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BIOLOGICAL GLOBALIZATION: THE OTHER GRAIN INVASION

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Biological Globalization: The Other Grain Invasion

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ABSTRACT: Contemporary accounts of the history of globalization place the grain trade in a leading role. Narrowing price gaps for wheat in world markets serve as the key indicator of increasing market integration. And the chief example of an early policy backlash is the rising protectionism of European importers in response to the "Great Grain Invasion" of New World grain in the late nineteenth century. These accounts focus on the important role of falling transportation cost, but neglect other crucial biological innovations that allowed expanding the wheat cultivation in the new lands, what we call the "other grain invasion." This paper documents that over the 1866-1930 the average distance of world wheat production from the core consumer markets doubled, as the wheat frontier moved on much harsher (colder and more arid) climates. Examining the detailed histories of major producers on the periphery, we show that this move involved, and indeed required extensive experimentation by farmers and crop scientists to find new suitable cultivars that could thrive in the new environments and survive the evolving pest and disease threats. Flows of germplasm and knowledge about breeding occurred not only from center to periphery, but also and importantly within the periphery and from the periphery to the center as an increasing integrated global community of crop scientists emerged over the late nineteenth and early twentieth centuries. Finally, we speculate about why in some regions pioneering plant breeders are heralded as national heroes whereas in others they are sadly under-appreciated.

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The long nineteenth century witnessed unprecedented flows of primary products from newly settled regions on the periphery to Western Europe. Vast sums of European capital along with armies of workers went the other direction seeking higher returns and better opportunities on the periphery. Here was an unprecedented engine for economic growth that dramatically increased the international division of labor. The recent economic history literature, as reflected by the works of Jeffrey Williamson, C. Knick Harley, Kevin O'Rourke, and others has defined nineteenth-century globalization in terms of these international factor and commodity movements. This emphasis has led to the conclusion that globalization did not really gain steam until after 1800. In these accounts, globalization was largely driven by innovations that drove down transportation costs, particularly of the cost of shipping foodstuffs which made up the bulk of international trade. As an example, O'Rourke has called attention to the effects of cheap grain from the periphery on factor prices in Europe, creating pressures for protectionism in an early policy backlash against globalization. [1]

This paper argues that the Great European Grain Invasion of the late nineteenth century was itself the product of the earlier invasion of the Americas and Oceania by Eurasian plants. We highlight the development and spread of new biological technologies that were essential for unlocking the productive potential of the immense tracks of virgin lands that made cheap grain exports possible. [2] Unlike primary products, which flowed from the periphery to the center, the flow of biological technologies moved in every direction. Understanding biological innovations requires a better sense of the

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[1] Kevin H. O'Rourke, "The European Grain Invasion, 1870-1913," *Journal of Economic History* 57, no. 4 (1997): 775-801.

[2] Biologists who catalog invasive species usually include wild oats, but not wheat. Why? Both are non-native plants, imported to many of the areas where they are now grown. The difference in billing is likely because wild oats are weeds, hardy but worthless, whereas wheat is of economic value but does not thrive without the sweat of our brows. If the invasive species are defined as non-native organisms that "completely take over and entirely change whole established ecosystems," then wheat grasses, aided by their human cultivators, clearly fit the bill. The definition of invasive species from http://www.eco-pros.com/invasive_non-native_species.htm. Weeds are typically defined as plants that grow where they are not wanted, plants that are hardy, aggressive, and prone to spread quickly. Vast tracts of forest and grass lands were cleared and broken in the Americas and Australia to allow for the cultivation of wheat.

changing locus of wheat production. This in turn suggests a need to reconsider one of the pillars of the globalization literature.

The Locus of World Wheat Production and the Tyranny of Distance

Economic historians have argued that that falling transportation costs undermined the "Tyranny of Distance" and encouraged the growth of wheat production across the world's periphery. The empirical evidence of changing transport cost typically measures the narrowing price gaps for wheat between two fixed points (as examples, between Chicago and Liverpool or Odessa and Liverpool).[3] The problem with such fixed-point measures is that they overstate the fall in transport cost for the average and marginal producers because the locus of wheat production was moving away from export shipping centers.[4] We can offer a concrete example of the dramatic geographic shift in U.S. grain production, using county-level agricultural output data. The mean geographic center of U.S. grain production was near Wheeling, West Virginia in 1839 but moved roughly 1,260 kilometers northwest to the region around Omaha, Nebraska by 1919.[5] To give context to these movements, we can combine our production data with the local 1910-14 farm-gate prices. The differentials in these prices are typically interpreted as reflecting transport costs.[6] These data indicate that under the 1839 distribution, wheat producers were roughly 10 cents (that is, 13 percent of the average farm-gate price) "closer" to the consumer markets than under the 1909 distribution.

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[3] Kevin H. O'Rourke and Jeffrey G. Williamson, *Globalization and History: the Evolution of a Nineteenth-Century Atlantic Economy* (Cambridge, MA: MIT Press, 1999): 43 and 53. See also Karl Gunnar Persson, "Mind the Gap! Transport costs and price convergence in the Atlantic economy, 1850-1900," *European Review of Economic History*, 8, no. 2, 2004.

[4] Jeffrey G. Williamson, *American Growth and the Balance of Payments, 1820-1913: A Study of the Long Swing* (Chapel Hill: University of North Carolina Press, 1964) and *Late Nineteenth-Century American Development: A General Equilibrium History* (New York: Cambridge University Press, 1974).

[5] Alan L. Olmstead and Paul W. Rhode, "The Red Queen and the Hard Reds: Productivity Growth in American Wheat, 1800-1940," *Journal of Economic History* 62, no. 4 (Dec. 2002): 929-966; and "Biological Innovation in American Wheat Production: Science, Policy, and Environmental Adaptation," In Susan Schrepfer and Philip Scranton (eds.), *Industrializing Organisms: Introducing Evolutionary History* (New York: Routledge, 2003): 43-83.

[6] Farm gate prices come from L. H. Zapoleon, "Geography of Wheat Prices: Summary of Conditions Affecting Farm Prices of Wheat in Different Parts of the United States," USDA Bulletin No. 594 (1918). Williamson was well aware of the importance of measuring the difference between farm prices (as opposed to Chicago prices) and urban markets, and in *Late Nineteenth-Century Economic Development* he calculated that between 1870-75 and 1905-10 the gap fell by about 55 percent between Iowa and Wisconsin and New York City. But this calculation fails to capture the effect of the moving wheat frontier over that period (pp. 257-62).

How far from the consumption centers of Western Europe did wheat production spread during the great globalization wave and how did the new areas of production compare to the old? Given the scope of the task required to answer these questions, we rely on aggregate national-level data. As discussed in the Appendix, we used Food Research Institute (FRI) data to compile a comprehensive production series for the 1885-1930 period, which we linked to the available production and export data for 18 nations over the 1866-1899 period. Our calculations required measuring distance from each country—the convention in gravity model literature is to use the national capitals—to a single global center, for which we used London. The Appendix discusses our reservations with this approach, but we note that the movements of the wheat belts to the interiors of the leading new producing countries suggest that the capital-to-capital measures generally understate the increase in distance.

Figure 1 shows the changing average distance of wheat production between 1866 and 1930. The distance from London almost doubled, climbing from 2,377 km in 1866-70 to 4,725 km in 1920-25. The most rapid change occurred between 1866 and 1880, when the average distance grew 2.5 percent per annum, or about 1,000 km. Growth slowed thereafter, but almost 600 km was added by the First World War. There was another rapid rise and then retreat in the aftermath of this conflict.

What geographic shifts explain these changes? Figure 2 charts wheat production statistics by major country from 1885 to 1930. The fluctuating distance over WWI and its aftermath was due to the Bolshevik Revolution. Russia's share (2,130 km from London) of world production fell from 25 percent in 1913 to 8 percent in 1922 and then rebounded to 21 percent by 1930. The rise in the shares of world production of Australia (16,956 km), Argentina (11,052 km), and Canada (5,401 km) largely explain the increasing distance from 1885 to 1914. The combined share of these three exporters rose from less than 4 percent in 1885 to over 10 percent in 1913 and then to 19 percent in 1930. Their growth accounted for four-fifths of the measured increase in distance between 1885 and 1930. Over this period, the output share of European countries excluding Russia fell from just over one-half of world production to less than one-third. India's share (6,747 km) declined by a similar percent while the U.S. share (5,932 km) was roughly equal at the beginning and end of the period. These data obviously cannot explain the rapid growth of distance before 1885. But it is clear that the United States was driving that change. The U.S. was the major country experiencing a rapidly growing share of world production (almost a doubling) that was also located further than the average distance of producers from London.

The global shift of wheat cultivation had dramatic effects on typical growing conditions, with a movement onto drier and colder lands. Table 1 documents these changes.[7] World production in 1926-30 was distributed to lands that, on average, were 3.2°C colder and received 10.8 fewer centimeters of precipitation than the areas where wheat had been cultivated in 1866-70. Given large and expanding production in Europe, the changes in the conditions facing farmers near the frontier were significantly greater than the changes displayed in Table 1. The 1926-30 land base was also associated with lower average yields per planted hectare. Had the production been distributed as it was in 1866-70, yields would have averaged about 12 percent higher. Clearly, global wheat cultivation was shifting to poorer lands, making the growth of world yields over this period all the more impressive. Actual world yields rose 17 percent between 1886-90 and 1926-30 in spite of a geographic redistribution of production that should have led to a 4 percent decline.

