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

George Grantham
McGill University
August, 2007

Paper prepared for the 67th Annual Meetings of the Economic History Association. Austin, Texas.
September 7-9, 2007 Please do not cite without permission.

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

George Grantham

To economic historians of the pre-industrial era, the overriding feature of space was the bounded extent of what Ricardo dubbed the 'original indestructible powers of the soil' and Von Thünen more prosaically called *der Boden en sich.* From that territorial inelasticity Ricardo deduced the principle of diminishing return, which together with Malthus's demographic hypothesis was the cornerstone of classical economic dynamics. That dynamics inspires the conventional interpretation of secular trends in European population, output and real wages before the early nineteenth century. According to that interpretation the long waves in population, real wages, and total output reflect interactions between a positive demographic response to increasing real wages, and the negative consequences of rising population density for agricultural labour productivity.[1] The model presumes that agricultural technology was stagnant, whence it follows that phases of economic expansion were inevitably reversed by rising cost of subsistence foodstuffs and the reallocation of land from supplying fuel, forage, and building materials to growing more food.

Because classical dynamics presumes a fixed stock of land to be the binding constraint on the supply of foodstuffs, technical change must play the critical role in any explanation of the documented surge in the late pre-industrial and early industrial population. On that logic, many economic historians have argued that between 1600 and 1800 farmers in northwest Europe discovered new ways to raise the productivity of land and labour: the great escape from the Malthusian trap. That escape presumes an 'agricultural revolution.' The problem is that none of the innovations commonly asserted as the key components of that revolution were novel in the seventeenth century, and as a result historians have found it exceedingly difficult to date with any precision.[2] The introduction of domesticated forage legumes dates

[1] Recent examples include Oded Galor and David Weil, 'Population, technology and growth: from Malthusian stagnation to the Demographic Transition and beyond,' *American economic review* 90 (2000), 806-828.E. A. Wrigley, 'The transition to an advanced organic economy: half a millennium of English agriculture,' *Economic history review* 59 (2006), 435-80, and Gregory Clark, 'The long march of history: farm wages, population, and economic growth, England, 1250-1869,' *Economic history review* 60 (2007), 97-135.
[2] George Grantham, 'In search of an agricultural revolution'. Stanford Social Science Workshop. May, 2007.

to antiquity; intensive crop rotations existed in the thirteenth century; large farms operated with teams of hired labour date to at least the eleventh and twelfth century. Yields and labour productivity generally associated with the agricultural revolution have been found as far back as the thirteenth century in contexts that by no means appear unusual.[3] These documented facts suggest that something other than technical and organizational change relieved the Malthusian constraint.

To understand the analytical issues raised by the failure to identify a technological revolution in pre-industrial farming, we have to go back to the drawing board. The effective supply of land is in fact not strictly fixed: it is augmented and diminished by investment and disinvestment, and technical innovations can turn worthless land into valuable property or make valuable land worthless. Nothing, however, can alter the distance between two points on the surface of the earth. As Alfred Marshall observed, that topological property is 'the foundation of much that is most interesting and most difficult in economic science.'[4] Pursuing hints in Adam Smith's analysis of the relation between transport costs and the extent of the market,[5] Von Thünen discovered its significance for agricultural productivity.[6] Synthesizing Smith's economics and Albrecht Thaer's Agricultural Statics (a primitive input-output model of the sources and uses of plant nutrients), Von Thünen realized that the economic optimality of any particular cropping system is contingent on its location in space with respect to points of final demand for farm produce. Assuming a homogeneous agricultural region within which labour and capital are perfectly mobile, and goods are mobile according to their transportation cost, he reasoned that at any given point in that closed space the extent of the market for its produce depends on the distance from points of final demand. Since commodities differ in handling and transport cost, the extent of the market at each point also varies by commodity. Assuming the cost of production to be unaffected by location,[7] Von Thünen showed that in competitive equilibrium the type of land use and system of husbandry will sort itself into a concentric series

---

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

[4] Alfred Marshall, *Principles of economics*. 8th edition [1920] London: Macmillan (1966), 121. For an analytical treatment of some of these interesting difficulties, see Paul Krugman, *The Self-organizing economy*. Oxford and Cambridge MA: Blackwell (1996).

[5] That discussion is conducted in chapter X 'On Rent' and the appended 'Digression on Silver'.

[6] Johann Heinrich von Thünen, *Isolated state: an English translation of Der Isolierte Staat*. Transls. Carla M. Wartenberg. Oxford, New York: Pergamon Press (1961).

[7] Von Thünen makes some adjustments for the lower cost of labour in outlying districts and the higher cost of manufactured inputs imported from the central place.

of specialized rings of production around a hypothesized central point of final demand. Because the sorting produces an efficient allocation of resources, the type and method of production at every point in that space are equally efficient.

From a purely technological perspective, however, systems of cultivation practiced in different rings are not equally efficient, since farms situated in the inner rings have higher yields and produce a higher value of output per hectare than farms in peripheral sectors. An observer unfamiliar with Von Thünen's model would thus be likely to perceive the variation in methods of cultivation in terms of degrees of technological backwardness. Von Thünen's finding therefore has important implications for the interpretation of the pre-modern agricultural record, because one of the salient features of that record is the regional disparity in agricultural productivity, which national indices commonly employed to support the Malthusian interpretation of the pre-modern economy mask. Consider the commonly accepted view that between 1300 and 1800 English cereal yields doubled from around 10 hectolitres per hectare to 20 hectolitres.[8] How does one interpret that doubling? Is it due to technological or institutional innovation, or to diffusion of techniques and institutional forms already in place by the late thirteenth century? There is strong empirical evidence for the latter interpretation. It is now well-documented that some estates in the late thirteenth and early fourteenth century attained yields close to double the presumed average of 10 hectolitres per hectare.[9] On the Continent, yields exceeding 25 hectolitres around 1300 are well attested for northern France and Flanders on holdings clearly cultivated by plough.[10] Were these points of progress islands of technical innovation, or endogenous responses to the short distance from points of final demand? Was the secular doubling of yields in England the pure product of technical progress or does it reflect territorial extension of intensive systems of cultivation previously confined to a limited space? If the latter, the explanation of agricultural progress before the nineteenth century turns on the factors that limited and

---

[8] Wrigley, 'Transition to an advanced organic economy'; Bruce M. S. Campbell and Mark Overton, 'Statistics of production and productivity in English agriculture, 1086-1871,' 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.
[9] See Grantham, 'In search of an agricultural revolution.'
[10] Alain Derville, 'Dîmes, rendements du blé et "révolution agricole" dans le nord de la France au moyen âge,' *Annales E.S.C.* 42 (1987), 1411-1432.

then released economic and technological mechanisms that supported the restricted spatial distribution of high-productive farming.

What range of yields and labour productivity did traditional husbandry support? Though suggestive, currently available medieval and early modern sources are too sparse and recalcitrant to support statistically significant regional yield and labour productivity distributions.[11] The late eighteenth and early nineteenth centuries are much better provided, especially in France, where the stimulus given to collecting information on yields and input coefficients by Duhamel du Monceau's agronomical treatises and Quesnay's conjectural estimates of the relative productivity of large farms and sharecrops generated a large technical and administrative record that spans almost the whole range of European climatic and soil conditions.[12] These data indicate a productivity spread on the order of four to one. Regional crop yields range from five to 25 hectolitres per hectare, while the labour input coefficient for wheat runs from a little less than 2.5 to about 10 man days per hectolitre.[13] The differences are regionally systemic. As a rule, high yields and high labour productivity occur in the north of France, and most particularly in districts that supplied cities, including well-cultivated strips of land on the south coast of Brittany that regularly shipped grain to Bordeaux and the Basque towns. Low yields characterize districts poorly situated with respect to important sites of non-farm consumption of cereals and other farm produce. None of this is surprising; economic historians have long known that districts situated near cities tended to be more productively farmed than the boondocks. Intensive cultivation rendered higher yields and thus saved land; larger and more compact farms saved labour; the combination of intensive cultivation and large farms saved both. Yet that relation raises a series of other questions. How, exactly, did being close to a city raise agricultural productivity? Why was the urban impact so limited? Why were practices that raised productivity near

[11] Price data provide a possible way of circumventing this problem. See Philip T. Hoffman, *Growth in a traditional society: the French countryside, 1450-1850,* Princeton (1996). I have pointed out the analytical pitfalls in this approach in 'The French agricultural productivity paradox: measuring the unmeasurable,' *Historical methods* 33 (2000), 36-46.

[12] For a brief survey of this evidence with references, see G. Grantham, 'Divisions of labour: agricultural productivity and occupational specialization in pre-industrial France,' *Economic history review* 46 (1993), 480-81. Quesnay's made his estimates in the articles entitled 'Fermiers' and 'Grains' in Diderot's *Encyclopédie* (1757).

[13] George Grantham, '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.

towns not adopted in peripheral regions? Was the size of cities limited by the agricultural productivity of their hinterland or by demographic processes unrelated to the food supply? To answer these questions, we need to consider another set. How did the peculiar spatial characteristics of farming affect exploitation of the productive potential locked up in traditional husbandry? This requires a brief summary of the impact of space in general.

Space, Agricultural Productivity, and the City

For many services and most manufacturing the advantages of proximity manifest themselves in external economies of market pooling for highly specialized labour and other inputs, and the possibility of joint exploitation of specialized facilities.[14] Agglomeration also confers a cost advantage to suppliers of intermediate goods locating near customers and, symmetrically, to customers locating near their suppliers. Moreover, dense face-to-face networks of communication that are the by-product of the agglomeration of economic activity encourage sharing of technical information and that construction of standardized codes that lower transactions costs.[15] Such economies bulked large in pre-industrial manufacturing (though not in farming), because productivity growth was achieved by workers investing in specialized skills and by segmentation of manufacturing into sequences of specialized tasks often best coordinated when carried out in physical proximity to each other. The economies are 'external' in that the advantages accruing to a firm or specialized worker from locating in a particular town depend on the number of other firms and workers already located there. These positive spillovers create the increasing returns to agglomeration that supported the well-documented income differential between urban and non-urban occupations.[16]

As against these centripetal forces on manufacturing, the spatial forces affecting agriculture were strongly centrifugal. The land-intensity of the agricultural production function dispersed supply, while high water content of the output made it costly to transport. The spatial dispersion of agricultural

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

[15] The classic exposition of these points is book IV of Marshall's *Principles.* For a succinct summary, see Paul Krugman, *Geography and trade.* Leuven and Cambridge: MIT Press (1991)

[16] References here. Look for the early modern ref on transactions cost.

production was a fixed point to which other elements of pre-modern economies had to adapt, just as they had to adapt to the seasonal fluctuations in agricultural demand for labour.[17] Unlike manufacturers, farmers could not reduce distribution costs by locating closer to their markets; any such reduction thus had to come from the purchasers of farm produce moving closer to farmers. Such movements were feasible for a wide range of manufactured goods where the quality of the finished product was not so high as to require centralized supervision, as was the case with common nails and the cheaper qualities of cloth. Where fixed cost were low and the ratio of value to bulk was high, it was more efficient to locate near the supplies of food that fuelled the worked force than to transport highly dispersed stocks of food to an agglomeration of workers. That economic logic dominated the locational decisions of firms and workers until the advent of large-scale power plants and mechanized production conferred an overwhelming advantage on spatially agglomerated industry.

Yet, while sympathetic dispersion of industry towards farmers minimized the cost of distributing farm produce, it diffused demand for it. Unlike in industry, where the centripetal actions of individual workers and manufacturers raised productivity through economies of agglomeration, the location of industry in the countryside did little or nothing to raise agricultural productivity. The positive Von Thünen effect in agricultural productivity was the consequence of proximity to agglomerated customers. From this perspective, the agricultural development of the pre-industrial world may be seen in terms of the varying tension between the centrifugal forces resulting from the land-intensity of the agricultural production function and the high cost of transporting farm produce, and the centripetally attractive force of industrial agglomeration. It is this tension rather than the tension between population and the stock of cultivable land that set the parameters of pre-modern economic development.

An obvious question is whether the level of agricultural productivity posed a binding constraint on the size of urban agglomerations. I have examined this question by means of a simple identity that exploits information bearing on the yield of subsistence cereals, the labour input coefficients for wheat and rye, per

[17] Grantham, 'Divisions of labour; Gilles Postel-Vinay, 'The disintegration of traditional labour markets in France,' in George Grantham and Mary Mackinnon, eds., *Labour market evolution: the economic history of market integration, wage flexibility and the employment relation*. London: Routledge (1994), xx

capita consumption, and areas given over to arable cultivation.[18] Imagine a circular region self-sufficient in subsistence foodstuffs in which all persons not occupied in growing food are concentrated at a central point and that people consume food in the form of wheat or rye.[19] This mental construction permits investigation of two related questions: What is the minimum provisioning space for a city of given population that exactly balances the total regional supply and demand for foodstuffs? At given levels of land and labour productivity, what is the largest city nutritionally sustainable within a region of predetermined size?[20] The regional balance of food supply and demand can be expressed as an identity equating the amount of corn produced to the combined demand of farmers and city dwellers. Supply is computed as the mean regional yield (net of seed) times the number of hectares sown:

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

where r is the radius of the provisioning space in kilometers, γ the proportion of the region's territory planted in bread cereals, and y and s the average yield and seeding rate per hectare, respectively.[21] The rural population required to produce this supply (farmers plus dependents) is expressed by the identity:

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

where Z is the rural population and μ is adjusted man years of labour input per unit of grain output.[22]

---

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

[19] Identifying the total food intake with cereals is obviously inaccurate, as other foodstuffs provided up to 20 percent of the caloric intake in prosperous towns. Most of those calories, however, were by-products of the mixed husbandry organized to grow cereals.

