor, Oded, and David Weil, 'Population, technology and growth: from Malthusian stagnation to the Demographic Transition and beyond,' *American economic review* 90 (2000), 806-828.

Gilbert, Hilaire-François, *Traité des prairies artificielles ou recherches sur les espèces de plantes qu'on peut cultiver avec le plus d'avantages en prairies artificielles dans la généralité de Paris, et sur la culture qui lui convient le mieux.* 2nd ed. Paris (1826) [1790].

Grandvoinnet, J. A., *Etudes pratiques et théoriques sur les charrues.* Paris (1854).

Grantham, George, 'The persistence of open-field farming in nineteenth-century France,' *Journal of economic history* 40 (1980), 515-32.

Grantham, George, ''Agricultural supply in the Industrial Revolution: French evidence and European implications,' *Journal of economic history* 49 (1989). 1-30.

Grantham, George, 'The growth of labour productivity in the production of wheat in the *Cinq Grosses Fermes* of France, 1750-1929,' in Bruce M. S. Campbell and Mark Overton, eds., *Land labour and livestock. Historical studies in European agricultural productivity.* Manchester and New York: Manchester University Press (1991), 340-363.

Grantham, George, 'Divisions of labour: agricultural productivity and occupational specialization in pre-industrial France,' *Economic history review* 46 (1993), 478-502.

Grantham, George, 'Espaces privilégiés : productivité agraire et zones d'approvisionnement des villes dans l'Europe préindustrielle,' *Annales, histoire, sciences sociales* 3 (1997), 695-725.

George Grantham, 'La faucille et la faux. Un exemple de dépendance temporelle,' *Etudes rurales* 151-152 (1999), 103-131.

Grantham, George, 'In search of an agricultural revolution'. Stanford Social Science Workshop. Stanford, CA (May, 2007).

Grantham, George, 'French agriculture 1250-1500, Crisis and Continuity,' Paper presented at the New York University Conference on Late Medieval Agriculture. Villa La Pietra, Florence, Italy (May, 2008).

Grantham, George, 'The French agricultural productivity paradox: measuring the unmeasurable,' *Historical methods* 33 (2000), 36-46.

Fujita, Masahita, Paul Krugman, and Anthony J. Venables, *The Spatial Economy: cities, regions and international trade.* Cambridge MA: MIT Press (1999).

Fussell, G. E., *Crop nutrition. Science and practice before Liebig.* Lawrence (Kansas): Coronado Press (1971)

Higounet, Charles, *La grange de Vaulerent. Structure et exploitation d'un terroir Cistercien de la plaine de France, xii^e^- xv^e^ siècle.* Paris : S.E.V.P.E.N. (1965).

Hoffman, Philip T., *Growth in a traditional society: the French countryside, 1450-1850,* Princeton: Princeton University Press (1996).

Hoover, Edgar M., *The location of economic activity.* New York: McGraw-Hill (1963).

Husson, Armand, *Les consommations de Paris.* 2nd ed. Paris (1875)

Jacobi, Gerhard, *Die Ausgrabungen in Manching Bd. 5. Werkzeug und Gerät aus dem Oppidum von Manching*. Weisbaden, Franz Steiner Verlag (1974).

Kaplan, S. L., *Bread and politics in the age of Louis XV.* The Hauge: Martinus Nijhoff (1976)

Kaplan, Steven, *Provisioning Paris. Merchants and millers in the grain and flour trade in the eighteenth century.* Ithaca: Cornell University Press (1984)

Karakacili, Eona, 'English agrarian labor productivity before the Black Death: a case study,' *Journal of economic history* 64 (2004), 21-55.

Kerridge, Eric, *The agricultural revolution.* London: George Allen & Unwin (1967).

Magnou-Nortier, E., 'Trois approches de la question du manse, d'après le polyptique d'Irminon, les chartes de La-Chapelle et les cartulaires méridionaux pour le casal,' in Elizabeth Magnou-Noriter, ed., *Aux sources de la gestion publique, t. 1. Enquête lexicographique sur le fundus, villa, domus, mansus.* Lille : Presses Universitaire de Lille (1993), 123-207.

Hansen, Gary D., and Edward C. Prescott, 'Malthus to Solow,' *American economic review* (2002), 1205-17.

Harrison, D. F., 'Bridges and economic development, 10300-1800,' *Economic history review* 45 (1992), 240-261.