These changes in average climatic conditions were not exogenous to the globalization process. Rather they were the predictable consequences of lower transportation costs opening the continental interiors to profitable production. As the FRI researchers noted, there was a tendency

> for yields of wheat to decline from east and west toward the interior regions of each of the principal land masses, North America and Eurasia. The central regions of such large continents not only suffer from generally light precipitation, but are also characterized by extreme variations in precipitation and temperature.... These climatic characteristics are generally unfavorable for wheat yields.[8]

Globalization had induced a shift of wheat cultivation from maritime areas with temperate climates to interior regions with harsher continental climates.[9]

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[7] The construction of the data, which is discussed in the Appendix, involves aggregating regional FRI statistics on acreages, yields, and climates. M. K. Bennett and Helen C. Farnsworth, "World Wheat Acreage, Yields, and Climates," *Wheat Studies* 13, no. 6 (March 1937): 265-308.

[8] Bennett and Farnsworth, p. 283.

[9] The calendar of the world wheat harvest also filled out, dampening seasonal fluctuations in supplies and prices. Formerly the harvest relevant for the Center countries occurred almost exclusively in June, July, and August. By the 1920s, about one-quarter of the harvest took place in northern hemisphere's non-

These findings are in keeping with our earlier results for the United States, where grain production moved from the humid East to the dry and harsh Great Plains. Accounting for such internal shifts would increase the measured global changes.

In the United States, pushing wheat production onto the new lands required new technologies—the development and diffusion of new types of wheat and new cultural methods. If western farmers had persisted in planting old varieties, the boom in wheat production that fueled the global economy simply would not have been forthcoming. All the transportation improvements imaginable could not have induced English wheats to thrive in North Dakota. Success in the United States and Canada also depended on innovations that mitigated the destructive forces of ever-evolving pest and disease environments.

The biological transformation in the United States was part of a worldwide process. The farmers who extended the wheat frontier in Canada, Australia, Argentina, and Russia, faced similar challenges of producing in new and harsh environments. In all of these areas, the first attempts to grow wheat failed. Success depended on biological innovation. Farmers and plant breeders from all these countries scoured the globe for varieties that might meet local needs, they selected and increased the seeds from particularly promising plants, and by the end of the nineteenth century a number of scientists were creating hybrids that combined the favorable traits of varieties drawn from around the world. This was a purposeful and sophisticated process lead by men whom plant scientists today still revere as the pioneering giants of their discipline. Advances were accelerated by a loose but effective international network of plant scientists that facilitated the exchange of ideas, methods, and varieties. These exchanges highlight the importance of international technological spillovers in the globalization process.

The technological changes based on plant selection and breeding flowed in every direction. At first, they flowed from the center to the periphery. But the wheat varieties that made the expansion of the extensive margin possible for the most part did not come from the old center, but from the "old periphery." Poland, Ukraine, Russia, India, and Africa supplied much of the germplasm underpinning the Grain Invasion. The

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summer months. Australia and South America gathered their wheat crops in December and January; India, Iran, Turkey, and Mexico in March, April and May. "Wheat and Rye Statistics," *USDA Statistical Bulletin* 12 (1926): 23; *Monthly Crop Reporter* (July 1920): 71.

international flow of technology was even more complex because a succession of new varieties developed in the New World were sent back to the old center where breeders selectively combined their strengths (earliness, rust resistance, tolerance for drought and cold, and high gluten content and baking quality) with the best of Northern European varieties (typically high yielding). By the early twentieth century the new generations of successful European wheats, be they distinct varieties tailored for the UK, France, Germany, or Italy, often contained germplasm introduced from North America and Australia (as well as directly from other regions of the old periphery, including Russia, Ukraine, India, and Japan). A similar exchange linked the different lands of the New World—varieties developed in North America were a crucial factor in the expansion of the Australian wheat frontier, and Australian varieties proved valuable to producers in California and the Pacific Northwest. A brief account of the biological dynamics that accompanied the global expansion of wheat production will illustrate these general points.

The Development of Wheat Breeding in Britain and the Core

During Britain's age of industrialization, there were many key advances in cereal production. British farmers had long experimented with new wheats from across the Channel.[10] Largely through chance discoveries and "selections from a single particularly fine or productive individual," agricultural improvers developed several new wheats by 1840, and in the process, invented the method of pure-line selection.[11] John Le Couteur of Jersey discovered "Bellevue de Talavera"; Banham selected Browick from a field of Scotch Annat in Norfolk; and Patrick Shirreff, the Scottish agriculturalist, discovered Mungoswell in Haddingtonshire, Scotland in 1819 and found the basis for the Hopetoun

[10] John R. Walton, "Varietal Innovation and the Competitiveness of the British Cereals, 1760-1930," *Agricultural History Review* 47, pt. 1 (1999): 29-57, esp. 34.
[11] Paul Brassley, "Crop Varieties," pp. 522-32 in Ch. 7 on "Farming Techniques," In E. J. T. Collins, ed. *The Agrarian History of England and Wales*, Vol. 7, *1850-1914*, pt. 1 (Cambridge, Eng.: Cambridge Univ. Press, 2000): 522; William J. Angus, "United Kingdom Wheat Pool," Ch. 3 in *The World Wheat Book: A History of Wheat Breeding*, ed. Alain P. Bonjean and William J. Angus, 103-126 (Paris: Intercept, 2001), esp. 111-113. For a comprehensive examination of the general forces (other than breeding activities) determining yields, see Liam Brunt, "Nature or Nurture? Explaining English Wheat Yields in the Industrial Revolution, c. 1770," *Journal of Economic History* 64, no. 1 (2004): 193-225.

line in a single ear in a field near Sussex in 1832.[12] The efforts of Shirreff and Le Couteur received lengthy notice in Charles Darwin's *Variation of Animals and Plants Under Domestication* (1868).[13]

Over the 1840-70 period, "more organized attempts were set up to find superior specimens."[14] Building on British attempts to hybridize wheat dating to the 1790s, Frederic Hallett began extensive trials near Brighton in the late 1840s employing a variety of red and white wheats from England and Australia, the latter "which were fixed upon on account of their quality alone."[15] The leading new variety was Squarehead, which "offered a new combination of high yield and strong straw which was to have a profound influence on wheat breeding throughout north and central Europe, extending to Scandinavia, Germany, and even to Poland."[16] Squarehead was purportedly discovered in 1868; Mr. Scholey of Yorkshire increased and sold the seed of the new variety beginning in 1870. After 1870, the pace of improvement picked up with "a spate of selections, introductions and hybridizations" that would come to dominate the market by 1914. In 1873, Shirreff published his classic memoir, *Improvement of the Cereals*, detailing his selection and hybridization efforts.[17] Among the important introductions was Japhet (marketed in England as Red Marvel), developed by Henri Vilmorin of Paris in the 1890s. The leading new hybrid wheat was Squareheads Master, derived from a cross between Scholey's Squarehead and Golden Drop in 1880. The new varieties had important consequences in the battle against diseases.

The most serious rust problems in humid Britain were stripe rust and leaf rust. Angus indicates that Squareheads Master was developing problems with stripe rust.[18]

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[12] Hugo de Vries, *Plant-Breeding: Comments on the Experiments of Nilsson and Burbank* (Chicago: Open Court, 1907), 29-90, includes an extensive discussion of the ideas and work of Le Couteur and Shirreff.

[13] See Vol. 2, Chapter 9, "Cultivated Plants: Cereal and Culinary Plants." An alternative to the Le Couteur and Shirreff approach, which stressed initial selection and then multiplication of the self-pollinating wheat, was offered by F. Hallett who attempted to improve the seed by growing the plants under favorable conditions and continuing selection. Hallett developed and sold a series of pedigreed wheats under this name. Mark A. Carleton, *The Small Grains* (New York: Macmillan, 1916), 192-95.

[14] Brassley, p. 525.

[15] Frederic F. Hallett, "On 'Pedigree' in Wheat as a Means of Increasing the Crop," *Journal of the Royal Agricultural Society of England* 22 (1861): 371-81.

[16] F. G. H. Lupton, "History of Wheat Breeding," in *Wheat Breeding: Its Scientific Basis*, ed. F. G. H. Lupton, 51-70 (London: Chapman and Hall, 1987), esp. 51, 64-65.

[17] Patrick Shirreff, *Improvement of the Cereals and an Essay on the Wheat-Fly* (London: Blackwood, 1873); H. F. Roberts, *Plant Hybridization before Mendel* (Princeton: Princeton Univ. Press, 1929), 110-17.

[18] Angus, pp. 111-12.

But periodically, stem rust—the type that bedeviled growers in the arid lands of the United States, Canada, and Australia—also struck. In Britain, this fungal disease was known as Wheat Mildew. During a serious outbreak, as in 1892, stem rust could have locally devastating consequences, inducing a frantic search for less susceptible varieties.[19] Once a strain of rust adapted to attack a specific variety, that variety remained vulnerable.

At the turn of the century the rediscovery of Mendel's laws of inheritance opened up new possibilities. The most innovative work was done by Cambridge University's Rowland H. Biffen, who initiated a hybridization program in 1901. In addition to advancing basic science, Biffen made practical innovations such as Little Joss (1908), a cross between Squareheads Master and the rust-resistant Russian spring wheat, Ghirka.[20] The ability of Little Joss to withstand stripe rust made it popular with farmers following its release in 1910. Breeding research in the UK became more institutionalized in 1912 with the creation of the government-supported Plant Breeding Institute at Cambridge.[21] Another key advance came in 1916 with the release of Yeoman. This cross between Browick and the Canadian variety, Red Fife, offered superior milling and baking qualities and high yields. By this time, British breeders were transforming the wheat varieties grown in the UK by combining germplasm drawn from Western Europe, North America, Australia, and Russia.