[20] The exercise assumes that the input and consumption coefficients are fixed. Allowing substitution on both sides of the market would of course strengthen the conclusions offered here.

[21] A square kilometer contains 100 hectares. and normal rovisioning radii, of which the maximum for regular land transport on fair roads was probably around 45 kilometres

[22]To make the units of labour input and per caput rural consumption of subsistence foodstuffs commensurable, the man days per hectare must be transformed into man years, and man years must be transformed into the equivalent agricultural population. This transformation is accomplished by assuming a work year of 250 days and deflating the annual equivalent labour force by the participation rate and the age and sex structure of the population. The participation rate employed to transform the full-time labour equivalent into an estimate of the agricultural population is 60 percent. For evidence of the constancy in the ratio of the farm labour to the agricultural population, see O. Marchand et C. Thélot, *Deux siècles de travail en France*. Paris, INSEE (1991). For full details on the construction, see Grantham, 'Divisions of labour,' Appendices A and B.

The condition of regional self-sufficiency is that regional grain output cover regional consumption, which means that total production of grain has to equal the sum of consumption requirements of rural food producers and urban residents. If rural and urban people enjoy the same standard of food consumption, regional self-sufficiency is expressed by the identity:

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

where X is the size of the city and α is annual per caput consumption of cereals. Equations (2) and (3) can be reconfigured to compute the minimum radius of a self-sufficient provisioning space, given yields, the seeding rate, the labour input per hectolitre, per capita consumption, and the size of the city (X), or alternatively the maximum size of city given the provisioning radius (r).

Table 1 displays the results of this exercise for the parameters spanning the known range of land and labour productivity in cereal production for a region that maintained 21 percent of its area in wintger cereals, which under a three-course system would imply tht 64 percent of the territory is given over to arable cultivation. The yields range from 8 to 20 hectolitres per hectare; the labour input is taken to be 6 mandays per hectare, which was an average input on farms cultivated with horses. Since the area under crop, yields, and labour productivity were usually higher around the largest cities, the resulting rovisioning radii may be taken as upper bounds. If we take the outer bound of the normal provisioning radius to have been around 50 kilometres (31 miles), cities up to a half million could have been sustained by their hinterland at average yields of 20 hectolitres per hectare, which were commonly attained in urban provisioning zones in the late eighteenth century. Moreover, on well-managed farms, the labour input per hectolitre was 30 to 35 percent lower than the 6 man days hypothesized for these calculations.[23]

Taking these figures as a starting point, we can now ask whether the growth of cities was constrained by the food supply or by demographic mechanisms unrelated to it. An obvious test is whether the theoretical provisioning perimeter for cereals lies inside or outside the theoretical demographic perimeter. It is well known that pre-modern cities ran a demographic deficit that was filled by excess births

[23] For references, see Grantham, 'In search of an agricultural revolution,' April, 2007.

Table 1
Cereal Supply Radius (km)

Yield	*8*	*10*	*12*	*14*	*16*	*18*	*20*
City size							
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

Source: Grantham, 'Espaces privilégiées,' 707.

in their agricultural hinterland. If the perimeter of that demographic space lies inside the provisioning zone, then the demographic deficit poses a binding constraint on city size. De Vries has observed that prior to the early nineteenth century no European region had an urban population exceeding 35 percent of its total population. In simulating the demographic balance consistent with known urban and rural rates of natural increase in the pre-industrial period, he finds that an urbanization rate above 37.5 percent was unsustainable before the nineteenth-century decline in urban mortality. I have replicated his model of urban-rural demographic equilibrium, using the parameters developed for table 1 to estimate the rural population needed to provision a city of given size.[24] According to these calculations, at a yield of 10 hectolitres a town of 10,000 would have drawn its subsistence from a region containing no more than 19,587 inhabitants, of whom 9,587 were rural. Using De Vries' estimated urban rate of natural decrease of

[24] De Vries, *European Urbanization*, 224-231. In my replication I assume a rural manufacturing population of zero.

(-0.01) and his estimated rural rate of natural increase (0.005), that population distribution generates a negative rate of natural increase, implying local self-sufficiency in foodstuffs but not in people. At yields above 12 hectolitres per hectare, the demographic constraint dominates the food supply constraint for nearly all the known pre-industrial combinations of rates of natural increase. It was high urban mortality, not difficulties of securing food that ultimately limited the extent of early urbanization.

From a purely technological perspective, then, Western Europe's urbanization rate prior to the Industrial Revolution cannot be said to have been seriously constrained by low agricultural productivity. In the degree that yields and labour productivity responded positively to proximity to urban agglomerations, they were high enough to support much larger urban populations than generally appeared before the fourth or fifth decades of the nineteenth century. Indeed, to judge from Allen's suggestive analysis of regional economic development in the pre- and early industrial era, the direction of causation seems to have run the other way: from urbanization and commercialization to the productivity of the farming population.[25] These findings put the 'escape from the Malthusian trap' in a new light. Economic historians typically identify that 'escape' with technological change. The problem with this hypothesis is that the crucial innovations that relieved the binding land and labour constraints on output date to the early 1840s, and can therefore not explain the upswing in agricultural productivity in northwest Europe between 1750 and 1840.[26] Two classes of innovation mark the decade that ended the age of traditional husbandry. The first was the appearance of concentrated fertilizers, nitrates from the islands off the Peruvian coast and John Bennett Lawes discovery that treating phosphate rock with sulphuric acid yielded a concentrated soluble phosphate fertilizer. A decade later chemical analysis of rock salts uncovered the huge deposit of potash at Stassfurt in Saxony-Anhalt, thereby completing the triad of critical plant nutrients.[27] The second innovation was the development of mechanical reapers and mowers, which began in the 1830s but achieved commercial

[25] Robert C. Allen, 'Progress and poverty in early modern Europe,' *Economic history review* 56 (2003), 403-443.
[26] Total factor productivity in France accelerated from perhaps 0.3 to 0.5 percent in the late eighteenth century to a little over 1 percent between 1815 and 1840. None of that acceleration can be traced to true tecnological novelties. See. George Grantham, 'The French agricultural capital stock, 1789 – 1914,' *Research in economic history* 16 (1996), 58-59.
[27] For an ingenious attempt to estimate the implied consumption of these nutrients in the pre-modern era, see Jean-Michel Chevet, 'A new method of estimating land productivity,' in Bas J.P. van Bavel and Erik Thoen, *Land productivity and agro-systems in the North Sea area. Middle ages – 20th century*. Turnhout: Brepols (1999), 339-56.

adequacy only towards the end of the 1840s. It represents a general proliferation of agricultural machines made possible by contemporary advances in ferrous metallurgy and mechanical engineering. The two strands of innovation – the one chemical and the other mechanical – originated in scientific and technological developments whose narrative lies outside the agricultural sector. If there was a technological 'escape from the Malthusian trap' it can be dated no earlier than the middle third of the nineteenth century.[28] We are thus left with the question what exactly relieved the 'Malthusian' constraint on agricultural output. Wrigley has argued that the eighteenth-century transformation of coal into a source of mechanical energy and a fuel and reducing agent in ferrous metallurgy released enough land to arable farming from forests and coppices to provide a temporary breathing space for the more opaque sciences bearing on agriculture to develop to the point where they could have an impact on productivity.[29] The rise in agricultural output after 1750, however, was too extensive to be explained by the extension of farmland. Most of the increase resulted from rising yields within the technological context of traditional husbandry, and yields rose fastest in districts most directly exposed to growing urban demand.

Yet if city size was not restricted by agricultural productivity and if, as argued below, agricultural productivity responded positively to spatially agglomerated demand, the pre-nineteenth-century pattern of agricultural productivity change turns on the historical factors that governed the rise and decline of cities and urban systems. This is not the place to analyze those factors, though it seems clear enough that fiscal, monetary, and especially international political events played decisive roles between the twelfth and nineteenth centuries. Our question is why systems of agricultural husbandry were so recalcitrant to change in the absence of an urban demand stimulus, and exactly how that stimulus affected productivity. To understand the stasis in productivity outside the urban hinterlands of pre-modern Europe and before the late eighteenth-century upswing in urban agglomeration, we need first to understand how the spatial dispersion of farming impeded activation of the commercial circuits that stimulated productivity.

---

[28] J. L. van Zanden, 'The first green revolution: the growth of production and productivity in European agriculture, 1870-1914,' *Economic history review* 44 (1991), 215-239.
[29] Wrigley, 'Transition to advanced organic economy.'

Structures of Dispersion

The land-intensity of agriculture is a by-product of plant physiology. Plants require space above ground to capture sunlight and atmospheric gasses, and space below to secure a foundation for the plant and tap nutrients and water held in the soil. The amount of land consumed per unit of food produced varies. Crops grown for leaf or stem typically take up more space per calorie produced than cereals and root crops. Technology also matters. Putting land through a course of ploughed fallow is more land-intensive method of controlling weeds than simply dosing it with chemical herbicides; sowing legumes to bury nitrates in the soil requires more land than spreading nitrate fertilizers on it; draft animals need more land to fuel themselves than tractors.[30] The land-intensity of traditional husbandry can thus be seen as a phase in the technological evolution of agriculture. In livestock husbandry that space-intensive phase has been partly superseded by factory farming encouraged by advances in veterinary science that mitigate the epidemiological consequences of crowding animals in closed spaces. In vegetable husbandry one also sees a kind of factory system using non-solar energy and hydroponic delivery of nutrients in greenhouse cultivation of vegetables and illicit indoor cultivation of marijuana. In wilder stretches of imagination, one can even conceive skyscraper farms where domesticated bacteria transform atmospheric carbon, nitrogen and essential nutrients into food. The space-using character of pre-modern agriculture is thus not eternal, but marked a technological epoch in which the costs that, as Adam Smith quipped, deter Scots from making wine, imposed space-intensive system of farming throughout the temperate zone of human habitation.

The first farms were nevertheless not space-intensive. The common view that early farming was peripatetic is drawn from a false analogy with shifting cultivation of tropical districts where high temperature and heavy rainfall leach rapidly soils exposed by cultivation. Archaeological evidence shows that Neolithic settlements were geographically stable for centuries, and experiments in Neolithic methods of cultivation demonstrate that families armed only with stone tools and fire-hardened digging sticks can subsist on less than two hectares of row-sown cereals.[31] But small farms were not simply a matter of digging sticks and hoes;

---

[30] Find the citation on the amount of land saved from oats by substituting the tractor for horses.

[31] Peter J. Reynolds, *Iron-age farm: the Butser experiment.* London: British Museum Publications (1979). P. J. Reynolds, , 'A Study of the crop yield potential of the prehistoric cereals emmer and spelt wheats,' in

the miniscule holdings that were the fission product of the dissolution of the medieval manor were usually farmed by hand.[32] Many were self-sufficient. Richard Cantillon claimed that a French labourer content to wear hempen clothes and wooden clogs and prepared to live on vegetables, bread, and water could survive on an acre and a half, and sustain his family on the produce of three.[33] Although their share of arable land was insignificant, such holdings were still common in many parts of France seven decades later, though many were worked part-time by workers in rural industry.[34]

Extensive husbandry is a product of ploughing. Whereas it takes 35 to 60 days to hoe or spade a hectare of land, the same area can worked by a plough in two to five days.[35] The labour saved is of course much less than the seven to 30-fold difference implied by these figures, as ploughed fields are weedy and must be worked several times to secure a suitable seedbed. Moreover, the time it takes to carry out that cultivation usually requires putting the land through a year of fallow to prepare it for winter cereals sown in early autumn. For a normal course of four workings, including in three-course rotations a single ploughing for oats or barley, the saving afforded by the plough was four to seven fold. Given the fixed cost of maintaining draft animals and equipment and the obvious obstacles to sharing them, the minimum size holding capable of employing a plough to work the soil was about 6 hectares (15 acres). The technology of ploughing thus substituted capital *and* land for labour. The maximum area per plough team varied with the stiffness of the soil and the type and condition of the draft animals, but the upper limit was about 45 to 50 hectares for horses and perhaps 20 to 25 hectares for oxen.[36] Actual farms could be much larger, as it was

---

Jean-Pierre Devroey and Jean-Jacques Van Mol, eds. *L'épeautre (triticum spelta). Histoire et ethnologie*. Treignes (Belgium): Editions Dire. pp. 77-88 ; Gérard Firmin, 'Archéologie agraire et expérimentation,' in Jean Guilaine, ed., *Pour une archéologie agraire.* Paris: Armand Colin. pp. 279-30.