Haudricourt, André G, and Mariel Jean-Brunhes Delamarre, *L'homme et la charrue à travers le monde.* Paris : Gallimard (1955).

Hayes, Herbert Kendall, and Ralph John Garber, *Breeding crop plants.* New York: McGraw-Hill (1927).

Heuzé, Gustave, *Les assolements et les systèmes de culture.* Paris : Hachette (1862).

Jamet, Emile, *Cours d'agriculture théorique et pratique à l'usage des plus simples cultivateurs.* Chateau-Gontier (1846).

Komlos John, and Richard Landes, 'Anachronistic economics: grain storage in medieval England,' *Economic history review* 44 (1991), 36-45.

Krohn, Wolfgang, and Wolf Schafer, 'The origins and structure of agricultural chemistry,' in Gerard Lemaine et al., *Perspectives in the emergence of scientific disciplines*. Chicago: Aldine (1976)

Krugman, Paul, *Geography and trade.* Leuven and Cambridge: MIT Press (1991).

Kussmaul, A. S., 'The ambiguous mobility of farm servants,' *Economic history review* 34 (1981), 220-235.

Labrousse, C. E., *Le prix du froment en France au temps de la monnaie stable (1726-1913).* Paris : SEVPEN (1970)

Latham, A. J. H., and Larry Neale, 'The international market for wheat and rice,' *Economic history review* 36 (1983), 260-280.

Lecouteux, Édouard, *Traité élémentaire de l'agriculture de la Seine.* Paris : Bouchard-Huzard (1840).

Lecouteux, Édouard, *Cours d'économie rurale* 2 vols. Paris : Maison Rustique (1879).

Lepetit, Bernard, *Chemins de terre & voies d'eaux. Réseaux de transports, organisation de l'espace.* Paris : Editions EHESS (1984)

Lerche, Grith, 'Ridged fields and profiles of plough furrows. Ploughing practices in medieval and post-medieval times. A study in experimental archaeology,' *Tools and tillage* 5 (1986), 131-156.

Le Roy Ladurie, Emmanuel and Michel Demonet, *Anthropologie du conscrit français (1819-1826).* Paris : Mouton (1972)

Leure, Henri, *Guide des cultivateurs du Midi de la France*. Toulouse (1854).

Liger, Louis, *La nouvelle maison rustique.* Paris : Saugrain (1755)

Masschaele, James, *Peasants, merchants and markets. Inland trade in medieval England, 1150 – 1350*. New York: St Martin's Press (1997)

Manning, W. H., *Catalogue of the Romano-British iron tools, fittings and weapons in the British Museum.* London: Publications of the British Museum (1985).

Marchand, Oliver, et Claude Thélot, *Deux siècles de travail en France*. Paris, INSEE (1991).

Marin, Brigitte, 'Naples : Capital of the Enlightenment,' in Peter Clark and Bernard Lepetit, eds., *Capital cities and their hinterlands in early modern Europe.* Aldershot: Scholar Press (1996), 143-67.

Marquis, Jean Joseph, *Mémoir statistique du département de la Meurthe.* Paris (An XIII [1805])

Marshall,Alfred, *Principles of economics*. 8th edition [1920] London: Macmillan (1966).

Marshall, Geoffrey, 'The Rotherham plough: New evidence on its original manufacture and method of distribution,' *Tools and Tillage* 4 (1982), 131-38.

Martin, Alfred, *Étude historique et statistique sur les moyens de transport dans Paris.* Paris : Imprimerie Nationale (1894)

Masson de Saint-Amand, Amand-Narcisse, *Mémoire statistique du département de l'Eure.* Paris (An 13 [1804])

Mavré, Marcel, *Chevaux de trait d'hier et d'aujourd'hui.* Panazol : Lavauzlle (1988).

McCloskey, D., and J. Nash, 'Corn at interest: the extent and cost of grain storage in medieval England,' *American economic review* 74 (1984), 174-87

McCloskey, D., 'Conditional economic history: a reply to Komlos and Landes,' *Economic history review* 44 (1991), 128-32.