A similar process was at work on the Continent. Before 1850 in France and Belgium, a number of wheat varieties had been adapted for specific regions. For example, the wheat grown in eastern France was more tolerant of cold than that grown in the west. However, in any region there was little variation from farm to farm, resulting in "slow evolution over the centuries from the effect of natural selection due to the environment and the mass selection done by man selecting the best filled grains." After 1850 new varieties imported from Odessa gained importance in southern France, and English varieties such as Squarehead became popular in the North. These introductions were followed by a succession of new varieties developed by pioneering breeders. Most

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[19] Board of Agriculture. "Report of the Intelligence Department on Rust or Mildew on Wheat Plants, 1893-94," *British Parliamentary Papers* 23 (1894). We thank Liam Brunt for this reference.
[20] Brassley, p. 525.
[21] Angus, pp. 111-113; Lupton, pp. 64-65.

prominent was Henri Vilmorin who began experimenting with wheat hybridization in 1873. By the mid-1880s, Vilmorin had successfully crossed wheats from Aquitaine (which were themselves recent imports from the Ukraine) with the high yielding Squareheads. Although French breeders made important strides in the nineteenth century, it was not until 1921 that the government established a formal breeding program with the founding of the Institut de Recherches Agronomiques.[22]

The era's pioneering wheat breeder in Germany was Wilhelm Rimpau, who developed a scientific approach to plant heredity before the rediscovery of Mendel's laws.[23] In the second half of the nineteenth century early breeders, including Rimpau, Heine, Beseler, and Strube, "improved the landraces and successfully selected spontaneous variants" to create a large number of improved winter and spring wheats. In 1875, Rimpau began conducting fundamental research "on the flowering process and artificial crossing of cereals" with an eye to combining the high-yield potential ('gut dreschen') of English wheats with the winter-hardiness and good baking qualities of native German varieties.[24] He soon sought out other early, hardy varieties from the United States and Russia to add to his systematic breeding regime. An 1889 cross between Squarehead and an early American winter wheat led to his most famous progeny, Rimpaus früher Bastard. This was "the first cross-bred wheat cultivar in Germany" and was "cultivated very successfully" for the next half century.[25] (The development of wheat research in Italy, Hungary and Russia is further discussed in the appendix.)

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[22] Alain P. Bonjean, Gerard Doussinault, and Jayne Stragliati, "French Wheat Pool," In *The World Wheat Book,* 140-49; Lupton, pp. 53-56.
[23] A. Meinel, "An Early Scientific Approach to Heredity by the Plant Breeder Wilhelm Rimpau (1843-1903)," *Plant Breeding*, 122 (2003) pp. 195-98.
[24] Wolfgang Proche and Michael Taylor, "The German Wheat Pool," In Bonjean and Angus, *World Wheat Book,* pp. 168-191, especially, pp. 171-181
[25] Meinel, p. 197; Proche and Taylor, pp. 171-181.

From the Center to the Periphery

The histories of other land-abundant, labor-scarce economies such as Canada, Australia, and Argentina support our emphasis on the importance of biological learning in the long nineteenth century. The Canadian literature emphasizes the crucial role that new rapid fruiting and drought and cold tolerant varieties played in western settlement, and in particular credits Charles Saunders' path breaking achievement in creating Marquis. In a similar fashion, the Australian literature emphasizes the work of William Farrer in developing drought hardy and rust resistant varieties. Mechanization plays a prominent role in the histories of both nations, but there is a clear recognition that biological innovation was essential for the expansion of the wheat belts in both countries.

Canada

Wheat cultivation was introduced to Canada in 1605 at the first French settlement at Port Royal in what is now Nova Scotia. Cultivation in eastern Canada expanded over the coming centuries, but generally suffered from diseases, insects, and the propensity of the soft white winter wheat to die from winterkill. Farmers tried a "succession of types or landraces," including Red Chaff, White Flint, Kentucky White Bearded, and Genesee White Flint, "in search of ones that would overcome some of the impediments to successful wheat production."[26] The key breakthrough came with the development of Red Fife by David and Jane Fife of Peterborough, Ontario. The Fifes selected and increased the grain-stock from a single wheat plant grown on their farm in 1842. The original seed came from a Scottish source out of a cargo of winter wheat shipped from Danzig to Glasgow (the grain itself likely originated in Ukraine). Mrs. Fife, who was the daughter of a farmer and seedsman, evidently saved the precious seed stock from foraging cattle. Red Fife proved to be the first successful hard spring wheat grown in

[26] W. J. White, "Plant Breeding in Canada's Formative Years," in *Harvest of Gold: The History of Field Crop Breeding in Canada*, eds. A. E. Slinkard and D. R. Knott, Ch. 1 (Saskatoon: University Extension Press, University of Saskatchewan, 1995), esp. p. 6; and R. M. DePauw, G. R. Boughton, and D. R. Knott, "Hard Red Spring Wheat," in *Harvest of Gold*, Ch. 2.; and Ron DePauw and Tony Hunt, "Canadian Wheat Pool," in *World Wheat Book*, 479-515.

North America and became the basis for the westward and northern spread of the wheat frontier. It also provided much of the parental stock for later wheat innovations.[27]

Wheat cultivation in the region west of the Great Shield experienced an even more troubled development. The first sustained attempt to grow wheat was made in the 1810s by members of the ill-fated Selkirk settlement on the Red River near Lake Winnipeg. Winter wheat, first tried in 1811-12, proved a failure. The fields were resown with spring wheat, which died due to drought. In 1813-14, the settlers obtained a small amount of spring wheat from Fort Alexander which produced sufficient grain for the colony to continue cultivation. But in 1818, grasshoppers devoured most of what had been a promising crop. In 1819, another grasshopper attack devastated the colony's wheat crop, leaving it without seed. In the dead of winter, a band of the desperate settlers traveled over 1,060 km to Prairie du Chien on the upper Mississippi River to secure replacement seed. This spring wheat performed well but it was not until 1824 that the settlers had their first truly successful wheat crop. Over the next several decades, the region's farmers experimented with varieties from England, Ireland, and Ukraine.

Mennonites, who settled in southern Manitoba in 1874/75, are generally credited as the first Europeans to cultivate wheat on Canada's open prairie. These migrants planted a seed, White Russian, which they brought with them from Europe. But the future wheat of Manitoba, indeed the entire west, was Red Fife. According to one account, immigrants from Ontario first introduced Fife to the region around 1857.[28] An alternative account suggests Fife came in only after the devastating grasshopper attack that "destroyed every vestige of the crop in 1868."[29] The success of the hard red wheat was due in part to the efforts of Minnesota millers to import Hungarian techniques in the mid-1870s. With the application of the steel roller mill, flour made from Red Fife acquired a reputation of unparalleled quality. Fife wheats became the dominant cultivars

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[27] A.H. Reginald Buller, *Essays on Wheat* (New York: Macmillan, 1919); Stephan Symko, "From a Single Seed: Tracing the Marquis Wheat Success Story in Canada to Its Roots in the Ukraine," *Agriculture and Agri-Food Canada Web Publication* (1999), http://res2.agr.gc.ca/publications/marquis/index_e.htm.

[28] Murray, pp. 37; Pritchett, pp. 113, 228. Stanley N. Murray, *The Valley Comes of Age: A History of Agriculture in the Valley of the Red River of the North, 1812-1920* (Fargo: North Dakota Institute for Regional Studies, 1967). Fife had the decided advantage of maturing about ten days earlier than the variety from Prairie du Chien.

[29] DePauw, Boughton, and Knott, p. 6. These native insects had also injured the crops in 1857, 1858, 1864, and 1867. For a general treatment, see Jeffrey A. Lockwood, *Locust: the Devastating Rise and Mysterious Disappearance of the Insect that Shaped the American Frontier* (New York: Basic Books, 2004).

on the Canadian prairies as they opened to greater settlement after 1885. These wheats also played a role in Sir John A. Macdonald's National Policy of incorporating the West into Canada. To encourage the more rapid development of the prairies, the Canadian government and the Canadian Pacific Railway gave new settlers free Red Fife seed.[30]

But the role of state intervention was far greater. In 1886 Parliament created the Canadian federal experiment station system, with the Central Experimental Farm established in Ottawa and additional stations subsequently opened across the country. William Saunders began breeding work at Central Farm shortly after its inception. One of Saunders' early (if only partial) successes was the introduction of the Ladoga cultivar from northern (60° N) Russia in 1887. This wheat matured earlier than Red Fife, but yielded poorer quality flour. The value of earliness was reinforced by the virtual destruction of the western crop in 1888 by a very early autumn frost. William Saunders' more lasting contribution resulted from a systematic program of hybridizing early-maturing cultivars with high-quality cultivars. In 1903 his son, Charles Saunders, took over the work. The most valuable result of their combined research efforts was Marquis, a cross between Red Fife and Red Calcutta, a very early wheat from India.[31] Released in 1909, this cultivar matured about 10 days earlier than Red Fife and was more resistant to disease. These qualities led to its rapid adoption. By 1918 Marquis accounted for over 80 percent of western Canada's wheat.[32]

Tony Ward has convincingly linked the famed Canadian wheat boom to these biological developments. His estimates show that between 1885 and 1910, the ripening period of wheat at four Canadian experiment stations fell on average by 12 days—days that meant the difference between success and failure in many years. His regression estimates capture other effects besides the switch to Marquis. He notes for example that the time of ripening of Red Fife declined over the period due to changes in cultural techniques such as the use of grain drills. Kenneth Norrie's quantitative study of the

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[30] DePauw, Boughton, and Knott, pp. 6-14.

[31] The actual cross leading to Marquis was probably made in 1892. William Saunders led the effort and his sons, Arthur and Charles assisted. Elsie M. Pomeroy, *William Saunders and His Five Sons: The Story of the Marquis Wheat Family* (Toronto: Ryerson Press, 1956) 48-52; J. Allen Clark and B. B. Bayles, "The Classification of Wheat Varieties Grown in the United States," *USDA Technical Bulletin* 459 (1935): 69; Paul de Kruif, *Hunger Fighters* (New York: Harcourt, Brace and World, 1928), 42. J. W. Morrison, "Marquis Wheat—A Triumph of Scientific Endeavour," *Agricultural History* 34, no. 4 (1960): 182-188.