[32] The absorption of these tiny holdings into larger *métairies* in the Gatine district of Poitou is documented by Louis Merle, *Le métairie et l'évolution agraire de la Gâtine poitevine de la fin du Moyen Age à la Révolution*. Paris : S.E.V.P.E.N. (/958).

[33] Richard Cantillon, *Essay on the nature of commerce in general* [c. 1734]. Trans. Henry Higgs. New Brunswick NJ and London: Transaction Publishers (2001), 19.

[34] They are found in both agriculturally advanced and backward districts. At the end of the eighteenth century, only one out of five to seven households in the rural department district Vivarais in France possessed ploughs. Alain Molinier, *Stagnations et croissance. Le Vivarais aux xvii^{e}-xviii^{e} siècles.* Paris (1985), 181. In the well-cultivated neighborhood of Lille, the proportion of hand-cultivated land around 1800 was 20 percent. C. Dieudonné, *Statistique du département du Nord* (1804), 351.

[35] For the data and references, see Grantham, 'Growth of labour productivity.'

[36] In the Soissonais at the turn of the eighteenth century the size of the 'charrue' on the largest farms was 45 to 50 hectares. The 'charrue' was the area that for fiscal purposes was considered to be worked by a single plough team. Luc-Jacques Dauchy, *Statistique du département de l'Aisne*. Paris (An X), 19.

always possible to multiply the number of teams, but the rising marginal cost of supervising dispersed workers and the increasing travel time incurred in cultivating peripheral fields set an upper bound on the most extensive holdings of five to eight ploughs, or approximately 350 to 400 hectares.[37] The common size of farms worked by a single team was 15 to 30 hectares.[38] An average farm cultivated with horses or oxen thus kept three to five times more land in subsistence cereals than manual cultivation. In terms of output, the gap was smaller, since yields were normally about half as high. Nevertheless, assuming a steady-state ploughing yield of 10 hectolitres per hectare and a yield-seed ratio of 4:1, the net output of 10 hectares sown in wheat or rye comes to 70 hectolitres, enough to feed approximately 20 people at a per capita consumption of 3.5 hectolitres. By contrast, two hectares of grain cultivated by hand yielded perhaps 35 hectolitres net of seed. Assuming that each type of farm held five persons, the surpluses released by the plough and the spade are 17 and 52 hectolitres, respectively.

The function of plough-based farming, then, was to release a surplus of subsistence foodstuffs to persons occupied outside subsistence production.[39] Had farms been organized with a view to producing foodstuffs solely, the agricultural territory could have supported 10 to 20 times more people cultivated by hand. The spatial extension of pre-modern farming is thus more than a technological datum; it is an endogenous economic one. Spatial extension responded to the existence of non-agricultural demanders of

---

[37] The largest pre-modern farm was probably the Cistercian grange of Vaulerent situated some 25 kilometres northeast of Paris. It was endowed on the abbey of Chaalis in 1136 by Louis VII and colonized a dozen years later by monks from Pontigny, who by expropriation, purchase, and exchanges built up a compact holding four kilometres long by a kilometre wide, on which they erected a grange the size of a Cistercian church. At its peak the farm covered 380 hectares consolidated in parcels ranging in size from one to as much as 40 hectares.
François Blary, *Le domaine de Chaalis xii^{e}-xiii^{e} siècles.* Paris : Comité des travaux historiques et scientifiques (1989); Charles Higounet, *Le grange de Vaulerent. Structure et exploitation d'un terroir cistercien de la plaine de France xii^{e}-xiv^{e} siècles.* Paris : S.E.V.P.E.N. (1965).

[38] This average size is consistent with the notional task for a team of oxen cited by the unknown author of the *Senechaucy* and Walter of Henley, set at 240 days per year at one acre per day, which on land ploughed three times implies 32 hectares ploughed. See Dorothy Oschinsky, *Walter of Henley and other treatises on estate management and accounting,* Oxford: Clarendon (1971). In mid-eighteenth century Quesnay described 'petite culture' in terms of a 200 hectare estate divided into ten *métairies* eached worked with a single team of oxen. Quesnay, 'Grains,' *Oeuvres* (1969), 201.

[39] 'Avec les deux premières sortes d'instruments [hoes and spades], on ameublit la terre aussi parfaitement et aussi profondément qu'on le veut; il n'en est pas de même avec le troisième. Les avantages propres à cette dernière se rapportent principalement à la promptitude et à l'économie de l'opération; mais ces avantages sont tels que ce sont eux qui servent de fondement à la grande agriculture. Sans charrue, nous n'aurions pas autant de blé ni du blé à aussi bon marché, et par suite autant de bestiaux de toute sorte.' *Nouveau cours complet d'agriculture théorique et pratique* (1820) p.6

foodstuffs. It released surpluses by increasing the stock of agricultural capital in the form of draft animals and extra inputs of labour for tillage and on-farm transport of intermediate inputs. Unlike manual cultivation, whose possibilities for capital-labour substitution and technical innovation were limited by the simplicity of the tools,[40] plough-based agriculture possessed several openings for productive intensification through the perfection and specialization of farm equipment. In particular, ploughing supported scale economies in tillage.[41] Exploiting those avenues for productivity growth, however, depended on whether the surpluses released could find profitable outlets. It is here that space mattered most, because the dispersion of production resulting from the use of the plough imposed a transport tax on the sale of farm produce, and thus on the capital and labour invested in more intensive farming.

The 'escape from Malthus', then, turns on relationships that transcend the technological perspective of classical economics. In the degree that inputs of labour and capital raised agricultural output per hectare and per person, the search for causes of that escape is diverted from the hunt for technical innovations to the inducements to invest labour and capital in farming. In the past two decades, researchers have found that in places where the investment was warranted, neither labour nor capital was wanting at an economically sustainable supply price.[42] What was wanting was opportunity to invest, and it is here that the spatial extension of farming worked against the great escape. The initial dispersion of the stocks of grain and other crops made it costly to accumulate quantities in one place that were large enough to support efficient handling and transportation; high transport cost inhibited market aggregation of effective demand and reinforced agricultural self-sufficiency and slack methods of farming. It encouraged producers of more easily traded goods to establish themselves in the countryside, which provided local outlets for farm produce but did not generate demand prices high enough to induce significant investment in agricultural capital. The easiest part of the early agricultural revolution was increasing the food supply; the hard part was getting spatially dispersed surpluses off the farm and into the hands of consumers whose demand price was high enough to

---

[40] The two main innovations in hand culture were the introduction of the potato and the iron pronged sod fork, which appeared around the turn of the eighteenth century as one of the many agricultural improvements made possible by the cheapening price of iron.
[41] Moriceau and Postel Vinay; Allen.
[42] Jan de Vries, 'The industrial revolution and the industrious revolution,' *Journal of economic history* 54 (1994) Gilles Postel-Vinay, *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).

induce investment. We shall return to these connections below, but first we explore another way that the spatial dispersion of agriculture impeded improvement.

Ecological Niches and Technological Stasis

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. While the ultimate source of the secular stasis in plants, animals, and systems of husbandry is the opacity of life processes to direct observation, their adaptability to the ecological and economic niches they colonized contributed to that stasis by impeding more extensive exploitation of the genetic potential of the domesticated plants and animals. At first sight, that failure is paradoxical, as the geographical dispersion of plants and animals of European mixed husbandry revealed much of that potential in local adaptations to an exceptionally wide range of economic and ecological contexts. Sheer distance was part of the problem; it was not before the eighteenth century that wheat varieties from Asia and North Africa began to make their way into Europe, and not before the nineteenth century that the geographical search for new genetic material really got under way.[43] The fundamental obstacle, however, was that highly productive traits were usually maintained only under conditions similar to those in which they had emerged. This was less a matter of fixed physical effects related to climate, soil type, and elevation than of the temporal and regional variations in market circumstances that encouraged specialization of biological types, farm tools, and methods of cultivation. The connection between natural selection and economic circumstances is complex and reversible. For example, more intensive cultivation can raise cereal yields 20 to 24 percent over 25 to 30 generations as a result of natural selection for traits that succeed in a cleaner seed bed.[44] By the same token, however, reversion to less intensive rotations would restore the original types. Selection thus depends on economic conditions favoring or discouraging intensive cultivation. The same holds for natural selection for responsiveness to heavy doses of farm manure. Since the rate of fertilizing is an endogenous response to the demand price of farm produce, such variations are sensitive to regional and temporal variation in market conditions. We are here mainly

[43] C. R. Ball, 'The history of American wheat improvement,' *Agricultural history* 4 (1930); John Walton, Varietal innovation and the competitiveness of British cereals sector 1760 – 1930,' *Agricultural history review* 47 (1999), 31-32.
[44] L. T. Evans, *Crop evolution, adaptation, and yield*. Cambridge: CUP (1993), 293.

concerned with variations in systems of husbandry connected to distance from spatial agglomerations of demand, but the same dynamics affected productivity over time.[45]

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 that gave high yields under heavy doses of manure.[46] In most parts of Europe, wheat straw was a major component of 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 supplies of forage thus usually failed because the animals rejected the unpalatable straw.[47] High-yielding varieties of rye and oats faced similar obstacles. Rye straw was valued for plaiting, 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.[48] Variations in the value of the joint product thus affected diffusion of superior varieties of the foodstuff. Near cities, the obstacles were lower, since straw not consumed on the farm could be sold to urban stables for litter and to market gardeners for mulch.[49]

---

[45]In the absence of controlled data it is impossible to judge the quantitative impact of this effect on medieval and early crop yields, but given the magnitudes revealed by the experimental studies, it could well have been substantial. The selective effect of cultivation is independent of that caused by differences in the amount of fertilizer applied.

[46]The uptake of nitrates to the stalk causes the cells to swell, which weakens the walls and increases susceptibility to lodging. Traditional of wheat and rye that had evolved long stems as a defense against weeds were thus subject to selection favouring stiffer straw. Even so, the tendency of traditional species to lodge when intensively manured set an upper bound on yields at about 40 hectolitres per hectare (45 bushels).

[47] Citation from the Beauce here, and others as compiled.

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

[49] "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.

The fodder constraint was the principal obstacle to the diffusion of superior livestock. Anaimals 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.[50] The development of superior breeds thus depended entirely on the feeding regime, since farmers had no understanding of how inherited traits are transmitted in animals and in any event sold their best beasts, keeping culls for breeding in a kind of adverse selection that magnified the influence of the fodder constraint.[51] The relatively inexpensive movement of cattle permitted some specialization in breeds; in the sixteenth and seventh centuries lean cattle driven up to two thousand kilometers from Central and Eastern Europe to be fattened for urban markets on rich pastures of Lombardy and the Low Countries sometimes reached 450 to 500 kilograms, which was at least 50 percent heavier than ordinary stock.[52] In general, however, it was difficult to take improved stock and plant them in places where the common run was small and weak. The difficult dissemination of Flemish and Dutch cows provides a good example. By the early seventeenth century, animals bred for milk in the coastal districts of the Low Countries were producing upwards of 3000 litres a year, at a time when two centuries later the average yield on well-run farms in most of rural France probably did not exceed 800 litres and in some cases not even 200 litres.[53] Eighteenth-century attempts to introduce larger oxen from the Franch-Comté into Lorraine and cross milk cows from Switzerland with local stock in the Perche failed because the animals suffered on local fodder and their traits were not preserved in the offspring.[54] The weakness of draft animals adapted to scarce rations also affected methods of cultivation. Farmers adapted to the state of their stock by teaming animals

[50] '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.
[51] Nicholas Russell. *Like engendr'ing like. Heredity and animal breeding in early modern England*. Cambridge. CUP (1986).
[52] Ian Blanchard, 'The continental cattle trades, 1400 – 1600,' *Economic history review* 39 (1986), 427-60. The trade in oxen from Eastern Europe reached nearly to the Black Sea and serviced urban demand in the Low Countries. In view of arguments developed below, it is significant that in the first half of the seventeenth century, the average weight of oxen exported from the Hungarian Alföld was 450 kilograms, which was very large by early modern standards and a sure sign of specialization.
[53] Flemish milk yields are documented by Paul Vanderwolle, 'Stabilité et perfection d'un système agricole,' *Annales ESC* 36 (1981), 382-89 ; Jan de Vries, *Dutch economy* ..... The yield of cows held by cottars in Sarthe in the 1830s was as low as 200 litres and the average on better equipped farms did not exceed 800. Archives Départementales, Sarthe M166 bis. Statistique agricole 1836, canton de Montfort.
[54] V. Chevard, *Histoire de Chartres et de l'ancien pays chartrain*. Chartres (1800), 57 ; Texier-Olivier, *Statistique de la Haute-Vienne* (180x), 349.

up for the hard plowing in early spring when they were still weak from inadequate rations and lack of exercise. The strategy seems self-defeating, but it made sense when animals were worked intermittently, because farmers could reserve the best forage for intervals of peak effort.[55] But large teams required two men to drive, doubling the labour input. One of the sources of growth in labour productivity on large farms was the acquisition of larger stock. The animals were available, because they were commonly employed in road haulage, military transport where they were maintained year round on good rations. The profitability of this capital-intensive strategy depended on the demand price of farm produce, which was highest in the vicinity of cities.