Miller, Judith, *Mastering the market. The state and the grain trade in northern France, 1700-1860.* Cambridge: Cambridge University Press (1999)

Meuvret, Jean, *Le problème des subsistances à l'époque Louis xiv. T.1. La production des céréales dans la France du xvii^e^ et du xviii^e^ siècle.* Paris : Mouton (1977)

Meuvret, Jean, *Le problème des subsistances à l'époque Louis xiv, t. 3. Le commerce des grains et la conjoncture.* Paris : Editions de EHESS (1988)

Molinier, Alain, *Stagnations et croissance. Le Vivarais aux xvii^e^-xviii^e^ siècles.* Paris: Ed. EHESS (1985)

Moll, Louis, *Excursion agricole dans quelques départements du Nord de la France entreprise …dans l'automne de 1834.* Paris : Decourchant (1836)

Moll, Louis, *Manuel d'agriculture.* Nancy : Grimblot et Raybois(1841)

Moriceau, Jean Marc, and Gilles Postel-Vinay, *Ferme, entreprise, famille. Grande exploitation et changements agricoles xvii^e^-xix^e^ siècles.* Paris : Éd. EHESS (1992).

Morineau, Michel, 'Les Taques d'Onnaing et de Quarouble,' in M. Morineau, *Les faux-semblants d'un démarrage économique : agriculture et démographie en France au xviii^e^ siècle.* Paris : Armand Colin (1971), 155-162.

Muhly, James F., *Copper and tin. The distribution of mineral resources and the nature of the metals trade in the Bronze Age.* Yale University Ph.D. (1969)

Mulliez, Jacques, 'Du blé, "mal nécessaire"; Réflexions sur les progrès de l'agriculture de 1750 à 1850,' *Revue d'histoire moderne et contemporaine* 36. (1979), 3-47.

Munier, Étienne, *Observations …concernant les améliorations introduites depuis environ cinquante ans dans les diverses branches d'économie rurale du département de la Charente*. Angoulême (1812).

Munro, John, 'Spanish *merino* wools and the *nouvelles draperies*: an industrial transformation in the late medieval Low Countries,' *Economic history review* 58 (2005), 431-484.

Musset, René, *De l'élevage du cheval en France.* Paris : Maison Rustique (1917).

Olmstead, Alan L., and Paul W. Rhode, 'Reshaping the landscape: the impact and diffusion of the tractor in American agriculture, 1910-1960,' *Journal of economic history* 61 (2001), 663-698.

Oschinsky, Dorothy, *Walter of Henley and other treatises on estate management and accounting,* Oxford: Clarendon (1971).

Parker, William N., 'Communication techniques and social organization in the world economy,' in W. N. Parker, *Europe, America, and the wider world.* New York and Cambridge: Cambridge University Press (1984). 150-163.

Patten, John, *English towns 1500-1700.* Folkestone: Dawson Archon Books (1978)

Partington, J. R. *A history of chemistry*, London: Macmillan (1961-64)

Pelham, R. A., 'Medieval foreign trade: Eastern ports,' in H. C. Darby, ed. *An historical geography of England before 1800.* Cambridge: CUP (1961).

Percival, *The Wheat plant*. London: 1921).

Perroy, Edouard, *Le travail dans les régions du nord au xi^e^ au début du xiv^e^ siècle.* Paris: Centre de Documentation Universitaire (1963).

Persson, K. Gunnar, 'Labour productivity in medieval agriculture: Tuscany and the 'Low Countries'', in Bruce M. S. Campbell and Mark Overton, *Land, labour and livestock. Historical studies in European agriciultural lproductivity.* Manchester: Manchester University Press (1991), 124-143.

Plancouard, Léon, ed., *Mémoire sur un livre de ferme vexinoise.* Paris (1901)

Plancouard, Léon, ed., *Les comptes d'un charron-forgeron de Chérance (Seine-et-Oise, 1778-1800.* Versailles (1915).

Postel-Vinay, Gilles, *La terre et l'argent. L'agriculture et le crédit en France du xviii^e^-au début du xx^e^ siècle.* Paris : Albin Michel (1998).

Quellier, Florent, 'Growing peaches in Corbeil and Montreuil-aux-Pêches: how horticultural production adapted to Parisian demand, 1500-1800,' in John Broad, ed., *A common agricultural heritage? Revising French and British rural divergence.* Exeter: British Agricultural Society (2009), 155-170.

Quesnay, 'Fermiers,' Wilhelm Oncken, ed., *Œuvres économiques et philosophiques de F. Quesnay*. New York : B. Franklin (1968)

Raepset, Georges, 'Archéologie et icononographie des attelages dans le monde Greco-romain: le problématique économique,' in Tony Hackens and Patrick Marchette, eds., *Histoire économique de l'antiquité. Bilans et contributins.* Leuvain-la-Neuve : Institut Supérieur d'archéologie et d'histoire d'art (1987)

Georges, Raepset,, 'The development of farming implements between the Seine and the Rhine from the second to the twelfth centuries,' in Grenville Astill and John Langdon, eds., *Medieval farming and technology. The impact of agricultural change in northwest Europe.* Leiden and New York: Brill (1997), 41-68.