[32] Buller, p. 254

settlement of the Canadian prairies between 1870 and 1911 found that pushing the wheat frontier further north and west required the adoption of dry farming technologies and the development of drought-resistant and early-ripening wheat varieties suitable for the region. Midway through the period, by the 1890s, Canadian farmers were pushing the commercial wheat belt above 55° latitude.[33]

As wheat culture spread onto the prairies, it was increasingly subject to attacks of leaf and stem rusts. Rust was first noted in western Canada in 1891 and some damage was reported in 1892 and 1896.[34] Much more serious outbreaks occurred in 1902, 1904, 1911, 1916, 1927, and 1935. Eastern Saskatchewan and all of Manitoba proved especially prone to rust problems. In response to the severe 1916 epidemic, when 100 million bushels were destroyed, the Dominion Rust Research Laboratory was established in 1924 at the University of Manitoba. Its plant breeders, working closely with plant pathologists, developed a line of wheats possessing enhanced resistance to the rust diseases. These varieties—including Apex, Renown, Regent, and Redman—together with Thatcher from Minnesota rapidly replaced Marquis after it succumbed to the rust in the devastating 1935 attacks.

Argentina

In his 1994 *Frontier Development*, Jeremy Adelman makes a classic comparison between the expansion of wheat cultivation in Canada and Argentina.[35] No Argentine figure emerges to play the starring role as prominently as did the Saunders father and son in Canada. The Spanish introduced wheat into Argentina in the sixteenth century, but the crop did not emerge as an important export commodity until the mid-1880s.[36] In the first

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[33] Tony Ward, "The Origins of the Canadian Wheat Boom, 1880-1910," *Canadian Journal of Economics* 27, no. 4 (1994): 864-883. Buller, pp. 175-76, credits Marquis with giving adopters about one extra week between harvest and freezeup, thus giving farmers a significant advantage in preparing their land for the next season. De Kruif, p. 41.

[34] Thorvaldur Johnson, "Rust Research in Canada and Related Plant-Disease Investigation," *Agriculture Canada Publication* 1098 (1961).

[35] Jeremy Adelman, *Frontier Development: Land, Labour, and Capital on the Wheatlands of Argentina and Canada, 1890-1914* (Oxford: Clarendon Press, 1994).

[36] James R. Scobie, *Revolution on the Pampas: A Social History of Argentine Wheat, 1860-1910* (Austin: Texas University Press, 1964), 170.

half of the 1920s, Argentina ranked fourth in the world in wheat production and third in exports, behind only the United States and Canada.[37]

Much less is known about nineteenth century breeding activities in Argentina than in the other major New World producers. Richard Scobie is downright disdainful of the farming methods generally employed. He maintains that Argentine wheat growers "knew or cared little about seed selection" and often sold their best seed for consumption and kept poorer quality seed for planting.[38] Even if his critical assessment captures the attitudes and behavior of the vast majority of farmers, it is likely there was still considerable progress. By the turn of the century an important new Italian wheat variety, Barletta, had gained widespread favor, indicating that at least some farmers were making improvements.[39] Barletta was well suited to a wide range of Argentine conditions due to a tolerance for drought, the ability to survive relatively extreme temperatures, and rust resistance. In addition, it had high gluten content and was prized by European millers.[40] The names of some of the other popular varieties in the early twentieth century including Ruso, Hungaro, Rieti, Japones, Costa De Bari, Frances Blanco and Frances Colorado, suggest that the globalization of germplasm had not bypassed the Southern Cone.[41]

A major step was taken in 1912 when the Minister of Agriculture hired William O. Backhouse who initiated the country's first formal wheat breeding program. Backhouse, a Cambridge graduate who studied under Biffen, tested foreign varieties at diverse locations to establish their suitability for Argentine conditions. In 1913 he began crossing the best local varieties with the imports to fight leaf rust. Barletta was becoming increasingly vulnerable to rust, which destroyed roughly one-fifth of the nation's crop in 1916. Backhouse's endeavor was a global undertaking as he imported varieties from India, North America, Europe, and China. One by one Backhouse narrowed his search. The Indian wheat varieties, obtained through A.C. Howard, director of Economic Botany

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[37] "Canada as a Producer and Exporter of Wheat," *Wheat Studies* 1, no. 8 (July 1925): 218.

[38] Scobie, p. 77; this account draws heavily on Frank W. Bicknell, "Wheat Production And Farm Life in Argentina," *USDA Bureau of Statistics Bulletin* 27 (1904): 38-39.

[39] Presumably many other varieties were tried and rejected. As an example, Bicknell, p. 54 reports that in 1902-03 the USDA sent leading Argentine farmers a number of varieties, including "Pelissier," from Algeria and "Crimean" and "Kubanka" from Russia, for local testing.

[40] Scobie, p. 87.

[41] Bicknell, pp. 51-54, and Jorge Enrique Nisi and Enrique F. Antonelli, "Argentine Wheat Pool," in *World Wheat Book*, 519-547, esp. 535.

at Pusa, adapted very well to the new environment, but showed no resistance to leaf rust. The North American imports showed almost complete resistance to leaf rust but did not mature at the same time as its potential breeding partner, Barletta. Further experiments were conducted with Rieti (from Italy, containing English, Dutch, Italian, Japanese, and likely Ukrainian germplasm) and Chino. Chino, a native of Szechwan, possessed immunity to leaf rust. In 1925 the Backhouse team released a Chino-Barletta cross, wheat cultivar 38 M.A., which rapidly gained popularity over a wide region. Until the mid 1940s this variety accounted for roughly 20 percent of Argentine production.[42]

The Argentine program benefited from similar developments underway in Uruguay. In 1912/13 two German scientists Alberto Boerger and Enrique Klein began breeding programs at the National Nursery of Toledo near Montevideo and at the Agronomic Station of Cerro Largo in northeastern Uruguay. In 1919 Klein moved to Argentina where he founded the privately-owned Argentine Plant Breeding Company.[43] Backhouse, Boeger, and Klein were part of a growing cadre of plant scientists trained at European universities who brought their expertise to the far-flung periphery, including Kenya and India.

Australia

As in Canada, wheat breeding plays a prominent role in Australia's historiography. William Farrer, the nation's most famous wheat scientist, is regarded as Australia's "Great Benefactor" with his likeness adorning the two dollar bill. In his authoritative account, Bruce Davidson tells us that the first attempt to grow wheat near Sydney in 1788 failed:

> The original seed brought from Britain by Phillip failed to germinate. This was probably fortunate as these were the English winter wheats which are sown [in Britain] in the autumn and ripen in the shortening days of the following autumn. As they are light-sensitive they will not ripen when the days are lengthening. What was required in Australia was wheat which could be sown in autumn, grown through the winter and

[42] Guillermo Backhouse, "Mejoramiento de Trigos: Orientacion General, Primeros Resultados," Talleres Graficos del Ministerio de Agricultura de la Nacion, 1917; William Backhouse and Vicente Brunini, "Genetica del Trigo: Observaciones Generales sobre su Cultivo; Conclusiones Extraidas de los Trabajos de Mejoramiento de la Semilla," Talleres Graficos del Ministerio de Agricicultura de la Nacion, 1925; Nisi and Antonelli, pp. 535-36; and Marta Guitierrez, *El Origen de las Semillas Mejoradas de Trigo y Maiz en la Argentina: La Dinamica de las Creation y las Modalidades de Investigacion Publica y Privada* (Buenos Aires: Centro de Investigaciones Sociales sobre el Estado y la Administracion, 1985), 13.

[43] Nisi and Antonelli, pp. 519, 535-41.

> spring and ripen in the lengthening days of late spring before the summer drought sets in. By good fortune the next wheat seeds were obtained from Rio de Janeiro and were of the early flowering Mediterranean types which, because they are insensitive to light will ripen in a period when the hours of daylight are increasing.[44]

Other accounts confirm these difficulties: "the early colonists found themselves attempting to grow wheat under conditions that were completely different from anything that they had known, in a new country, in a new hemisphere."[45] But there is disagreement about what types of wheat the early settlers planted. Many assert that the first successful varieties were winter wheats from England (Red and White Lammas) while others speculate that they were spring wheats.[46]

An intriguing study by Yvonne Aitken suggests an answer to this puzzle. She argues that "the first wheats must have been early types, and it is likely that they were unwittingly introduced from Mediterranean stocks via Rio de Janeiro..." following the failure of the English and South African seed sown in 1788. Aitken's evidence is impressive. Drawing on contemporary testimony she first reconstructs the dates of sowing, flowering, and harvesting for the years 1789 to 1805 showing that the crops were mostly planted in June and harvested in November or early December. Aitken then conducted field experiments with several early and late flowering wheats including Red Lammas. The results showed that the late varieties did not ripen until January while the early varieties ripened in time for an early December harvest. The puzzle of the early years appears resolved—the first successful wheats grown in Australia most likely did not come from England.[47]

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[44] Bruce R. Davidson, *European Farming in Australia: An Economic History of Australian Farming* (Amsterdam: Elsevier, 1981): 49. The early settlers also obtain an unknown variety in Cape Town, but this too failed. S. L. Macindoe and D. C. Walkden Brown, *Wheat Breeding and Varieties in Australia*, 3rd ed. (Sydney: New South Wales Department of Agriculture, 1968): 1; C. W. Wrigley and A. Rathjen, "Wheat Breeding in Australia," in Plants and Man in Australia, eds. D. J. Carr and S. G. M. Carr, 96-135 (Sydney: Academic Press, 1981), esp. 96-98.; W. S. Campbell, "Wheats in New South Wales From the Foundation of the Colony," *Royal Australian Historical Society Journal and Proceedings* 22 (1937): 406-433.