Mutual adaptation of plants, livestock, and methods of cultivation to distinct ecological niches, then, resulted in technical complementarities that made it difficult to diffuse individually superior plants and animals. This was in large part a result of the non-specialized orientation of farm production, which privileged joint products over specialized traits. It was this factor as much as stasis in agronomical understanding that limited technical progress in farming. By the same token, however, changes in the structure of demand could have a liberating effect on the productivity of agriculture's biological *materiel.*

The stasis in farm tools and vehicles exhibits an analogous combination of geographical speciation and blocked diffusion. The original prototypes of the heavy ploughs, harvest implements and farm vehicles employed in the age of traditional husbandry date to Late Iron Age. Like biological prototypes, the original models supported a proliferation of regional types adapted to local soils, topography and systems of husbandry.. As Fitzherbert observed at the beginning of the sixteenth century,

> '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 grundes and soyles. Some whyte cley, some redde cley, some gravell or chylturne, some sande, some meane erthe, some

[55] '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 il marchent passablement, pour peu qu'on leur donne quelque nourriture à l'écurie. Que la longue saison du chômage revienne, ils reprennent leur vie presque sauvage, et à coup sûr, très-économique.' Édouard Lecouteux, *Cours d'économie rurale* vol. 2, (1879), 118-119.

> 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.'[56]

The spatial extension of agriculture posed a major obstacle to specialization in the manufacture of farm implements. In principle, the technology of pre-industrial wood and iron-working posed no insuperable barrier to serial production of farm implements. The obstacle to large-scale manufacture derived from the need to keep implements in repair. Subjected to wide fluctuations in moisture and mechanical stress, and joined by mortise and tenon, wooden implements had continually to be refitted and adjusted; abraded and dulled by sand and stones, plough-shares and coulters had continually to be sharpened and forged anew; harness and rolling stock had to be kept in good repair.[57] While most farmers could make simple repairs on their tools and fabricate primitive types of ard,[58] the more complex heavy plows and vehicles demanded the skill of specialists in wood and iron, and the urgency of repairs in the high season meant they had to be on the spot.[59] The one exception was scythe and sickle blades, light enough to stand the cost of long-distance transport, easy to repair in the field, and requiring steel-forging skills not easily exportable.[60] Well into the

---

[56] *The Boke of Husbandrie* (1534). Ed. Walter W. Skeat. London: English Dialect Society. (1882), 9.

[57] Plows in medieval England had to be rebuilt after every season. (Ag Hist Eng & Wales vol.3 p. 204) Using replicas of medieval plows, Danish investigators plowing at the rate of 20 to 40 ares per day wore out one share per two hectares, or once every five days, and the wooden plow twice fractured. (Lerche 1986). These findings are consistent with later information. In the eighteenth-century farmers working stiff soils renewed shares three times a season (Woronoff 1984: 431). At the end of the nineteenth century Ringelmann reported that shares used on dry stony soils were re-forged after plowing only 2400 to 3000 meters, or roughly two hectares. In damp soils, however, they could run 30 to 34 thousand meters. (*Culture mécanique* vol. 7, p. 145). Wooden parts also wore out. The 'ears' on ards in southern France had to be replaced every five months. Leure (1854:126)

[58]'Les anciennes charrues sont si simples, que la plupart des colons les construisent eux-mêmes.' Munier (1812).

[59] 'Quelque emploi qu'on fasse de la terre, soit pâturage, blé, vignes, il faut que les fermiers ou laboureurs qui en conduisent le travail, résident tout proche; autrement le temps qu'il faudrait pour aller à leurs champs et revenir à leurs maisons, consommerait une trop grande partie de la journée. De ce point dépend la nécessité des villages répandus dans toutes les campagnes et terres cultivées, où l'on doit avoir aussi des maréchaux et charrons pour les outils, la charrue et les charrettes dont on a besoin; surtout lorsque le village est éloigné des bourgs et villes.' Cantillon, *Essai sur le commerce en générale*. Paris INED (1952), 4-5.

[60]'Le fer qui nous vient de Suéde, d'Allemagne & DlÉspagne est excellent pour les ouvrages polis & délicats, & non pour les bâtimens; celui de Champagne & de Normandie est cassant, sur-tout celui de Saint-Dizier, qui a le grain plus gros; celui de Niverois est doux & propre à faire des armes; celui de Bo8rgogne l'est moins; celui de la Roche est doux & fin; celui de Senonches doux & pliant, & celui de Vibray ou Mans est plus fermes: l'acier n'est autre chose qu'un fer affiné." (Liger, *Maison rustiqe,* 39. In the eighteenth century, an attempt by the authorities in Limousin to replace imported by domestically manufactured scythes failed because works lacked the needed skill. 'Toutes celles qu'on emploie viennent du Breisgau. 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. see also 'lente progression de la faux.'

nineteenth century their manufacture remained a monopoly of districts specialized in agricultural cutlery. As a consequence no specialized manufacturer of farm equipment capable of exploiting limited but real economies of scale in handicraft production emerged before the late eighteenth century, and then in England, where the growth of the market and ease of communication favoured it.[61]

One might expect that the sheer number of craftsmen to have imparted an upward drift in implement design. But it was difficult for minor improvements arrived as local solutions to particular problems to spread to other areas because of the spatial dispersion of production, 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.'[62]

Invention thus ran its course in geographic differentiation of types rather than in widely diffused improvements, of which there are few examples.[63] The improved light swing plough developed in the Low Countries towards the end of the Middle Ages took more than two centuries to cross the English channel. As in the case of crop varieties and livestock, the primary stimulus to improvement was increased demand for farm produce, and increased demand generally. Kerridge notes that the large four-wheeled introduced into English farming in the late sixteenth century replicated models used for road transport.[64] The high skill of rural smiths and wrights in eighteenth-century Flanders was reputedly owing to demands on local craftsmen to build the vehicles and fortifications generated by the region's nearly continuous warfare in the seventeenth and eighteenth centuries.[65] In general, however, the improvement in farm tools awaited the eighteenth-century breakthroughs in ferrous metallurgy that made it possible to produce standardized iron

---

[61] Liam Brunt's article. Plus other refs here.
[62] *The Boke of Husbondrie* (1540), 4.
[63] 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 modern elongated S-shape, which is mechanically more efficient. Comet (xxx). As the evidence for this change is iconographic, it does not exclude an earlier invention.
[64] Eric Kerridge, *The agricultural revolution* (1967), 36.
[65]'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 (1823) (p.193)

pieces on a large scale. Regional differentiation of types persisted, but the constant improvement and falling cost of mass-produced pieces assembled centrally or in the countryside by rural blacksmiths gradually reduced their number until, by the end of the nineteenth century they were largely relics of a distant past.

The regional differentiation of farm tools was associated with complementary regional differentiation of techniques for using them. Ploughs differ in the way they are handled: on some the handles are pushed down, on others they are raised; some are turned to the side, others held straight up. These and other variations reflect regional differences in soil type and drainage to which the implements and their handlers adapted. That differentiation kept skilled farm workers in districts where their human capital was most productive and thus impeded the diffusion of more general skills they might have acquired. Markets for hired hands who handled most of the ploughing were local, and though one occasionally finds a distant migrant in farm accounts, the majority of hands engaged were drawn from a radius of about a dozen miles.[66] As one expects, it was harvest work, where the technical conditions were if not identical, at least similar from place to place, that migration was most intense, and it was in this sector of agricultural technology that the diffusion of new techniques seems to have originally been most rapid.[67]

Most of the technological blockages reviewed above could be overcome by specialization. The main obstacle to the diffusion of improved breeds, varieties and tools was thus insufficient effective demand for farm produce, which depressed incentives to specialize inputs and reorganize husbandry with a view to supporting more and better animals. In the pre-modern era that insufficiency was largely due to the dispersion of production and also of demand for farm produce. In what follows we review some of the structures adapted to that dispersion which impeded aggregation of market demand. These adaptations include self-sufficiency of farms in intermediate inputs and, to a large extent in labour, the difficulty of aggregating tradable stocks of produce large enough to capture scale economies in storage and distribution.

[66] Kussmaul found that the median distance between successive employers of a sample of seventeenth- and eighteenth-century farm servants in Sussex and Hertfordshire was between 4 and 5 kilometres, and fewer than 10 percent were drawn from places further than 15 kilometres. In the more dispersed agricultural county of Yorkshire, the median was a little over 10 kilometres. A. S. Kussmaul, 'The ambiguous mobility of farm servants,' *Economic history review* 34 (1981), 228-29.
[67] Citation on scythes here, with some detail on pik and resistance.

Dispersion of farms and their stock of tradable surpluses paradoxically limited incentives to improve the means of transport for agricultural produce. As in other domains, the stimuli to improvement of the means of transport usually originated outside the agricultural sector.

Dispersion and Agricultural Autarky

How dispersed were pre-modern farms? The clustering of habitations in villages and hamlets and the proliferation of non-agricultural rural industry leaves a misleading picture of the essential emptiness of pre-modern agricultural space. At the lower bound for a farm utilizing its own animal traction (6 to 8 hectares), a square kilometer could support 12 to 15 holdings; at a more economical size of 20 hectares it supported five, and at the 40 to 60 hectare size that marks the division between peasant and 'capitalist' farming, no more than two. Since the larger the farm, the greater the surplus released into trade, the growth of commercialized farming typically emptied the countryside of its farmers.[68] The resulting dispersion manifested itself in farmsteads 200 to 500 meters apart and nucleated villages separated by distances of three to six kilometres. That distribution reflects a practical limit to the extension of individual farms set by the maximum distance a team and its equipment could negotiate over across fields and rough access paths in an hour.[69]

The implications of agricultural dispersal and high transport cost for agricultural autarky are so evident only a few points need to be made concerning them. The primary consequence was self-sufficiency in intermediate agricultural inputs at the level of individual farms. While easy mobility of livestock permitted specialized breeding of draft animals and stores, nearly all farms produced their own fodder, fertilizer, traction, and food for workers. This affected the allocation of land. In climates supporting spring cereals, crop rotations were arranged to ensure a supply of oats and barley (and spring-sown pulses) sufficient to power the draft animals. The logical counterpart of that production was thin local markets for

[68] This is a major theme of Robert Allen's *Enclosure and the yoeman*. Cambridge (1992), who argues that the growth in farm size in the seventeenth and early eighteenth century reflects the superior productivity of large farms. It is worth noting that the relevance of that productivity was the capacity to serve off-farm markets, and that farm enlargement in response to market opportunity occurred around Paris without enclosure. Economies of scale were a necessary but not sufficient condition for growth in farm size.
[69] The distance was about 2500 meters. Citations here if needed.

fodder, as farmers whose only market was other farmers had little incentive to grow more than they needed to support an intermediate input of animals required by the target level of final output. In years when the supply of forage was greater than normal, they typically purchased or hired additional animals to exhaust the surplus.[70] Farmers tried to minimize the input of capital and labour employed in cultivating oats and barley, because from the perspective of their cash crops, these intermediate inputs were no more than a necessary evil. Self-sufficiency in fodder thus reinforced features of traditional husbandry making for low productivity. In three-course rotations light plowing for oats and barley left fields infested with weeds, necessitating a year of fallow to prepare the ground for bread cereals. By the same logic, however, off-farm outlets for the forage cereals could induce intensive cultivation of the third field that not only raised yields, but left the ground cleaner for succeeding crops. This normally occurred near towns where horse-drawn transport generated a demand for good hay and oats, and around army camps and military theatres.[71] In eighteenth-century Britain, where transport demand for oats was growing rapidly, the yield of oats rose two to eight times faster than that of wheat.[72] We see here one of the positive feedbacks between dispersion and productivity that on the one hand reinforced the stasis of traditional husbandry when demand was dispersed, and on the other provided openings for improvement when it became spatially concentrated.

---

[70] '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. See also remarks by Liger in *Maison rustique,* 581.

[71]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. Ces gerbes se vendent assez cher près des grandes villes; encore plus, près des armées, & dans tous les pays de pacages où les fourrages secs sont rares, sur-tout l'hiver & jusqu'à la moisson, principalement dans les années sèches, où les foins & herbes ont peu donné." Liger, *Maison rustique*,581. 'Les foins sont de très-bonne défaite pour les pays de montagnes & de plaines, pour les endroits où il y a guerre, & pour toutes les grosses villes, principalement pour Paris, où l'on ne donne aux chevaux que le foin avec l'avoine. On l'y amene de fort loin par bateaux: il en vient aussi par charrois des lieux voisins.'*Ibid,* 814. 'Les propriétaires et les cultivateurs qui récoltent au dela de leurs besoins vendent l'excédent aux aubergistes des villes où le conduisent sur les place de garnison.' Enquête sur les forrages, 1813,' Dept de la Mayenne.

[72] The sample of yields assembled by Turner and his associates indicates a rise in the median yield of oats of 39 percent between the 1720s and 1800s, whereas wheat yields rose only 18 percent. The increase in mean yields are 49 percent and 5 percent for oats and wheat, respectively. M. E. Turner, J. V. Beckett and B. Afton, *Farm production in England 1700 – 1914,* Oxford: OUP (2001), Tables 4.4 and 5.5.