Peter J. Reynolds, *Iron-age farm: the Butser experiment.* London: British Museum Publications (1979).

Reynolds, P. J., 'A Study of the crop yield potential of the prehistoric cereals emmer and spelt wheats,' in Jean-Pierre Devroey and Jean-Jacques Van Mol, eds. *L'épeautre (triticum spelta). Histoire et ethnologie*. Treignes (Belgium): Editions Dire, 77-88.
Scott, Allen J., *Metropolis. From the division of labour to urban form.* Berkeley: University of California Press (1988).

Richard, J.-M. 'Thierry d'Hireçon, agriculteur artésien,' *Bibliothèque de l'École des Chartes* 53 (1892), 383-416 ; 571-604.

Ringelmann, Max, *Compte rendu des travaux du Congrès de mécanique agricole de 1911* Paris (1911).

Ringelman, Max, *Culture mécanique, 7.* Paris (1926)

Russell, Nicholas, *Like engend'ring like. . Heredity and animal breeding in early modern England.* Cambridge: Cambridge University Press (1984).

Sabel, Charles, and Jonathan Zeitlin, 'Historical alternatives to mass production: Politics, markets, and technology in nineteenth-century industrialization, *Past & Present* 108 (1985), pp. 133-76.

Sandars, Nancy K. 'Wheelwrights and smiths,' *Celticum* 3 (1962), 405-408.

Seguin de Pazzis, M. *Mémoire statistique sur le département de Vaucluse.* Carpentras (1808)

Simmonds, N. W., ed., *The evolution of crop plants.* London and NewYork: Longman (1976).

Slicher van Bath, B. H., 'The rise of intensive husbandry in the Low Countries,' in J. S. Bromley and E. H. Kossman, eds., *Britain and the Netherlands. Papers delivered to the Oxford-Netherlands Historical Conference.* London: Chatto and Windus (1960).130-153

Slicher van Bath, B. H., 'The yield of different crops (mainly cereals) in relation to the seed c. 810-1820,' *Acta historiae neerlandica* 2 (1967) 26-106.

Smith, Adam. *An inquiry into the nature and causes of the wealth of nations.* Cannan Edition. New York: Everyman Library (1937)

Smith, Woodword D. 'The function of commercial centers in the modernization of European capitalism: Amsterdam as an information exchange in the seventeenth century,' *Journal of economic history* 44 (1984), 985-1005.

Sortor, Marci, 'The Ieperleet affair: the struggle for market position in late medieval Flanders,' *Speculum* 73 (1998), 1068-1100

Stephenson, M. J., 'Wool yields in the medieval economy,' *Economic history review* 41 (1988), 368-91.

Tessier, Alexandre-Henri, André Thouin and Louis Bosc, *Encyclopédie méthodique. Agriculture* 7 v. Paris (1787-1821).

Texier-Olivier, M.-L., *Statistique générale de la France...département de la Haute-Vienne.* Paris (1808).

Thaer, Albrecht, *Grundsätze der rationellen Landwirtschaft.* Berlin: G. Reimer (1837) [1804-1812]

Thirsk, Joan, *Alternative agriculture, a history. From the Black Death to the present day.* Ôxford: Oxford University Press (1997).

Thompson, F. M. L., 'Nineteenth-century horse sense,' *Economic history review* 29 (1976), 60-81.

Tits-Dieuaide, Marie-Jeanne, 'L'évolution des techniques agricoles en Flandre et en Brabant xiv^{e}-xvi^{e} siècle,' *Annales ESC* 36 (1981), 362-81.

Tresse, René, 'Le développement de la fabrication des faux en France de 1786 à 1827,' *Annales ESC* (1955), 341-58.

Tricard, Jean, *Les campagnes limousines du xiv^{e} au xvi^{e} siècle.* Paris : Publications de la Sorbonne (1996)

Trow-Smith, Robert, *A history of British livestock to 1700.* London: Routledge & Kegan Paul (1957).
Turner, Michael E., 'Agricultural productivity in England in the eighteenth century: Evidence from crop yields,' *Economic history review* 35 (1982), 489-510.