[45] Lindsay O'Brien, Matthew Morrel, Colin Wrigley, and Rudy Appels, "Genetic Pool of Australian Wheats," in *World Wheat Book*, Ch. 23, esp. p. 611.

[46] Macindoe and Walkken, pp. 2, 147, 152; Edgars Dunsdorfs, *The Australian Wheat-Growing Industry: 1788-1948* (Melbourne: University Press, 1956): 16, 73, 101.

[47] The blanket assertion that winter wheat could not be grown is undermined by an 1868 survey of wheat varieties. But we still have little idea why farmers adopted late varieties such as Red Lammas. Such varieties evidently would ripen, albeit dangerously late, in the relatively favorable wheat growing areas of New South Wales, Victoria, and South Australia which comprised the early Australian wheat belt. They

Starting with the first pioneers, there was an ongoing effort to discover varieties more suitable for Australian conditions. In 1822 the Agricultural Society of New South Wales initiated a program to introduce and test new wheat varieties, but with little success. Although scores of varieties were introduced, the first significant breakthrough occurred around 1860 in South Australia with the selection of the Purple Straw variety.[48] This variety ripened earlier than previous varieties, providing some rust protection and helping extend the wheat-sheep grazing frontier. At about the same time, Dr. Richard Schomburgh, Director of Botanic Gardens in Adelaide, introduced Du Toit from South Africa. Du Toit was distributed "widely in South Australia, where it became popular because of its early maturity and moderate resistance to stem rust."[49] Over the next several decades, astute farmers and plant breeders selected varieties including Ward's Prolific, Steinwedel, and Gluyas that were more suitable for the drier areas of South Australia. Another important variety, Early Baart, was introduced from South Africa in 1884 by Professor Custance of the Roseworthy Agricultural College.[50] These new varieties provided the genetic material for many subsequent varieties developed by deliberate hybridization.

By the 1880s successful programs to artificially outcross wheat were underway in England, the United States, Germany, France, Australia, and Austro-Hungary, among others. The first Australian efforts to hybridize wheat date to the work of A. B. Robin (also of Roseworthy) who evidently was experimenting with F1 hybrids by 1887. But the most prominent plant breeder of this era was William Farrer.

Farrer belongs to a small group of scientists who fundamentally changed the agricultural prospects of a nation. Farrer became interested in rust after witnessing the enormous damage it caused in 1882. Drawing on both his reading of Darwin and his knowledge that European and American breeders were developing disease-resistance in other crops, Farrer reasoned that creating rust-resistant wheat varieties might be possible.

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would be totally unacceptable for what would eventually become the new areas of production in the more arid inland regions. For regional production data see Dunsdorfs, pp. 206 and 531-33.

48 Macindoe and Brown and many others attribute Purple Straw to a selection made by a now anonymous farmer in the Adelaide area ca 1860, but based on an 1862 Adelaide newspaper account, Wrigley and Rathjen attribute the creation to John Fraine whom they credit with employing relatively sophisticated "pure line" breeding methods to develop Purple Straw, p. 100. Also see Dunsdorfs, p. 148.

49 Macindoe and Brown, p. 2.

50 Wrigley and Rathjen, pp. 99-103; Macindoe and Brown, p. 102; Dunsdorfs, pp. 189-90.

Without conducting any experiments, he published his plans for "making" high quality rust resistant wheats. This bold pronouncement earned him considerable scorn—as befitting of an unknown dilettante with no formal training in plant sciences.[51]

Farrer would have the last laugh. He began his experimental work in 1885 at the age of 41, and in 1889 he commenced work on hybridization. His objectives were to breed for rust resistance, to increase the gluten content and lower the starch content, to develop wheat to meet Australian conditions, and finally to increase yields in a farming regime characterized by low inputs. He would succeed on all fronts.[52] Farrer's most important creation was Federation. In 1894 he discovered a particularly early maturing plant with purple straw (probably a pure Purple Straw) growing in a row of Improved Fife. In 1895 Farrer crossed this purple straw with Yandilla, a variety that he had previously created by crossing Improved Fife (obtained from Canada) with Etawah (from India). In 1901 Farrer released the new variety, Federation, and by 1910 it had become the most popular variety on the continent, proving remarkably productive over a diverse range of growing conditions.[53] Within a decade Federation became an important variety on the west coast of the United States. It was early maturing, rust resistant, of excellent quality and, because of its Purple Straw lineage, it was relatively high yielding. It possessed short, strong straw suitable for stripper harvesting as practiced in Australia. Before Farrer, wheat growing had been largely limited to the cooler table lands where later maturing varieties could survive. Federation, along with new varieties (based on drought resistant introductions from South Africa and India), allowed farmers to push wheat cultivation into drier, hotter regions, less susceptible to rust. The early maturation of Farrer's wheats gave them added rust protection because there was less time for the spores to multiply. In New South Wales alone wheat acreage increased from 1 to 4 million acres largely due to Farrer's accomplishments.

In the course of his work he would experiment with varieties from all over the world. Many of these varieties were sent by other breeders. Farrer returned the favor.

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[51] L. T. Evans, "Response to Challenge: William Farrer and the Making of Wheats: Farrer Memorial Oration, 1979," *Journal of the Australian Institute of Agricultural Science* 46 (1980): 3-5 and Wrigley and Rathjen, p. 105. Farrer attended Pembroke College, Cambridge where he studied mathematics. He worked as a surveyor from 1875 to 1886 before becoming one of the world's leading plant scientists.

[52] Evans, pp. 3-13; also see "Farrer Memorial Trust; William James Farrer papers, Feb 1885-May 1906, CGS 55," http://www.records.nsw.gov.au/cguide/ab/agric.htm.

[53] Macindoe and Brown, pp. 110-111.

Evans captures the essence of these transactions: "In 1894 he [Farrer] wrote, 'I have been sending wheats to Europe and America, and intend to send some to India and France. I hope also to soon be able to start a correspondence with people in different parts of the world….' He was in fact, a one-man international agricultural research centre…."[54] In addition to exchanging seeds, Farrer discussed experimental procedures and myriad details of his research with some of the leading breeders of the day including Henri Vilmorin in France, A. E. Blount, B. T. Galloway, and Mark A. Carleton in the United States, Charles Saunders of Canada, and Rowland H. Biffen in England.[55] The international exchange of ideas and germplasm represents an important way that the world was getting smaller.[56]

Aitken's agronomic studies highlight the importance of the new varieties. In the late 1950s she conducted experiments on the physical development of a number of modern and obsolete wheat varieties. The out-of-date varieties included the winter wheats, Purple Straw, Red Lammas, and Little Joss, and the spring wheat, Federation. Under a variety of geoclimatic conditions the winter wheats suffered damage to their root structures due to high soil temperature and were later to mature thus exposing them to environmental risks. The root damage was far more serious than generally thought, lowering yields and in some instances preventing fruiting. Of special interest, she found that when winter-sown, Federation wheat flowered five weeks earlier than Lammas and developed leaf structures more suitable to hot climates.[57]

Although wheat producers in Canada and Australia confronted dramatically different environments, major concerns being frigid weather in Canada and hot weather in Australia, there were also striking similarities in conditions and in the responses. In both countries, farmers pushed wheat production into arid regions unlike anything experienced in the old Northern European center. Moreover, the challenge created by both cold and heat called for spring wheat varieties with relatively short growing seasons.

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[54] Evans, p. 13.
[55] See "Farrer Memorial Trust" and Evans, pp. 5 and 10.
[56] The exchange, even very early in his career was a two way street. Evans notes that Farrer's mention of using cross breeding to improve wheat quality was an innovative proposition and that Farrer put the idea into practice a decade before Biffen's successes in England. Evans, p. 6.
[57] Yvonne Aitken, "Flower Initiation in Relation to Maturity in Crop Plants: The Flowering Response of Early and Late Cereal Varieties to Australian Environments," *Australian Journal of Agriculture Research* 17 (1966): 1-15. Federation also out-performed Red Fife, which was the latest of the spring wheats tested.

A variety that did not ripen early was in danger of being damaged or killed by frost in Canada and by heat in Australia. Thus both Charles Saunders and William Farrer followed a common path by cross-breeding Red Fife (originating in the Ukraine, shipped to Poland, forwarded to Scotland, reshipped to Canada, and later sent to Australia) with Indian wheats noted for early ripening and drought tolerance. Such were the international pedigrees of the two wheat varieties, Marquis and Federation, credited with making possible the opening of millions of acres of new wheat lands.

Global Exchange of Wheat Germplasm

Two common misperceptions prevail regarding the global exchange of germplasm. One view, which we suspect many economic historians implicitly hold, treats the wheat seed used in the New World and Australia colonies as flowing directly from the mother countries in Western Europe. A second more general view, based on ideas of unequal exchange between the North and South, holds that the "industrial nations have benefited disproportionately from crop improvement programs that have had free access to genetic resources from developing countries."[58] Obviously given wheat's Eurasian origins, the crop represents one of many important exceptions to this latter claim. Neither view properly captures the degree or direction of flows of wheat seed as revealed by careful scientific studies of the ancestry of germplasm in the current wheat stock. The recent CIMMYT report on wheat notes:

> Contrary to popular notions that depict certain regions as mere appropriators of genetic resources, our findings suggest that farmers from *all* of today's major wheat-producing zones have made important germplasm contributions. Landraces that were first used by plant breeders before 1920 and that still figure heavily in the pedigrees of today's bread wheats include Sheriff's Squarehead, Zeeuwse Witte, Turkey, Blount's Lambrigg, Purple Straw, and Fife" (Emphasis in the original).[59]

The report includes the valuable map documenting global flows of wheat germplasm over the 1500-1900 period, reproduced as Figure 3. In addition to the flows out of Western

[58] Melinda Smale and Tim McBride. "Understanding global trends in the use of wheat diversity and international flows of wheat genetic resources." In Part 1 of *CIMMYT 1995/96 World Wheat Facts and Trends: Understanding Global Trends in the Use of Wheat Diversity and International Flows of Wheat Genetic Resources.* (Mexico, D.F.: CIMMYT, 1996).
http://www.cimmyt.org/Research/economics/map/facts_trends/wft9596/htm/wft9596contents.htm
[59] Small and McBride.