Dispersion and the Marketing of Farm Produce

The dispersion of stocks affected the marketing of subsistence foodstuffs and fodder crops in ways that are not as well-appreciated by economists who overlook the substantial fixed costs entailed in storing grain and preparing it for market, and the factors controlling the timing of the flow of surpluses into trade. A thirty-hectare holding growing 10 hectares of winter cereal at 10 hectolitres per hectare produced a tradable surplus of 50 to 55 hectolitres of wheat, a quantity amounting to about five contemporary one-tonne cart loads.[73] But that surplus was not all available. Grain in the sheaf was too bulky to be carried any distance at a profit, and therefore had to be threshed first.[74] Moreover, because quality of grain improves in the sheaf and becomes easier to thresh, farmers had good reason to delay threshing until December.[75] Moreover, the natural aeration provided by loosely piled sheaves protected the crop from mildew and fermentation. It was only in spring when insects hatched in the straw forced farmers to thresh the lot that large quantities became available. Even then storage was costly because threshed grain had continually to be stirred and tossed to inhibit heating and germination. Thomas Tusser's doggerel sums the traditional view:

> '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.'[76]

These factors raised the internal rate of return to holding grain in the sheaf well above the normal cost of capital.[77] Having limited surpluses to begin with, small holders were the most likely to sell their grain first,

---

[73] Citations here on cart capacity. Wagons were two tonnes.

[74] Straw made up 70 percent of the weight of a sheaf of wheat and a higher proportion of oats and barley. Note here on importance of this factor for displacement of spelt by wheat in the eleventh and twelfth centuries.

[75] '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. And after Christmas, when the sowing of oats is commencing have your oats threshed; their freshly threshed straw, if mixed with some hay, will be then worth as much as hay by itself and will give great strength to your oxen and stamina for work.' *The Rules of Robert Grosseteste*, in D. Oschinsky, ed. *Walter of Henley and other treatises on estate management and accounting.* Oxford (1971), 307. Estienne and Liébaut, advised farmers to let the grain ripen in the sheaf at least three months before threshing it. Charles Estienne and Jean Liébaut, *L'agriculture et la maison rustique*. Lyon (1583), 300. Tusser's versified agricultural calendar situates threshing in the month of December. Thomas Tusser *A hundreth good pointes of husbandrie* (1557). v. 36.

[76] Tusser, *Hundreth good pointes* ((1585 edition), V: verse 5.

and whereas larger producers waited until spring to market marketed the bulk of their grain.[78] In the highly-commercialized region of Paris the seasonal pattern of deliveries was unrelated to the normal seasonal variation in price.[79]

The primary reason for the slow flow of grain onto the market, however, was the tempo of demand for straw as fodder.[80] Just as grain improved in the straw, straw preserved its palatability in the grain. When threshed, it dried out and quickly lost value as feed for animals. It was always inferior feed, and farmers were advised not to mix it with hay, because the animals refused the straw. As a result it was reserved for winter rations, which imposed a gradual rate of threshing until spring, when plowing demands required more substantial rations for the draft animals.[81] Contemporary writers are quite explicit that the rate of threshing was controlled by the rate of on-farm consumption of straw.[82] The cereals thus came into commercial circuits in a continuous trickle rather than all at once. Let us reconsider our 30 hectare farm. If the grain were threshed between December and May, its 55 hectolitre surplus became available at the rate of about one cart load per month. While that rate put little stress on rural paths, it made it difficult to

---

[77] The high cost of reversing transactions in threshed grain make it unlikely that the implicit return to holding stocks measures the opportunity cost of free capital to farmers. Discussion of this issue has unfortunately turned on the question whether farmers were 'rational' rather than on the technological details of the particular case. See D. McCloskey and J. Nash, 'Corn at interest: the extent and cost of grain storage in medieval England,' *American economic review* 74 (1984), 174-87; John Komlos and Richard Landes, 'Anachronistic economics: grain storage in medieval England,' *Economic history review* 44 (1991), 36-45; D. McCloskey, 'Conditional economic history: a reply to Komlos and Landes, *Ibid.* 128-32.

[78] Bruce M. S. Campbell, James A. Galloway, Derek Keene and Margaret Murphy, *A medieval capital and its grain supply: Agrarian production and distribution in the London region c. 1300*. Historical Geography Research Series 30 1993), 95-97.

[79] The following table gives the monthly deliveries as a percent of total sales for a 'normal' harvest in the early 1690s.

Month	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July
Sales	1.8	1.9	1.4	6.4	8.4	8.8	11.6	11.1	8.7	11.9	17.4	10.6
Price	15.3	14.7	14	13.8	14.3	14.3	14.5	13.8	14	14.6	14.7	14.3

Source: J.-M. Moriceau and G. Postel-Vinay, *Ferme, entreprise, famille. Grande exploitation et changements agricoles xvii^e^-xix^e^ siècles.* Editions EHESS (1992), 226.

[80] 'Car la paille du froment est le fourrage qui convient aux chevaux.' François Quesnay, 'Fermiers,' *Œuvres économiques et philosophiques de F. Quesnay*. Ed. August Oncken. [1888] Reprint. New York: Burt Fanklin (1969), 168.

[81] 'But serve them with haye while thy strawe stover last/They love no more straw, they had rather to fast.' Tusser, *Hundreth good pointes* (1557), v. 40.

[82] '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 du département de l'Eure* Paris (1805), 92. Threshing 'à mesure de la consommation des pailles.' *Statistique de l'Aisne*, 9.

accumulate large stocks at staging points for further shipment by water on vessels that commonly carried loads of 20 to 90 tonnes.[83] All this raised the cost of marketing grain at a distance. It is no wonder Madame de Sévigny was more than happy to sell off a piece of land on her isolated estate in eastern Brittany because 'it only yielded corn.'[84] Yet, here again, proximity to points of concentrated demand for newly threshed straw could upset that timing by providing opportunities for immediate sale of large quantities of produce.[85] This was another of the many ways that urbanization and other forms of spatially agglomerating demand could affect agricultural practice.

For various but complementary reasons, then, harvested grain remained in its bulkiest phase on farms rather than in centralized granaries, making its way to market in discontinuous trickles that tracked the constant trickle of demand. The same pattern marks the marketing of fodder consumed by urban stables, military encampments, and at post and stage relays strung out like beads on the main roads that connected capitals to provincial towns and the frontier. In this case it was the possibility of a cheap backhaul of stable manure and the cost of erecting buildings to store the bulky produce in town that made for a continuous flow from farm to final consumer.

The dispersal of farm produce has important implications for the functioning of regional grain markets. As long as grain was marketed locally, marketing involved little manipulation. The clientele were poor and did not demand highly refined flour. Cereals destined for more distant markets, however, had to be prepared to a state – or 'merchant quality' – sufficient to fetch a price covering the often considerable cost of transport. Local consumers knew what they were getting from long experience and if poor were not too demanding, distant customers needed guarantees that it was reasonably purged of

---

[83] Jean Meuvret, *Le problème des subsistances à l'époque Louis XIV. Le commerce des grains et la conjoncture.* Paris (1988) ; François Billaçois 'La batellerie de la Loire au xvii[e] siècle,' *Revue d'histoire moderne et contemporaine* 11 (1964), 173-75.

[84] 'Nous en avons vendu une petite où *il ne venait que du blé,* dont la vente me fait un fort grand plaisir et m'augmente mon revenu.' *Lettres de Madame de Sévigné*. 21 juin (1671).

[85] '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. Ces gerbes se vendent assez cher près des grandes villes; encore plus, près des armées, & dans tous les pays de pacages où les fourrages secs sont rares, sur-tout l'hiver & jusqu'à la moisson, principalement dans les années sèches, où les foins & herbes ont peu donné.' Liger, *Maison rustique*, 581.

impurities. The guarantees took the form of repeated screening and cleaning of threshed grain to remove bran, pieces of straw, weed seeds, insect remains and mouse droppings. All this took time, and it is not surprising that, along with threshing, the screening of grain was the first operation to be subjected to mechanization.[86] It also drove a wedge between the cost of cereals consumed locally and the cost of cereals entering into more distant trade.

In normal years, the long-run adjustment of supply to mainly local demand ensured that the flow of grain and other produce maintained seasonally stable prices that accurately, though implicitly reflected the value of the unknowable stocks held in the countryside. But disturbances to the market from the side of demand or supply could throw that delicate balance out of kilter.[87] The most serious imbalances occurred when harvest shortfalls caused the provisioning space of major urban centres to expand into new districts, driving up prices and carrying away produce that often led to localized famine in food-producing districts.[88] In the worst shortages, the government had to send out commissioners into the countryside to take inventories of stocks held in the barn. In brief, the fragmentation of the stock of cereals into thousands of inventories stocked on farms made it impossible to gauge true supplies in periods of marked disturbance in demand or supply, intensifying speculative price movements. All this deterred investment in specialized agricultural capital, which was the main way of exploiting the productivity locked up in traditional husbandry.[89]

Dispersion and Transport of Farm Produce

Despite the bulkiness and geographical dispersion of farm produce, its commerce gave little stimulus to improving the means of transportation, with the possible exception of wine, the production of

---

[86] Meuvret, *Commerce des grains,* 20-21.

[87] One of the most common demand shocks came from military operations. We turn again to the testimony of Madame de Sévigné. Writing to her daughter in the spring of 1672, she remarks, 'Le roi est à Charleroi, et y fera un assez long séjour. Il n'y a point encore de fourrages, les équipages portent la famine avec eux : on est assez embarrassé dès le premier pas de cette campagne.' *Lettres,* 6 may 1672.

[88] Grantham, Espaces privilégiées,' 719-22.

[89] 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, Charles. *Description générale du département de la Vienne* Paris (1802), 71.

which gravitated towards waterways that carried it away to distant consumers, and of vessels specialized for the tradein lumber and grain from the Baltic.[90] For fodder and cereals, however, inland and coastal transport of foodstuffs generated a system externality in which mutual adaptation of itineraries, tracks and means of transportation to spatial dispersion of production sustained the practice of costly displacements in small packets.[91] Trade in dispersed stocks of farm produce resulted in a dense network of rural paths and tracks well suited to the light traffic they carried, but nothing heavier. The multiplicity of routes serving the same destination permitted haulers to circumvent bottlenecks and breaks in the route at the cost of a slight detour, which removed pressure to correct them and any incentive to levy tolls to finance their improvement. While no route was easily traversed, few were totally impassable. Such primitive networks, which in France dated to the Celtic era, were well suited to pack animals and carts that fully loaded usually carried little more than half a tonne of produce. A cost of such networks was depressed incentive to improve the 'rolling stock', which would have been useless on deeply rutted and muddy paths.[92] To avoid flooding roads avoided the low country and followed the ridge line to minimize the cost of bridges and causeways, which entailed steep pitches and thus light loads.[93] For this reason the slow-moving oxen dominated horses on the unimproved tracks.[94] Yet, even had the paths been precipitous, loads had to be proportioned to the strength of draft animals drawn from the stock held by farmers.[95] Once again we see positive feedbacks connecting the extent of the market to the productivity of agriculture. Low productivity increased the effective dispersion of disposable surpluses, raising the cost of transporting them to central

---

[90] On the importance of waterways as a predominate locational factor in commercial production of wine in France, see Roger Dion, *Histoire de la vigne et du vin en France des origines au xix^e siècle*. Paris (1959). It is important to keep in mind that grain shipped by sea usually arrived in a deteriorated state.

[91] Meuvret, *Le commerce des grains et la conjoncture*, 47-96.

[92] The effect of the condition of the paths is well brought out by evidence from early fourteenth-century purveyance accounts from Sussex. It cost £4 to carry 100 quarters of grain 30 kilometers through the rough Wealden track connecting Mayfield and Lewes, but only £1 15s to carry it the last 22 kilometers from Lewes to the coast at Stoneham. R. A. Pelham, 'Studies in the historical geography of medieval Sussex,' *Sussex archaeological collections* 72 (1931), 170. As late as the 1760s cotton bales were carried from Liverpool to Manchester by pack animals rather than on carts. William Albert, *The turnpike road system in England, 1663-1840*. Cambridge : CUP (1972), 8.

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

[94] '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 â peine praticables pour les hommes même.' M.-L. Texier-Olivier, *Statistique générale de la France...département de la Haute-Vienne.* Paris (1808), 334.

[95] Citation here on off-season haulage by farm animals and its problems.

points. Dispersion discouraged specialized haulage because the quantities involved were too small to cover the cost of setting up permanent facilities.[96] High transport costs taxed investment in agricultural improvement, and thus sustained the low yields that made accumulating significant stocks of grain in one place a transport-intensive undertaking.