Turner, M. E., J. V. Becket, and B. Afton, *Farm production in England 1700-1914.* Oxford: Oxford University Press (2001)

Tusser, Thomas, *Five Hundreth good pointes of husbandrie.* London (1585)

Unger, Richard W. *The ship in the medieval economy 600-1600.* Montreal: McGill-Queen's University Press (1980)

Van Bavel, Bas, 'Elements in the transition of the rural economy. Factors contributing to the emergene of large farms in the Dutch River area (15th-16th centuries), in Peter Hoppenbrouwers and Jan Luiten van Zanden, eds., *Peasants into farmers? The transformation of rural economy and society in the Low Countries (middle-ages-19th century) in light of the Brenner debate.* Turnhout: Brepols (2001),179-201.

Vanderwalle, Paul, 'Stabilité et perfection d'un système agricole,' *Annales ESC* 36 (1981), 382-89.

Van Zanden, Jan Luiten, 'Wages and the Standard of Living in Europe, 1500 - 1800,' *European review of economic history* 3 (1999), 175-97

Verhulst, Adriaan, 'L'intensification et la commercialisation de l'agriculture dans les Pays-bas méridionaux au xiiie siècle,' in *La Belgique rurale du moyen-âge a nos jours. Mélanges offertes â J.-J. Hoebaux.*, Bruxelles:, Éd. de l'Université de Bruxelles, (1985), 89-100.

Von Thünen, Johann Heinrich, *Isolated state: an English translation of Der Isolierte Staat*. Trans. Carla M. Wartenberg. Oxford, New York: Pergamon Press (1961).

Walton, John, Varietal innovation and the competitiveness of the British cereals sector 1760 – 1930,' *Agricultural history review* 47 (1999), 31-32.

Weller, Judith, 'Roman traction systems,' www.humanist.de/rome/rts

White, K. D., *Agricultural implements of the Roman world*. Cambridge: Cambridge University Press (1967).

Woronoff, Denis, *L'industrie sidérurgique en France pendant la Révolution et l'Empire.* Paris: Ed. EHESS (1984

Wrigley, E. A., 'The transition to an advanced organic economy: half a millennium of English agriculture,' *Economic history review* 59 (2006), 435-80.

Zohary, M. and D. Heller, *The genus* Trifolium. Jerusalem: The Israel Academy of Sciences and Humanities (1984).

Table 1
Standard Deviation of Wheat Prices
1756-1790
(Paris = 100)

Généralité	Index
Paris-Ville	100
Paris-Généralité	100
Soissons	104
Champagne	113
Lorraine	126
Metz	109
Amiens	117
Flandres	104
Orléans	109
Tours	109
Lyon	100
Bourgogne	100
Moulins	122
Riom	117

Source: Labrousse, *Esquisse du movement des prix*, 106-113.

Table 2
Size of Arable Plots, Selected Cantons in Northern France 1852

Region (*département*)	Hectares/plot	No. observations
Ile de France (*Seine-et-Oise*)	0.56	8
Beauce (*Eure-et-Loire*)	0.54	10
Champagne (*Aube*)	0.21	9
Lorraine (*Meurthe*)	0.28	19
Lorraine (*Haute Marne*)	0.23	19

Source : Canton and communal returns from *Enquête Agricole* of 1852 deposited in the departmental archives. The number of plots is computed as plots reported in gardens and arable minus the plots reported separately in gardens and orchards. The effect of orchard plots on the averages is insignificant.

Table A-1

Theoretical Provisioning Radius (kilometres)

Yield (hl/ha)	***8***	***10***	***12***	***14***	***16***	***18***	***20***
City Population							
5,000	9.9	8.1	7.1	6.3	5.8	5.4	5.0
10,000	14.0	11.5	10.0	9.0	8.2	7.6	7.1
20,000	19.8	16.3	14.1	12.7	11.6	10.7	10.1
50,000	31.3	25.8	22.4	20.0	18.3	17.0	15.9
100,000	44.3	36.4	31.6	28.4	25.9	24.0	22.5
200,000	62.7	51.5	44.3	40.1	36.6	34.0	31.8
400,000	88.7	72.8	63.3	56.7	51.8	48.0	45.0
500,000	99.1	81.4	70.7	63.4	57.9	53.7	50.3
600,000	108.6	89.2	77.5	69.4	63.5	58.8	59.5

Labour input: six man days per hectoliter, with 21 percent of land sown in wheat.