Europe (labeled in the figure as Primary imperial flows) to the New World and Australia, there were vitally important flows from the periphery. These included "Nonimperial flows" from Italy, German, Poland, Hungary, Ukraine, and Russia and "Secondary imperial flows" from North Africa and the Indian sub-continent. Even this map understates the degree of genetic interchange, especially after scientific breeding took off in the late nineteenth and early twentieth centuries. The new wheat varieties in Europe often incorporated American germstock; the new Canadian wheats and all their descendents included Indian germstock, and eventually the Norin stock from in Japan.

Modern genetic analysis offers a hint of the past international traffic in germplasm. In 1990 the landraces in the pedigrees of the bread wheat grown in the developing world literally came from almost everywhere (except Antarctica). As an example 37 percent of the landraces in the pedigrees of bread wheat grown in the Mexico/Guatemala region came from other developing regions (i.e. Sub-Saharan Africa, South Asia, etc.), and 50 percent originated in the industrialized world (including Eastern Europe and the former USSR). The origins of the remaining 13 percent are unclear.[60] The CIMMYT findings point to the significance of past global exchanges of knowledge and genetic material. Similar studies tracing genetic markers for the end of the long nineteenth century do not exist, but there is not the slightest doubt that the global process of trade in the biological materials laid the foundation of the international grain trade. It is common to think of the "grain invasion" as the trade in grain and flour that flowed from the periphery to the center, but the other "grain invasion"—the technological changes based on plant selection and breeding flowed in every direction.

Conclusion

The long nineteenth century saw substantial changes in the locus of wheat production. Between the late 1860s and the late 1920s, the average distance of world wheat production from London almost doubled, as measured in our capital-to-capital calculations. This change in average distance occurred in spite of a large increase in production in Western Europe. Allowing for internal shifts *within* the United States, Canada, and other producing countries on the periphery would add further to the

[60] Small and McBride.

economically meaningful change in distance. Relative to the 1860s, wheat cultivation in the 1920s was distributed to lower yielding lands that were typically both colder and drier. The geoclimatic differences between the old center and the frontiers of wheat production were so great that few varieties grown in Western Europe were of value in the new lands. These shifts in production would not have been possible without a sustained and highly successful research and development effort to find wheat varieties that would prosper in the more hostile conditions. This was truly an international endeavor that depended on identifying, transferring, selecting, and genetically recombining varieties from both the center and distant locales on the periphery.

Wheat breeding in many ways reflected the character of the nation where it was conducted. In Britain, the work was performed by heroic improvers such as Shirreff, Le Couteur, and Biffen. In the United States, improvement efforts were more decentralized at the State Agricultural Experiment Stations with federal officials such as Mark A. Carleton concentrating on discovering and testing appropriate varieties from around the globe. Efforts were more organized in Canada resulting in the early creation of Marquis, which crossed eastern European and Indian wheats. Australia followed a similar course. In Argentina, the first varieties were imported by migrants, with wheats from Italy, Hungary, and Russia gaining popularity. Later breeding involved scientists from Britain and Germany who were well connected to the scientific institutions of Europe. It is interesting to observe that in Canada and Australia, the leading wheat breeders such as the Saunders and Farrer became national heroes known to every school child. But in the United States, with its larger, more diversified agricultural sector, innovative plant scientists such as Minnesota's Willet Hayes who developed crop lines for the northern Great Plains never gained comparable national public stature.[61] The reaper inventor, Cyrus McCormick, aided by his propaganda machine, had long ago laid claim to the American title as the "man who made bread cheap."

Although the breeding efforts in different countries evolved in ways reflecting their individual national character and environmental conditions, by the end of the nineteenth century, breeding had become a global enterprise with the exchange of ideas,

[61] A. F. Troyer and H. Stoehr, "Willet M. Hays, Great Benefactor to Plant Breeding and the Founder of Our Association," *Journal of Heredity* 94 (6), 2003, pp. 435-41.

scientists, and germstock between every continent. These exchanges were facilitated by the research and extension programs that flourished in every major wheat-producing nation (and within the United States in every important wheat-producing state). The scientific community functioned more efficiently as personal contacts, informal networks, and professional journals united researchers into a closely-knit community, driven by a common purpose.

Wherever wheat was grown commercially in the nineteenth and early twentieth centuries, it was constantly being reformulated to fit local conditions, conditions that were constantly evolving due to changing disease and pest environments. Even more than the immigrants who populated the new lands, the grains they grew were the product of "melting pots" with their "ancestors" coming from areas across the expanses of Europe, Asia, and many of the periphery countries of recent settlement.[62] Advances in basic science and the international exchange of ideas and biological material constituted the "other grain invasion" that was a necessary condition for and an integral part of the globalization story.

[62] Some of the flows of wheat germplasm may be interpreted as a variant of the South-South migration that Williamson and Hatton have recently highlighted in their studies on nineteenth century labor flows. Williamson and Hatton observe that the causes and consequences of the migration of 50 million Europeans before 1914 have attracted intense scholarly attention while the 50 million people who left their homes in China and India for jobs elsewhere in the periphery have largely escaped notice. Timothy J. Hatton and Jeffrey G. Williamson, "What Fundamentals Drive Mass Migration," *NBER Working Paper* 9159 (2002).

Table 1: Changing Climatic Conditions of Wheat Production

	Annual Temperature (Degrees C)	Pre-harvest Temperature (Degrees C)	Annual Precipitation (Cm)	Yield (M tons per hectare)
1866-70	14.4	20.1	72.8	1.01
1886-90	12.7	18.6	68.1	0.94
1910-14	11.7	18.3	63.9	0.91
1926-30	11.2	18.0	62.0	0.90

Note: The series were derived from fixed national climate and yield values reflecting typical 1920-34 conditions and changing national shares in global wheat production. The 1866-70 data were derived from splicing the 1866-99 series for the 18 countries to the 1885-1930 series calculated for the full FRI sample.