These relations were not significantly offset by the possibility of transporting produce by water. To be sure, four to six horses could haul two tonnes by land, while a dozen horses on a tow path could draw 20 to 40 tonnes floated in a barge. The cost differential affected the geographical configuration of urban supply zones. A map of the sources of grain destined for Nantes in the eighteenth century shows a scattering of points on the middle and upper Loire and up and down the coast, but relatively few suppliers from Nantes' immediate hinterland. By contrast, the origins of other products map the contemporary economic geography of northern and western France.[97] Medieval London drew much of its food supply from ports situated on the Kentish and East Anglian coast.[98] The disposition of navigable waterways also affected the spatial configuration of the road network. As late as the eighteenth century, the most important roads outside the immediate environs of major cities of France were routes that portaged goods from one river basin to another. In the 1670s Colbert instructed the Intendant at Soissons to put aside improving roads leading to Paris, and concentrate on the route across the height of land separating the watershed of the Seine from the streams draining towards the Low Countries.[99]

River transport was nevertheless affected by capacity constraints analogous to those holding back the productivity of land transport, and suffered from one additional obstacle -- the ease with which tolls

---

[96] This was equally true of river transport. This ws true even of transport on the on the Loire river, which was one of the most heavily trafficked waterways in pre-industrial France. Billaçois, 'La batellerie de la Loire.'

[97] Guillaume Daudin, *Commerce et prospérité. La France au xviii^e^ siècle.* Paris : PUPS (2005), 62.

[98] Campbell et all, *A medieval capital and its grain supply*, xx

[99] 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 Henri Cavaillès, *La route française. Son histoire et sa fonction.* Paris (1946), 54-55.

could be levied at bridges past which boats had to float, which unlike tolls on land passages could not be circumvented. To the problems created by ice and low water were added the often circuitous routes that often made the more costly but shorter transport by land more advantageous. Exposure to water coming in from the sides or leaking into the hold damaged the product, which meant later deduction from selling price.[100] The main problem, however, was accumulating enough grain in one place to fill a boat, which was made difficult by the underlying dispersion of available stocks and the slow speed with which they were released into trade. This was as true along the coast, where the grain found its way to hundreds of small ports dividing the stock among them, as it was along the rivers, where a 'port' might be something no more than a wide-spot in the tow path with a couple of iron rings driven into a rock to moor the boats.[101] Filling vessels took time, which raised the cost. As in land transport, the cost deterred the development of more specialized facilities that might have lowered it.

The dispersion of agricultural production entailed high costs of aggregating supplies for final consumption at non-farm locations. Low yields dilated the space from which produce had to be gathered to accumulate a given stock at any one point, and the high costs of that accumulation deterred specialization by farmers except where, as in the case of wine or wool, they produced a valuable and readily transported commodity. In the case of wine, the solution to transport cost was clustering of vineyards along the slopes and benches that lined the rivers. The stasis of pre-modern farming can be in large part attributed to factors resulting from spatial dispersion of production. While nothing could be done to modify the elements of the agricultural production function generating that dispersion, there was a way of extracting more productivity from it. That way was through spatial aggregation of demand, to which we now turn.

Structures of Agglomeration

The dynamics of urbanization are located in scale economies of trade, manufacturing, and market pooling of specialized resources and financial instruments, which as early as classical antiquity were strong

---

[100] Baltic grain was notoriously inferior because of this damage. In France, demagogues commonly charged that merchants charged with importing stocks stored in Amsterdam were part of a a government plot to poison the people. S. L. Kaplan, *Bread and politics in the age of Louis XV.* The Hague: Martinus Nihhoff (1976),

[101] On the rings, see, Billaçois, 'La batellerie de la Loire,' 168. The small ports from which grain was exported as far as Gascony in the thirteenth century are documented in Pelham, 'Studies' and Pelham, 'The foreign trade of Sussex, 1300 – 1350,' *Sussex archaeological collections* 70 (1929), 117-118.

enough to support significant concentrations of specialized traders and producers. The dynamics of urban growth and decay are still poorly understood, despite recent progress.[102] The economic consequences for agriculture, however, have long been recognized. Urban agglomerations concentrated demand in a way that raised the return to agricultural investment. We begin with the simplest effects analyzed by Von Thünen.

The Rings of Von Thünen

Among economists Von Thünen is best known for demonstrating that under perfect competition a space in which goods, capital, and labour are perfectly mobile organizes itself into a series of concentric rings of specialized production. Because the English translation omits much relevant material, it is less well appreciated that Von Thünen's primary goal in writing *Der Isiolerte Staat* was agronomical. He wanted to show that contrary to conventional wisdom, there is no absolute 'best' system of farming, but that what is best is conditioned by location with respect to a market outlet. He was drawn to that focus by early studies in agronomy under Albrecht Thaer, who pioneered the quantitative study of sources and uses of plant food, a discipline then known as Agricultural Statics.[103] Agricultural Statics was a theory of plant nutrition based on the concept of an enigmatic life-giving substance called 'humus' thought to be embodied in dung and composted plant and animal matter.[104] Developed several decades before Liebig's breakthrough in analytic organic chemistry in the late 1820s, the agronomical research inspired by this concept attempted to measure the balance of 'humus' by computing the amount of humus added to and removed from the soil by different crops and systems of husbandry. Agricultural Statics was book-keeping in 'humus' units of account.[105] As crop rotations generated different steady-state stocks of 'humus' supporting different levels of crop yield, the measure indexed the potential the physical productivity of

---

[102] Masahisa Fujita, Paul Krugman, and Anthony J. Venables, *The spatial economy: cities, regions and international trade*. Cambridge MA: MIT Press (1999).

[103] 'Adam Smith taught me political economy, Thaer scientific farming.' *Isolated state*, 225. On Thaer, see Gunter Franz, *Grosse Landwirte*. Hanover (1970).

[104] On the theory of agricultural statics, see G. E. Fussell, *Crop nutrition: science and practice before Liebig*. Lawrence: Coronado Press (1971).

[105] The analytical difficulty was precisely defining that unit. Liebig's discovery of a speedy and accurate method of analyzing organic substances allowed the notion of balance to be reformulated in terms of specific chemical elements, the quantities of which could be compared directly with various measures of agricultural yield. This analysis opened the door to agricultural chemistry and the use of commercial fertilizers. J. R. Partington, *A history of chemistry*, vol. 3. London (1964), 237-39. On the early development of the discipline, see Wolfgang Krohn and Wolf Schafer, 'The origins and structure of agricultural chemistry,' in Gerard Lemaine et al., *Perspectives in the emergence of scientific disciplines*. Paris (1976),

different systems of farming. Intensive rotations classed under the rubric of 'New Husbandry' generated the highest the steady-state stock of humus, so it followed that they supported the highest steady-state agricultural output per hectare and were thus the 'best' system of farming. Von Thünen challenged this proposition on the grounds that in a market economy, the determining criterion is not physical productivity of a given system of husbandry, but its net return, which owing to transport costs is not independent of locations. His work is thus as much a treatise in agronomy as it is in spatial economics.

Von Thünen's quantitative analysis is based on records of production costs and product flows that he kept between 1810 and 1815 on his estate at Tellow, situated 37 kilometres south of the Baltic port town of Rostock. Emptied of its population during the wars of the seventeenth century, by the turn of the eighteenth century it had become home to a short form of up-and-down husbandry that he termed the 'improved system,' which alternated three years of sown leys followed by a four-course arable rotation of fallow, rye, barley, and oats. Comparing it with a traditional three-course Mccklenburg rotation of fallow, rye, and spring cereal and calibrating the two rotations to his index of soil fertility, Von Thünen determined that in order to restore the humus removed in the three-course rotation with animal manure, farmers had to keep 64 percent of the agricultural territory in pasture, whereas the 'improved' rotation was self-sustaining. Normalizing agricultural output on a rye-equivalent measure he defines as 'bushel-crops', he found that while the 'improved system' was 19 percent more productive than the traditional system, its cost per hectare was 17 percent higher. Since the net return to the sale of farm produce (as well as some of the labour costs) declined with distance from the market as a consequence of transport cost, it followed that more intensive and technically more advanced system of husbandry was not the best system at distant locations. It followed that

> '[I]mproved 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.'[106]

And since the price of grain is distance-dependent, it follows that the extent of improvement of improved farming is a spatial variable.

Thus, while the analytical originality of Von Thünen's work rests in its connecting distance, transport cost and the spatial mix of economic activity – he even has a short passage on urban scale

[106] *Isolated state*, 71.

economies that prefigures Marshall's discussion of spatial external economies – the most extensive discussion concerns the relation between distance and systems of husbandry, all of which were traditional in the sense that they had all been around a long time. For all its tedious calculations, the message is that no single system dominates all others under all conditions. Different intensities of cultivation supported different population densities. The improved Mecklenburg system supported 59 persons per square kilometre, while the greatly improved Belgian system supported twice as many.[107] The difference was not due to any difference in crop yields, which for ease of calculation Von Thünen held constant, but to the larger output of subsistence foodstuffs produced by the Belgian system, which produced three food crops in five years (rye, potatoes and wheat), whereas the Mecklenburg system produced only one (rye) in seven.[108] But that more productive system cost more to operate, and was profitable only where the market could absorb the additional output at its additional cost. Once again, we return to the primordial role of demand in determining not only the crop mix, but systems of production within the technical context of traditional husbandry. For the agricultural history of the pre-modern age, the critical rings of Von Thünen are the inner ones.

The mechanisms by which space-dominated intensification increases agricultural productivity are well-known and were for the most part spelled out by Von Thünen. The first was the production externality provided by urban transformation of straw and animal fodder into manure, which reduced the capital cost to farmers of maintaining a stock of animals to produce an equivalent quantity of fertilizer. That externality was reinforced by a transportation externality in the form of cheap backhaul, as the same carts that delivered produce to a town return loaded with stable manure and night soil.[109] This trade had a major impact on the fertility of soils in the vicinity of the large towns. For example, much of the soil on the lower benches of the Seine around Paris was of low quality as compared to the loess that covered the

[107] *Isolated state*, 87.
[108] *Isolated state,*
[109] That the traffic could be intense is illustrated by a mid-thirteenth-century court case that actually reached the court of Henri III. It involves a dispute between the town of Huntingdon and the parish of Godmanchester situated just across the river Ouse. Godmanchster complained that the burgesses of Huntingdon had damaged the bridge by carting manure to their properties on the Godmanchester side and returning fully loaded with grain, straw and fodder. The court held for Godmanchester. James Masschaele, *Peasants, merchants and markets. Inland trade in medieval England, 1150 – 1350*. New York: St Martin's Press. 1997, 200. On an example of an extremely profitable exchange of straw for manure in the huge eighteenth-century Parisian market, see Moriceau and Postel-Vinay, *Ferme, entreprise, famille,* 235-36.

plateaux immediately to the east and west of the French capital. But the import of manure and night soil that transformed produce from an enormous catchment area made them among the highest yielding properties in France.[110] Another powerful externality of proximity to cities was the facility of sharing the fixed cost of maintaining draft animals by sharing them with urban haulers. Farm work was intermittent, and renting or selling and repurchasing animals to entrepreneurs in urban transport during the off season reduced farmers' fixed cost and greatly increased the flexibility of the supply of traction. In contrast, farmers in more isolated districts had to maintain large teams to meet an occasional demand for them. Farmers who exchanged horses with haulers also secured better animals, as animals employed in commercial drayage were larger and better maintained than the animals employed exclusively in farming, particularly in peripheral districts.[111] Temporary labour was also more easily secured near towns than further out. The intensity of cultivation also raised yields and indirectly raised labour productivity. Aggressive weeding cleaned fields for successive crops raising their yields, while intensive cultivation loosened the soil to the point where in time it became easier to cultivate.[112] Mention has been made of the relation between cultivation and natural selection of genes making for higher yields. Intensive cultivation, then, generated a series of linked positive feedbacks that despite the increased input per hectare, raised total factor productivity. As Adam Smith pointed out, innovations in husbandry stimulated by a short-term rise in demand price often resulted in a lower long-run supply price.[113]

The second effect is less well-known but just as powerful. The development of a secure market for grain provided the opportunity to increase productivity by increasing farm size. As noted above, the main source of labour-saving in farming before the nineteenth century was more efficient use of animal

---

[110] '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.' Hilaire-François Gilbert, *Traité des prairies artificielles* [1789] Paris (1826), 20.
[111] Édouard Lecouteux, *Traité de l'agriculture de la Seine*. Paris (1840), 125.
[112] Cordier, *Flanders* citation here.
[113] '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' Adam Smith, *Wealth of Nations.* Cannan Edition, New York: Everyman Library (1935), 225.

traction, which could be achieved by enlarging the size of farms, making them more compact, and increasing the size of individual plots to reduce time lost in transporting teams and equipment from plot to plot and in turning ploughs at the end of the furrow. These savings were substantial. In the course of the eighteenth century the Chartiers reduced the number of ploughmen per cultivated hectare by nearly a third as a result of these changes.[114] That the changes were induced by market opportunity may be inferred from the geographical distribution of plot sizes in open-field districts of northern France. Table 2 shows the average size of arable plots in a sample of cantons drawn from five *départements* in 1852. The parcels in cantons inside the Paris provisioning zone were twice as in peripheral regions (from the perspective of Paris) of Champagne and Loraine.

Table 2
Size of Arable Plots, 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
Loraine (*Haute Marne*)	0.23	19

Source : Canton and communal returns from *Enquête Agricole* of 1853 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 on the averages of orchard plots is insignificant.