Figure 1: Average Distance of World Wheat Production from London, 1866-1930

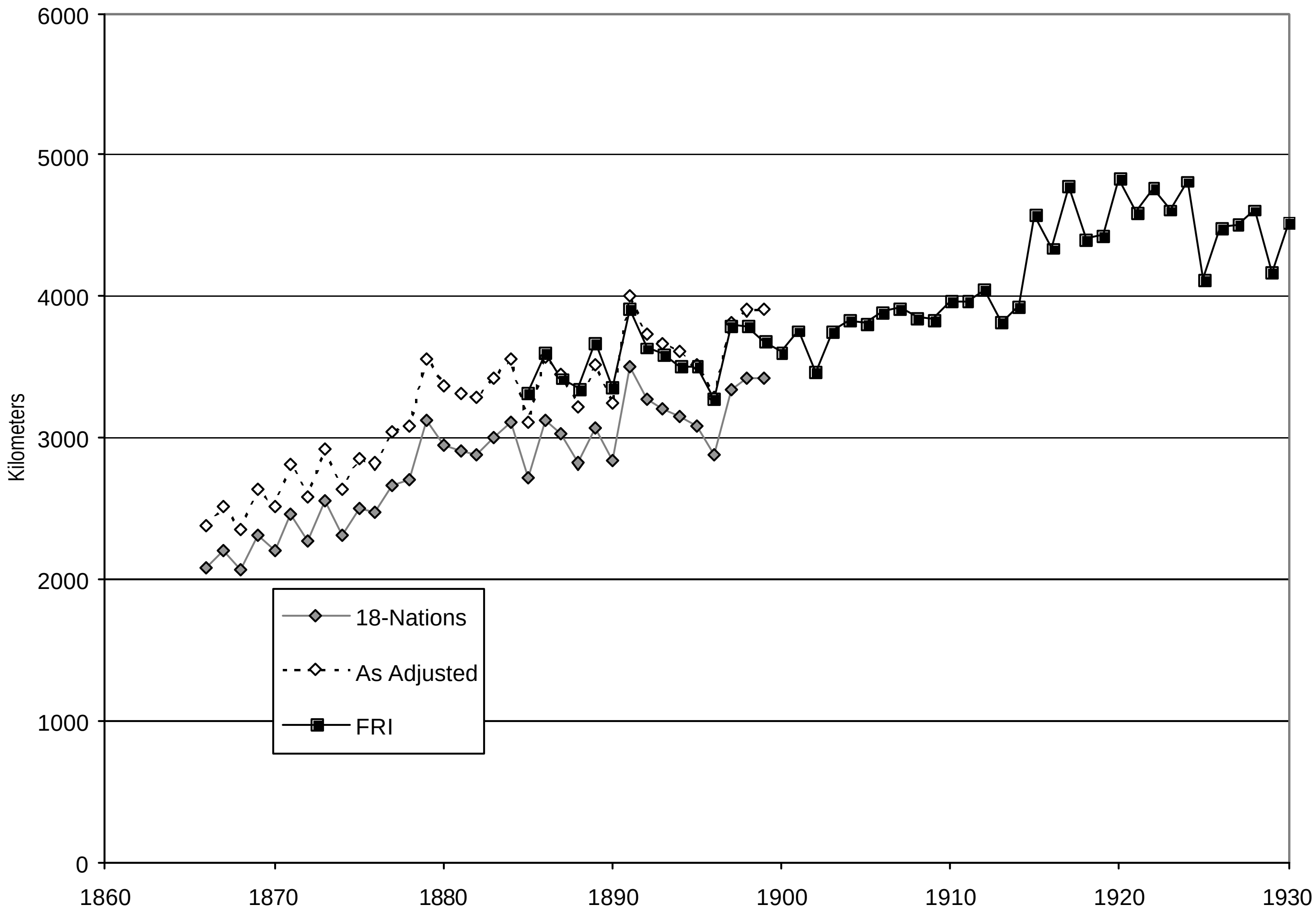


Figure 2: World Wheat Production, 1885-1930

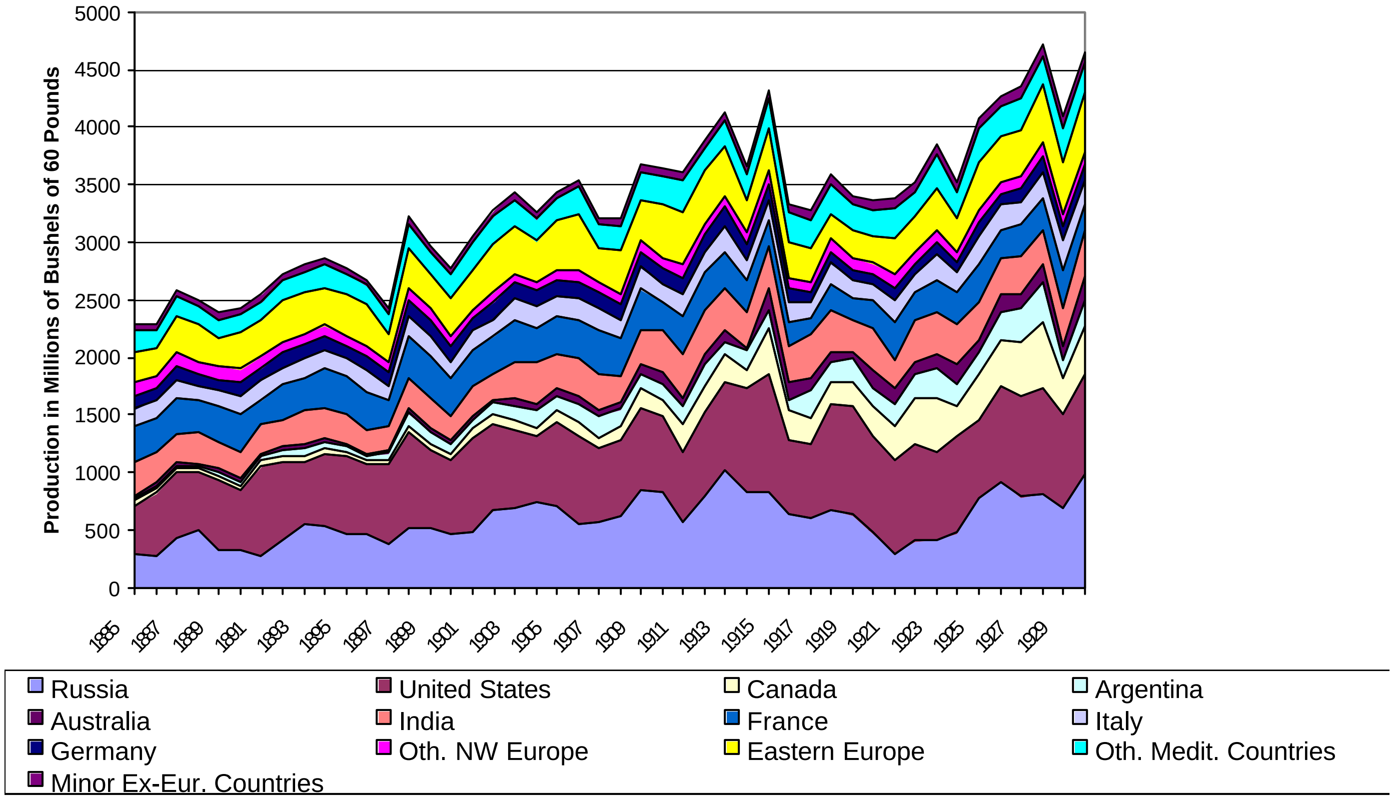
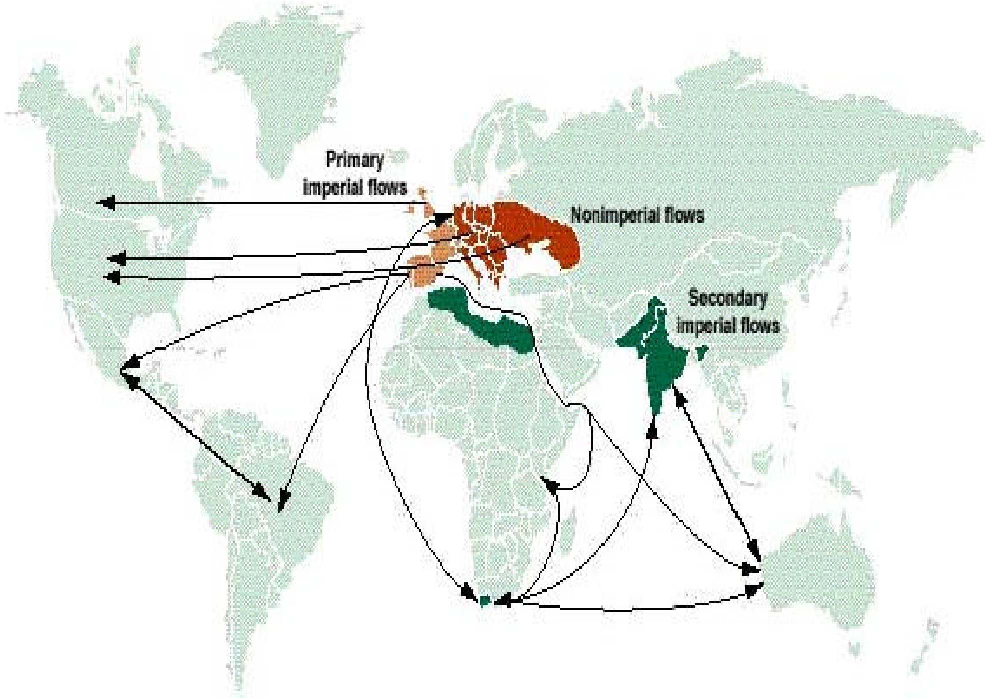


Figure 3: Global Wheat Germplasm Flows



Source: Taken directly from M. Smale and T. McBride. "Understanding global trends in the use of wheat diversity and international flows of wheat genetic resources." In Part 1 of *CIMMYT 1995/96 World Wheat Facts and Trends: Understanding Global Trends in the Use of Wheat Diversity and International Flows of Wheat Genetic Resources.* (Mexico, D.F.: CIMMYT, 1996).

Appendix

Wheat Production:

Comprehensive data on world wheat production from 1885 to 1930 are available in the Food Research Institute's *Wheat Studies*. The data cover 43 wheat-producing countries spread across every continent (except, of course, Antarctica).[63] The FRI data exclude "large wheat-producing areas in China and southwestern Asia, and also numerous insignificant producing areas," but this is not too worrisome because little wheat from these areas was exported to European markets. What is more important is that the series, assembled by leading authorities, contain reasonably consistent data for every major player in world grain markets.

Production data before 1885 are more problematic. Our approach is to assemble annual series, where available, for the period between 1866 and 1896. We rely heavily on Mitchell's *International Historical Statistics*. Reasonably consistent production data exist for many European countries (Austria, France, Denmark, Great Britain, Germany, Hungary, Italy, the Netherlands, Romania, and Sweden) as well as Algeria, Australia, Canada, and the United States.[64] We thank Albert Carreras for providing his unpublished production series for Spain. Long annual series exist for exports (though not total production) from Argentina, Russia, and British India. Unfortunately, we have located annual production series for only a few of the small producing countries in Europe, Asia, and Africa. Given that the consistent data available for Russia before 1885 cover only exports (which represent less than one-third of the total crop during the brief 1870-77 period when both series are reported) the series from the early period understates the average distance of production from London. In the 1885-1896 period when the comprehensive FRI-based series and our 18-nation series overlap, the ratio between the two distances averages 1.142. For purposes of comparison, we raise the 1866 distance from 2,081 km to 2,377 km, and so on, to form the adjusted series.

[63] M. K. Bennett, "World Wheat Crops, 1885-1932," *Wheat Studies of the Food Research Institute* 9, no. 7 (April 1933): 239-74. The FRI series do make adjustments for the United States and Russia that create differences from standard series. For a critical evaluation of these data, see Wilfred Malenbaum, *The World Wheat Economy: 1885-1939* (Cambridge, MA: Harvard Univ. Press, 1953): 54-62.

[64] In a handful of cases, we extrapolate and interpolate the series for smaller producers to extend and fill in their series over small stretches. It would be possible to add series for Finland and Norway using this procedure, but wheat production is negligible in these countries.

Distance

It is conventional in the international trade literature investigating gravity models to measure distance between countries based on the locations of their capitals.[65] Using London as the "Center" of the world wheat market is not too problematic. Liverpool might be a better choice, but the differences are small. Taking Buenos Aires or Canberra as the centers of production in Argentina and Australia, respectively, will likely raise concerns among some scholars. But each of these capitals is located near its nation's main grain-producing belt. We have far stronger reservations about using Washington, DC as the center for United States wheat production and Ottawa as Canada's center. For example, based on our earlier work, we know that the geographic center of United States wheat production circa 1839 was well north and west of the nation's capital and moving further westward over time. Whereas London was always 5,932 kilometers from Washington, DC, it was 6,136 km from the 1839 center and 6,989 km from the 1919 center. The difference in the distances measured from London is less than the distance between the two centers because the three locations form a triangle rather than lying on a straight line. The 1919 centroid was also closer to London in latitude (though further in longitude) than the 1839 centroid.

An examination of maps for Canada showing the spread of wheat production from Ontario to Manitoba, Saskatchewan, and Alberta indicates a similar process was at work. But to abide by the conventions of the gravity literature, we will retain Washington, DC and Ottawa as the measuring points for the United States and Canada, respectively. The North American examples do suggest that our calculations will likely understate the increase in distance during the great globalization wave. We know that between 1885 and 1904, the Russian wheat belt moved about one-half a degree in longitude to the east.

[65] Another convention is that distance is measured as zero in the home country and in all countries sharing a land border. Further, the calculations use great arc distance between the capitals. One might well object that, as least before the advent of aircraft, great arc distances poorly reflect the number of the kilometers that shipments would actually travel. To take an extreme example, San Francisco and Liverpool are 8,362 km apart by great arc distance but wheat shipped from the California port to the English had to travel 25,006 km around the Straights of Magellan or 14,492 km after the Panama Canal became available.

And we suspect similar results would hold for other expanding producers on the periphery.[66]

Climate Data

The climate data were constructed from data in "World Wheat Acreage," appendix data, pp. 303-308. This presents a highly detailed survey of the geographic distribution of wheat acreage, yields, and climates covering 223 subunits. As an example of the detail, the province of Saskatchewan is divided into nine subregions. For each of the subunits, the FRI reports the acreage (planted), yields, and average precipitation and temperature that were typical during the 1920-34 period. From these data, we can form national aggregates, reflecting average conditions prevailing in the wheat-producing areas, that can be combined by using weights derived from the production data investigated above to derive series showing the changing conditions under which wheat was grown. Note that the national aggregate captures conditions prevailing at the end of the period and to the extent that there were shifts within the United States, Canada, Russia, and other countries that mirrored the shifts occurring among nations, our series are likely to understate the overall changes in climatic conditions.

Research in the Core and Old Periphery

The main body of the paper details the development of wheat breeding in Britain, France, and Germany. Here we extend the story to other European producers. In Italy, the first formal breeding program may be traced to the work of Nazareno Strampelli in Camerino. In 1900 Strampelli created an intervarietal cross of two Italian landraces and by 1905 he had made over 100 additional crosses. Francesco Todaro also began an intensive breeding program at about this same time at the University of Bologna. In a search for yield, rust resistance, and other qualities, early Italian breeders imported wheat varieties from across Europe (particularly important was a Dutch variety, Wilhelmina Tarwe), North America, and Japan (the short strawed, Akagomughi, was a key ingredient

[66] The exception might be Australia where production moved westward as well as inland. We will make one important concession to the actual geography of production for Russia by using the Ukrainian capital, Kiev, in place of Moscow. Kiev is 2,130 km from London and is located proximate to (if somewhat west of) the nation's wheat-producing region whereas Moscow (2,512 km away from London) is far outside the wheat belt.

because of its early ripening characteristic). In 1907 the Italian government founded the Royal Experimental Station for Cereals in Rieti. And In 1919 the government established the National Institute of Cereal Genetics centered in Rome with experiment stations located through the country. The first private breeding company, the Societá Produttori Senenti, opened for business in Bologna in 1911.[67]

The story of wheat production in Hungary illustrates the process and importance of varietal change. In the ninth century the Hungarian tribes brought with them at least three species of wheat: a hexaploid dwarf wheat, diploid einkorn wheat, and tetraploid emmer wheat. The latter two species gradually were abandoned, and the dwarf wheat mixed with varieties that were already indigenous to the region. In the eighteenth century conscious efforts to import new varieties from France and England generally failed because the imports did not fair well in the harsher Hungarian climate. Hungarian farmers obtained better results with imports of Polish and Galician varieties. Systematic wheat breeding activities in Hungary date back to at least the mid 1860s with the work of Sámuel Mokry and by the early nineteenth century Hungarian breeders had achieved considerable success. The problems that Mokry and his fellow breeders confronted would have been familiar to they American counterparts: How to design wheat varieties that offered high yields and quality and were resistant to drought, cold, heat, diseases (especially stem rust), and lodging.[68]

Ukraine was once Europe's bread basket. For most economic historians this meant the region supplied significant exports to feed the growing urban populations further west. But Ukraine was the bread basket in a second and more important sense, because the region also supplied much of the germplasm that by the early twentieth century had become the foundation for immense increases in production in Western Europe and North America. The great range of local geoclimatic conditions running from north to south and east to west in Ukraine and Russia gave rise to a wide variety of spring and winter wheat characteristics, as ancient peoples selected and maintained unique local wheats. Among the most important of these Ukrainian creations was

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[67] Basilio Borghi, "Italian Wheat Pool," pp. 289-309 In Bonjean and Angus, *World Wheat Book*, pp. 295-300. Note that Lupton, *Wheat Breeding*, has Strampelli starting about 1930.

[68] Zoltan Bedo, Lazlo Lang, Jozsef Suther, and Marta Molnár-Láng, "Hungarian Wheat Pool," In Bonjean and Angus, *World Wheat Book*, pp. 194-218, especially, pp. 199-200. Mokry's early efforts were evidently in part a response to sever losses suffered during the drought of 1863 and subsequent stem rust epidemics.

Krimka misceva, which became important in the development of a number of important varieties.[69]

One of the achievements of pre-WWI plant breeders in many countries was to develop hardier winter wheats that could survive more extreme temperatures and more arid conditions. Spring wheat was more likely to survive harsh conditions but offered significantly lower yields in areas where winter wheat could also be planted with some security. In the United States, where we have relatively good data, we can trace a fairly narrow boundary running from east to west separating the two wheat types, with winter wheat to the south and spring wheat to the north. Within a few decades following the introduction of hard "Turkey" red winter wheat varieties from Southern Ukraine, winter wheat production shifted hundreds of km to the north dramatically increasing yields and wheat production. A similar process was surely underway in Russia and Ukraine. The "Turkey" wheat the transformed wheat production in the American Wheat Belt was a relatively recent introduction into Ukraine where it also spread rapidly, displacing older spring wheat varieties. As an example, one of America's pioneering wheat breeders, Mark Alfred Carlton, noted that "in the Molochna district spring wheat was grown up to 1860, when Turkey was introduced there from the Crimea, and entirely replaced the spring wheat." Maps of the distribution of wheat types offer a crude indication of the northward movement on the Spring-winter wheat frontier.[70] The scant data we have for European Russia points to the economic importance of the advance of winter wheats. Between 1883 and 1914, the total area of wheat sown in European Russia increased 84 percent, from 11.2 to 20.4 million hectares. Wheat production wheat production outpaced the growth in area increasing by 116 percent, from 5.6 million tones to 12.1 million tones. Over this period, the yield of spring wheat remained almost constant at about 0.50 tones/hectare, while the yield of winter wheat nearly doubled from 0.52 to 0.93 tones/hectare. Although not definitive, this evidence is consistent with the hypothesis that the share of the (increasingly) higher yielding winter wheats was increasing and this shift was driving the Russian yield increases.

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[69] Mikola Litvinenko, Saveliy Lyfenk, Fedir Poperelya, Lasar Babajants, and Anatoliy, Palamatchuk, "Ukrainian Wheat Pool," In Bonjean and Angus, *World Wheat Book*, pp. 351-375.

[70] Mark Alfred Carleton, "Hard Wheats Winning Their Way," in *Yearbook of the United States Department of Agriculture, 1914* (Washington: GPO, 1915): 399-400

Russian wheat varieties were important inputs in the breeding programs around the world. As one example, Carleton traveled extensively in Russia in 1898-99, securing "twenty-three varieties of cereals…." He then experimented with these along with roughly 1,000 other varieties over a four year period. "The results show conclusively that Russian cereals, especially wheats, are the sorts best adapted for culture in the prairie and northern portions of this country." Carleton's introduction of Kabanka from the Kirgihiz Steppes became the basis for the boom in durum wheat production in the northern American Wheat Belt.[71] Formal breeding was also improving wheat in Russia Empire. In 1894, the Bureau of Applied Botany in St. Petersburg started the formal study of plant breeding and by WWI several other experiment stations were in operation in the Czarist state. Government institutes to promote scientific wheat breeding in Ukraine date to the creation of the agricultural experiment station in Odessa in 1912. At about the same time breeding stations were also founded near Kiev and in Kharkov. As should be expected, there were failures as well as successes. As an example, in the late nineteenth century, Polish, Hungarian, and Ukrainian breeders all imported English Squarehead cultivars, hoping to capture the landrace's high yields and resistance to lodging, but these efforts were abandoned due to lack of winter hardiness.[72]

The eastward movement of the wheat frontier onto the steppes in the eighteenth- and nineteenth-century shared many of the characteristics that were common to the settlement of North and South America and Australia. These include the introduction of new varieties, the matching of varieties to soil and climatic conditions, and the "wearing out" of varieties. Foreign settlers also appear to have been the catalyst for change. James W. Long's book on the Volga Germans offers a hint of the dynamic changes in wheat production with settlers tailoring varieties to meet highly specific geoclimatic conditions, and growing different varieties for the export market than for domestic consumption.

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[71] Mark Alfred Carleton, "Russian Cereals," Bulletin No. 23, Division of Botany, USDA, 1900, pp. 7-37.
[72] Anatoly F. Merezhko, "Wheat Pool of European Russia," In Bonjean and Angus, *World Wheat Book* pp. 257-288, especially, pp. 259-270. Mikola Litvinenko, Saveliy Lyfenk, Fedir Poperelya, Lasar Babajants, and Anatoliy, Palamatchuk, "Ukrainian Wheat Pool," pp. 351-375. Regarding Squarehead, see p. 227.

The mention of varieties such as “Saxony” suggests the importance of foreign introductions.[73]

[73] James W. *Long, From Privileged to Disposed: The Volga Germans, 1860-1917* (Lincoln, NE: University of Nebraska Press, 1988): 97.