Growth in farm size in the early modern age is usually attributed to the superior efficiency of large holdings; but the savings in ploughing time resulting from the changes listed above were available from the start, as was the possibility of breeding and maintaining powerful draft animals. Farms grew large around Paris in the twelfth and thirteenth century just as the city was becoming the most populous capital in Western Europe. It is thought that the spread of the mouldboard plough was induced in part by its labour-saving characteristics.[115] The main effect of enlarged farm size was the saving in labour. This is why purely agricultural population of the large-farm districts that supplied the major cities with grain was relatively small. It is perhaps no coincidence that in the eighteenth century, the rural populations in English

[114] Moriceau and Postel-Vinay, *Ferme, entreprise, famille,* 208.
[115] Because it held the furrow better than non-stabilized types, the wheeled plough was easier to direct and demanded less skilled labour. Citation here: Comet.

counties specializing in cereals had the lowest rates of population growth.[116] Along with the increased crop yields that resulted from more intense trade in urban-originating fertilizers, endogenous growth in farm size provided sufficient elasticity in agricultural supply needed to meet the needs of a rising population.

Demand price was critical, because rearranging the system of husbandry to render higher yields and higher labour productivity was capital-intensive. To extract that productivity farmers had to invest in buildings, animals, equipment and working capital. Von Thünen reckoned the outlays in the intensive Belgian system at 8034 thalers, as compared with 4863 thalers for the traditional three-course Mecklenburg system. If we take overhead costs as a proxy for the cost of fixed capital, the Belgian system was almost two and a half times more capital-intensive than Mecklenburg.[117] At a rough estimate, intensive rotations were probably twice as capital-intensive as traditional extensive culture. Capital supply, then, lies at the core of the responsiveness of productivity within the technology of traditional husbandry to market opportunity. Labour was mobile enough, and endogenous demographic responses to local labour market opportunities were powerful enough to induce adequate labour supplies. The ease with which underemployed farm labourers and artisans in marginal districts could tramp long distances in search of seasonal employment in specialized grain-farming regions and the seasonal flow of workers from rural industry into the fields in summer came close to eliminating bottlenecks in labour supply posed by the surge in demand for harvest hands. Agricultural specialization and rural non-agricultural specialization went hand in hand.[118] Moreover, the transition from low- to high-intensive specialized farming pulled out underemployed labour locked up in farm families practicing subsistence farming.[119] Labour was not the binding constraint on agricultural intensification and specialization.

The conditions governing the supply of agricultural capital, however, were crucial to agricultural progress. What were those conditions? Postel-Vinay's study of agricultural credit in allegedly capital-scarce France reveals that notary-brokered annuities secured by mortgages provided a flexible and

---

[116] E. A. Wrigley, 'English county populations in the later eighteenth century,' *Economic history review* 60 (2007), 35-69. Removing the borough towns from the agricultural counties in Wrigley's list lowers their rate of population growth to 0.35 percent. p. 58.
[117] *Isolated state,* 85-86. The fixed capital estimates are 3046 and 1296 thalers.
[118] See Grantham, 'Divisions of labour' for an extended discussion of this point with references.
[119] Devries, 'Industrial revolution and industrious revolution.'

generally adequate means of financing transfers of property, intergenerational settlements, and investment in farm structures and improvements. The cumbersome procedures of land-secured loans, however, were not generally suitable to financing rapidly depreciating capital like animals, equipment, and the still more rapidly depreciating advances for seed, rent, and labour cost.[120] Although farmers could borrow on security of land -- and it appears that large tenant farmers in France acquired property for that very purpose –the primary source of liquid capital was cash flow, which as the Physiocrats correctly argued, depended mainly on the demand price of farm produce.[121] Adam Smith put it as succinctly as it can be put:

> 'The lands of no country, it is evident, 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.'[122]

Cash flow stood at the heart of the Physiocratic critique of French economic policy. By encouraging production of manufactures worked up from exotic raw materials rather than from the produce of the *terroir*, and by regulating grain prices to keep wages low in order to compete with foreign manufacturers in sectors where France had no real claim to advantage, government policy had strangled the true source of national wealth by depriving farmers of their main source of capital. Tracking net cash flows between farmers, merchants and manufacturers, and rent claimants (including the state), Quesnay's *Tabeau écononomique* showed how low farm prices prevented farmers from renewing and augmenting advances required by a productive agriculture. His ideal was the large well-capitalized farms of the Île de France that provisioned Paris, whose market was large enough to generate the sales that replenished needed to replenish the hefty stock of cash reserves they required. For, although landlords could finance fixed capital directly from their own resources or by granting rent rebates to farmers making the investment for them, working capital had to be financed from farmers' own reserves. A system of farming that demanded heavy inputs of capital, labour, and seed in advance of any return from the harvest demanded heavy outlays of working capital. The risks attached to those outlays inhibited the development of an efficient system of short-term credit in bank loans or the agricultural equivalent of commercial paper. Fixed capital was a

---

120 Postel-Vinay, *La terre et l'argent.*

121 '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 rentren : 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 meme entreprise de culture.' Quesnay, 'Fermiers,' *Œuvres complètes,* 181-82.

122 *Wealth of Nations,* 227.

different matter, and in especially favorable circumstances could attract urban capital.[123] But farmers intending to practice a capital-intensive husbandry had to self-finance. This was the basis of the Physiocratic case for free trade in grain. Just as the high prices and extensive market outlets created by urban demand provided the cash flows that sustained capital-intensive farming in the Low Countries and the Île de France, free trade in grain, both domestic and foreign, would provide the 'good prices' to sustain heavier investment in the capital-poor districts of France.

The Physiocrats emphasized the level of grain prices because they believed most elements of the cost of production were predetermined. Probably more important for investment, however, was the variance in price, which along with stochastic fluctuations in output determined the risk attached to farmers' net cash flow. The spatial constraints on farm size described above made it impossible to hedge those risks internally. The main determinant of that variance was the thickness of markets. Because they pooled the output of more individual producers, markets for farm produce were 'thicker' in the vicinity of cities, and cash flows were more secure. This does not mean they were completely secure, of course. In the late seventeenth and early eighteenth century many farms in the Paris region failed under the weight of harvest failures and fluctuating grain prices.[124] Nevertheless, the large pool of grain that fed urban markets buffered price fluctuations better than the shallow pool serving rural markets in the hinterland. Within a radius of roughly 50 kilometres that marked the perimeter of direct delivery by farmers, a large central market provided a competitive outlet that worked the way the Physiocrats thought free trade in grain should work. It encouraged agricultural investments within the normal urban provisioning zone of 50 to 55 kilometres within which farmers could handle their own transportation. One can get a very crude sense of the urban effect on price volatility from the statistics collected by Labrousse for the 26 *généralités* of France and the city of Paris. The data average observations from a number of towns within each *généralité*, and therefore understate the true relative variance, which in any event was much less than it had been a century earlier. Table 3 shows the standard deviation of prices between 1756 and 1790 for a

[123] In the golden age of agricultural growth in the Netherlands, the drainage of lakes and peat removal to make land for new farms was financed by urban capital. Jan de Vries and Ad van der Woude, *The first modern economy. Success, failure and perseverance of the Dutch economy, 1500 – 1815.* Camridge: CUP (1997), 202-203.
[124] Jean-Marc Moriceau, *Les fermiers de l'Île de France*. Paris (1994). Cite examples here.

representative set *genéralités* of as a percentage of Paris prices. The *généralités* of Paris exhibits the same standard deviation as the capital; that of Soisson, which was mainly inside the normal provisioning space

Table 3
Standard Deviation of Wheat Prices
1756-1790

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: C. E. Labrousse, *Esquisse du movement des prix et des revenus en France au xviii^e siècle.* Paris : Dalloz (1933), 106-113.

is four percent higher. On the other hand, the outlying regions of Champagne, Lorraine, and the middle Loire (Orléans and Tours), show significantly higher price fluctuations. Amiens is an interesting case because the soils were as rich as those of the *Genéralité* of Paris, but river access to this district straddling the height of land between Flanders and the Paris basin was poor and significant portions of the road network remained unimproved in the late eighteenth century.[125] In the heavily urbanized and well-watered *généralité* of Flanders price fluctuations were similar to Paris. The test case is Lyon, which was situated in at the centre of a region that, while providing a wide variety of foodstuffs, was far from being a breadbasket. Here the deviations within the district of Lyon and its main provisioning province Burgundy are the same as for Paris and its provisioning zone. In the seventeenth century, however, the major source of extra-local supplies came from the Loire basin and Auvergne, here represented by the *généralité* of Riom and in much smaller measure Moulins.

In contexts where most of the costs are pre-determined long in advance, as was the case of most farm produce, the variance in product price becomes a major determinant of the required rate of return to

[125] Bernard Lepetit, *Chemins de terre & voies d'eaux. Réseaux de transports, organisation de l'espace.* Paris : Editions EHESS (1984) 55-57.

capital. The theory of option pricing teaches us that the opportunity cost of an irreversible investment includes the expected value of avoiding an immediate negative shock by delaying investment without sacrificing the expected returns to investing in the following period.[126] To put it most simply, farmers always had an option to hold back on extra plowing, extra weeding, hiring additional workers and animals, and putting more effort into the production of forage. Simple calculations for a trendless cash flow indicate that a coefficient of variation of 20 percent raises the value of the option to delay enough to double the required rate of return over the normal supply price of capital.[127] The thicker markets of urban provisioning zones, then, encouraged investment not simply because net prices were higher, but because they were more stable.

What was the effect of higher prices on productivity? I have elsewhere attempted to estimate vegetable-product supply elasticity from cross-section data for pre-railway France, and find that controlling for proximity to cities it was as high as one.[128] This seems unreasonably high, but if we assume that supply elasticity was only 0.5 and demand elasticity -0.7, a one percent rise in aggregate demand for vegetable product would increase price by 0.8 percent and supply by 0.4 percent. The supply elasticity for the yield of cereals is similar, except for oats, which is about half that of the bread cereals. As the level of prices roughly tracks the distance from cities, the pattern suggests an impact of urban demand on agricultural productivity. Indirect estimation by Hoffman using rent data from pre-eighteenth-century sources turns up the same relation.[129] The regression results are nevertheless deceptive in that the relation between distance and agricultural productivity was discontinuous. That discontinuity stemmed from the discontinuity of transport costs. Within a radius of 50 or so kilometres, farmers could deliver their produce by land directly to their principal urban market. Beyond that boundary, the flow of food required complex and costly intermediation.[130] In the case of Paris, they were legally obliged to do so, though the obligation

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

[127] The formula for the trendless required rate of return is $\rho^* = \frac{\beta\rho}{\beta - 1}$, where β is the parameter that optimizes the value of weighting. For the derivation of the formula that calculates β, see Dixit, *op. cit.*

[128] Grantham, 'Agricultural supply in the Industrial Revolution: French evidence and European implications,' *Journal of economic history* 49 (1989), 60-61.

[129] Philip Hoffman, *Growth in a traditional society*, 171-72.

[130] Grantham, 'Espaces privilégiés,' 715-718.

was honoured more in the breach than in the observance.[131] Within that zone farmers could employ draft animals not otherwise engaged in agricultural operations to cart and carry produce to market. That haulage, which to be sure was unavailable during the seasons of agricultural demand for traction, competed with commercial haulage, thereby keeping rates low and farm gate prices high.

The most important unanswered question is where that productivity growth comes from. Given the fundamental stasis in agricultural know-how prior to the late eighteenth century, the potential causes are few in number: diffusion and elaboration of intensive cropping systems making greater place for forage and other legumes; increase in farm size; specialization of animals and equipment, and more generally, greater specialization in production. The most complete account of such changes in traditional husbandry is DeVries's study of the flowering of Dutch agriculture between 1500 and 1650, where all of these elements can be seen operating together.[132] Here we see increased inputs of labour, capital, and specialized animals and materials made in response to growing demand opportunities in a region that was far from being blessed with good soils. Increased productivity was in large part the consequence of tapping underutilized labour locked up in the multi-product agriculture of subsistence farming, reallocating (mainly women's) time from household manufacture to farming, and increasing the stock of capital by reinvesting cash flow. Because so many of these changes are statistically unobservable, they appear in our accounts as productivity change, and because there was learning by doing and invention precipitated by the technological bottlenecks thrown up by greater specialization, some of that change is real. But it is difficult to believe that it was entirely new, and that the same pressures at other times and other places would not have given rise to similar technical solutions. Traditional agriculture possessed considerable medium-term elasticity of supply.

Space and Demand Aggregation

The key to the 'escape from Malthus' before the technological innovations of the 1840s was greater agricultural investment induced by high demand prices for farm produce. Until the fall in the cost of transporting bulky produce brought about by drained and surfaced roads, canals, and ultimately

---

[131] Citations here from Steve Kaplan's work.
[132] Jan de Vries, *The Dutch rural economy in the Golden Age, 1500 – 1700*. New Haven (1974)

railroads, virtually the only way of effectively aggregating demand for foodstuffs of low value was by spatially concentrating consumers. Dispersion of consumption to sources of supply simply did not provide enough demand pressure to induce agricultural investment. The same dynamics holds for coal, early demand for which was centered on London and cities along the North Sea coast.[133] The history of agricultural productive in the age of traditional husbandry thus turns on the history of urbanization, and in lesser but nevertheless important measure, on the history of transportation and distribution costs. The rise in agricultural productivity after 1650 was not a technological miracle or a mysterious 'escape from Malthus' resulting from technological or institutional innovation. It was a natural and predictable effect of growing urban demand for foodstuffs. It occurred within the constraints of a technology that had changed little since classical antiquity. That it was not as extensive in earlier times as it would be in the eighteenth and early nineteenth century is due less to changes in attitudes or in technical knowledge, but in the market opportunities facing those persons whose decisions controlled the level of inputs to farming.

Transportation

Transportation improvement has often been asserted as an exogenous cause of agricultural productivity growth, and it is evident that farming in regions with good water transport usually progressed faster than those without.[134] The logic is transparent. Falling transport costs raises the net price received by individual farmers and increases the demand elasticity for their produce, inducing productivity-enhancing investment over a larger economic space. This hypothesis is supported by the simultaneous improvement in transportation and agricultural productivity in northwest Europe after 1650. As with population growth, however, the analytical difficulty is assigning cause. Just as in farming, the technology of land and inland water transport was stagnant through the age of traditional husbandry. Variations in the productivity of that network, like that of farming, responded to demands put on it, which affected both the means and willingness of users and promoters to put resources into improvements. The underlying dynamics determining movements in the productivity of transportation are thus similar to those affecting the productivity of agriculture. The one (major) difference was that road and river improvements were

---

[133] On medieval exports of English coal to the Continent see R. A. Pelham, 'Medieval foreign trade: Eastern ports,' in H. C. Darby, ed. *An historical geography of England before 1800.* Cambridge: CUP (1961), 321. See also data in Allen, *Yoeman,*
[134] Quote here, from chapter 1, *Wealth of Nations*.

public goods, and thus posed different institutional problems of finance that affects their historical development.[135] Nevertheless, the parallelism with agricultural history is striking.

The well-drained and paved Roman highways are legendary, and were not surpassed until the late eighteenth century. The rolling stock was not dissimilar, and as later most of the long-distance land traffic went by pack animals. [136] Writing in the first century B.C., Diodorus Siculus reports that British tin unloaded from the ships near Mont Saint-Michel took about a month to reach Marseilles by road.[137] We know from Caesar that the Celts had bridges over the Rhone, which implies bridges over lesser streams on principal routes elsewhere. Medieval documents from the thirteenth and early fourteenth century indicate similar organization. A table listing the per diem travel expenses of royal lawyers travelling between their jurisdictions and Paris indicates a rate of travel (presumably on horseback) of 60 kilometres a day. Under truly exceptional circumstances, letters travelled at a rate of 150 kilometres per day.[138] The post at the start of the nineteenth century was no faster. In the 1940s the hazards of archival research turned up a stained and rat-nibbled parchment that is one of the only original notarial registers to survive from the medieval fairs of Champagne.[139] The register is dated July, 1296, and contains agreements between merchants and transporters to ship bales of cloth and other commodities from Troyes to various ports on the Mediterranean Sea. The agreements specify the dates by which the goods were to be delivered, and thus inform us of the travelling time along a route that unlike in later centuries, did not follow the Rhone, but took the more eastward route through the mountains of Auvergne.[140] What stands out in this record is the travel times. It took 22 days to cover the 590 kilometres separating Troyes from Nimes, for an average of 26 kilometres per day; the 630 kilometres to the port at Aigues-Mortes were covered at a rate of 28

[135] Citations here.
[136] Cavailles, La route francaise. Citing Jullian's Hist Gaule.
[137] James David Muhly, *Copper and tin. The distribution of mineral resources and the nature of the metals trade in the Bronze Age*. New Haven: Yale Ph. D. Dissertation(1969) 473-74.
[138] Robert-Henri Bautier, 'Recherches sur les routes de l'Europe médiévale. I. De Paris et des foires de Champagnes à la Méditerannée par le Massif Central,' *Bulletin philologue et historique (jusqu'à 1610, ann 1960*. Paris (1961), 102-103. Reprinted in R.-H. Bautier, *Sur l'histoire économique de la France médiévale. La route, le fleuve, la foire*. Brookfield VT : Variorum (1991).
[139] Robert-Henri Bautier, 'Les registres des foires de Champagne. À propos d'un feuillet récemment découvert.' *Bulletin philologique et historique (jusqu'à 1775). Ann. 1942-1943.* Paris (1945), 157-188. reprinted in R.-H. Bautier, *Sur l'histoire économique de la France médiévale. La route, le fleuve, la foire.* Aldershot and Brookfield VT: Variorum (1991).
[140] The valley of the Rhone was then still part of the Empire. The mountain route was entirely within the realm of France.

kilometres per day. It took 23 days to reach Montpellier, 640 kilometres away. The seven contracts for which we have this information indicate travel times by road of 24 to 32 kilometres per day. In 1837, the speed for standard haulage on the Paris-Aix route was 30 kilometres per day; onthe Paris-Nîmes route 28 kilometres; on Paris-Troyes, 27 kilometres.[141] In short, at a distance of five and a half centuries, and after strenuous efforts made by the post-Napoleonic governments to improve the main roads, the travel times for commercial haulage had not budged. Where traffic warranted it, the roads were maintained and improved.[142] The same has been found true of England, where the bridges were as numerous in 1300 as they would be in 1750.[143]

The same was largely true of the rivers that carried most of the long and medium distance traffic in bulky produce. The Greek geographer Strabo marvelled at the network of rivers that descended from the Alpes, the Cevennes and the Vosges, which were so well disposed that one could pass from one Ocean to another at the cost of a short portage.[144] The Romans maintained an intense waterway circulation, but by the fourth century the panegyrist of Autun was complaining that the town had no navigable river, and that the military road was so full of holes and so uneven that 'only half-empty and sometimes almost completely empty carts' can negotiate it.[145] As with roads, the resurgence of commerce in the thirteenth century led to substantial investment in waterways. It is from this period that the levees on the Loire, intended both to prevent flooding and deepen the channel for shipping, were constructed. Phillipe the Bel had the navigation of the Seine prolonged from Nogent to Troyes to aliment the fairs.[146] In the fifteenth century Charles V conceived (but did not execute) the construction of a canal linking the Loire to the Seine. In the seventeenth century this would be one of the most active waterways in the kingdom.[147] In the North,

[141] Bautier, 'Régistres,' 173-174.
[142] R.-H. Bautier, 'Recherches sur les routes de l'Europe médiévale. I. De Paris et des foires de Champagne à la Méditerannée par le Massif Central,' *Bulletin philologiue et historique (jusqu'à 1610).* Paris (1961), 99-143. Repr. in Bautier, *Sur l'histoire économique.*
[143] D. F. Harrison, 'Bridges and economic development,' *Economic history review* 45 (1992), 240-261. Apart from bridges, however, there was little investment in the road system of medieval England. F. M. Stenton, 'The road system of medieval England,' *Economic history review* 7 (1936), 1-21.
[144] *The Geograophy of Strabo.* 4.1.14. Trans. Leonard Horace Jones. New York: Loeb Library (1923).
[145] Cited in R.-H. Bautier, 'La circulation fluviale dans la France médiévale,' *Recherches sur l'économie de la France méediévale. Actes du 112^{e} Congrès national des sociétés savantes (Lyon, 1987)*, 12. Repr. Bautier, *Sur l'histoire économique.*
[146] *Ibid.* 24-25.
[147] *Ibid.*

the Burgundians constructed locks to canalize the Sambre and the Senne linking Brussels with Mechelin. Even the city of Chartres on the edge of the Beauce plateau had a port provided by the canalization of the river Eure.[148]

It was in Flanders, however, where the most impressive improvements to water transport were carried out. By the early fourteenth century the system of inland waterways was more developed than it would be in the age of Napoleon.[149] From the middle of the twelfth century the burghers of these lowland cities were canalized rivers to make inland ports like St-Omer situated 30 kilometres from the coast accessible to ships displacing 150 tonnes. Further inland, investment in locks opened a water access linking the grain-producing plateaux of Artois accessible to the burgeoning industrial districts to the North. In this district where road transport was almost impossible, canals and canalized rivers carried farm produce to the industrial cities of Lille, Saint-Omer, Ghent, and Ypres. The canals were substantial. In 1241 the upper Deûle was deepened to four feet and could carry barges into Artois seeking grain for Lille that displaced 30 to 50 tonnes. By 1800 many of these canals were abandoned and none exceeded a meter in depth.[150] The purpose of these inland waterways was to carry grain and fodder to urban districts. By 1300 the region served by this transport system was probably the most productive agricultural region in Europe. By the eighteenth century, most of it had long been abandoned.

The development of the transport system, then, can be seen in large part as endogenous to the growth of urban populations. In the case of the road system, the emergence of large capital cities like London and Paris created a hub and spoke road pattern that necessarily increased the density of roads near the hub, which provided a further externality to farmers situated within the privileged provisioning zone of direct delivery. Analysis of the density of government financed highways in France around 1820 shows this pattern unambiguously. The density of the roads in the *département* of Seine-et-Oise was 1.27 kilometers per km^2; in the Seine-et-Marne situated adjacent to the first department but further out, it was 0.92. Further out in Aisne, it was 0.82. By contrast, in the densely settled and urbanized *département* of

---

[148] *Ibid.* 25-26.
[149] Alain Derville, 'Rivières et canaux du Nord/Pas de Calais aux époques médiévales et modernes,' *Revue du Nord* 72 (1990), 5-22.
[150] Alain Derville, 'La première révolution des transports continentaux (c. 1000 – c. 1300),' *Revue de Bretagne* 85 (1978), 181-205.

Nord, the density was 1.01.[151] Urbanization, then, not only stimulated agriculture in its near hinterland; it also stimulated investments in transportation infrastructure that magnified the effect of urban demand on the profitability of more intensive farming. To be sure, the development of the transport network between 1650 and 1830 responded to other factors than urban growth alone; on the continent strategic considerations were paramount. But the primary effect of improved road systems on farming worked itself out inside the urban provisioning zones.

Conclusion

We are now in a position to sum up. Until the constraints on productivity embedded in the agricultural production function were relieved in the 1840s by technical innovations in agricultural machinery and manufacture and trade in concentrated fertilizers, agricultural improvement depended on rising demand prices for farm produce, of which because of its connection to the production of farm manure, the demand price of animal products was probably determinative. The responsiveness of traditional agriculture to the growth of markets accessible by contemporary means of transport was such that when the railway appeared in the 1840s, it had at first no effect on the provisioning zones for the main subsistence cereals.[152] By the beginning of the twentieth century this was no longer true. The continued decline in transport costs and the opening up of vast spaces suitable to growing cereals and raising animals led to a new definition of agricultural space that was only partly thwarted by the imposition of tariffs in the Old World. 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. Cities were the main destination of that trade, but they were no longer drove the growth of agricultural productivity. From the static perspective of transport costs and agricultural dispersion, the growth of cities in medieval and early modern times thus seems anomalous, since agglomeration was deterred by the high cost of transporting necessarily dispersed supplies of food. That centrifugal tendency was, however, overcome by the responsiveness of local supply to the high net price of food near towns, and by endogenous improvements in transportation and methods of distribution that enlarged the area of accessible provisioning. These effects,

[151] Lepetit, *Chemins de terre,* 50-51.
[152] Paul Bairoch, 'The Impact of crop yields, agricultural productivity, and transport costs on urban growth between 1800 and 1910,' in A. Van der Woude, J. De Vries and A. Hayami, eds. *Urbanization in History: a process of dynamic interaction* Oxford: pp. 134-51

however, affected only that portion of the farming population within provisioning range of urban markets, which explains why in societies where most people lived on the land, productivity could remain low while in a few islands of intensive husbandry surrounding major urbanized districts, it could be as high as it was in the early nineteenth century. The history of agricultural productivity in the pre-railway age, then, is intimately bound up with the histories of urbanization and transportation that, more than technological changes, dominated the process of agricultural change.

Coda

This evidence draws heavily on evidence from France, which is abundant, well-understood, and accessible. That dependence raises the question whether the mechanisms described and analyzed above were unique to France, which as a partly landlocked nation faced higher transport costs than the Low Countries or England. I do not believe this to be the case for the following reasons. The English case is special because of the abundance of drowned river estuaries that drain the whole region east of the Pennine hills, and which made the greater part of England's best corn-growing regions accessible to seaborne transport. Like the Low Countries, England exemplifies Adam Smith's point that regions blessed with good water transport were likely to develop productive systems of farming at an early date because of the ease of shipping produce. The early administrative unification of England, and the island's immunity from the cost of conflicts both foreign and domestic (the continental conflicts usually reflecting foreign interference) significantly lowered the costs of internal trade in foodstuffs relative to the situation on the Continent. A test case of this argument would be 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 that approached populations of 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.[153] 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,

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

they were thinking of these extreme cases. The history of agriculture, then, is linked to the broader histories that determined the timing of large-scale violence. That history has yet to be written.