The Distributional Consequences of Trade: Evidence from the Grain Invasion*

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Abstract

We provide new evidence on the income distributional consequences of trade using the New World Grain Invasion in the 19th Century and variation in agroclimatic suitability for wheat across locations within England and Wales. We show that this large-scale agricultural trade shock led to structural transformation away from agriculture and a redistribution of population from rural to urban areas. We develop a quantitative spatial model to rationalize our empirical findings and evaluate the aggregate implications of this international trade shock. We use our model to undertake counterfactuals for the Grain invasion, holding constant other exogenous determinants of economic activity. We find modest aggregate welfare gains combined with much larger income distributional effects, with geography an important dimension along which these income distributional effects occur.

KEYWORDS: international trade, income distribution, geography
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1 Introduction

One of the classic insights from international economics is that aggregate welfare gains are combined with winners and losers from trade. This insight lies at the heart of recent debates about the economic effects of trade and trade policy. Traditional research has focused on distributional consequences across factors of production or sectors for the aggregate economy as a whole. More recent research has highlighted geography across locations within countries as another dimension along which the income distributional consequences of trade occur.

Much of the existing research on the role of geography as a dimension along which the income distributional consequences of trade occur has focused on a small number of recent episodes (e.g., the China shock or Brazilian and Indian trade liberalization). Identification is based on the assumption of the exogeneity of domestic policy reforms or the orthogonality of tariff reductions to other domestic demand or supply shocks. A central finding from this literature is that despite the geographically uneven effects of trade shocks, there is relatively little labor mobility across locations in response to these shocks.

We make five main contributions. First, we use a new source of exogenous variation, based on the New World Grain Invasion during the second half of the 19th century and the suitability of agroclimatic conditions for wheat cultivation across locations within England and Wales.[1] The key idea behind our approach is that there is a marked difference in agroclimatic conditions between the Western and Eastern parts of England and Wales, with Western locations more suitable for grass (and hence the grazing of cattle and sheep), and Eastern locations more suitable for the cultivation of cereal grains (historically mainly wheat).

Second, whereas much existing research has focused on manufacturing trade shocks, we examine a large-scale agricultural trade shock. Therefore we can assess the extent to which trade shocks can promote structural transformation, shifting labor away from agriculture, and driving urbanization. By examining the effects of a trade shock to a different sector (agriculture versus manufacturing) in a different time period (late-19th century versus today), we can examine the extent to which findings for recent trade shocks generalize to other empirical settings.

Third, since we focus on a trade shock to the land-intensive agricultural sector, we would ultimately expect the effects of a negative agricultural trade shock to be capitalized into land values and affect specialization within the agricultural sector. We have unusually rich data on property values and agricultural specialization over a long historical time period during the 19th century with which to examine these predictions. We combine our rich micro data with a new quantitative spatial model to evaluate both the aggregate welfare effects and income distributional

[1] Throughout the paper, we use the word "corn" according to the historical British usage of all cereal grains, including wheat, oats, barley and rye, and not restricted to maize. Of all these cereal grains, wheat was by far the most important in the British market.

consequences of this agricultural trade shock.

Fourth, we consider an empirical setting in which one might expect labor mobility across regions to be relatively high, because of the limited welfare state and laissez-faire economy of 19th-century England and Wales, as in many developing economies. Therefore, we are able to provide new evidence on the extent to which trade shocks lead to population mobility when the assumptions required for this labor mobility to occur are satisfied.

Finally, we make a substantive contribution to economic research on the Grain Invasion in England and Wales that occurred in the second half of the 19th century after the Repeal of the Corn Laws. This trade liberalization is arguably one of the most influential in history. The foundational insights for the theory of comparative advantage in Ricardo (1817) were motivated by the debate over Repeal. This debate was centered around the economic interests of urban workers (as represented by the Anti-Corn Law League) and the rural land-owning aristocracy.[2] The original discussion of the Kaldor-Hicks compensation criteria was motivated by the example of the Corn Laws (see Kaldor 1939, pp. 550). Despite substantial historical discussion that grain-growing Eastern regions were more heavily hit by the Grain Invasion, there has been no systematic quantitative analysis of these uneven geographical effects and the extent to which they are consistent with spatial equilibrium models.

We make use of a newly-created, spatially-disaggregated dataset on population, employment by sector, property values, and poor law transfers for over 10,000 parishes in England and Wales from 1801–1901. We begin by showing that Britain experienced a large-scale trade shock from the New World Grain Invasion. Over the twenty-five year period from 1846–1871, the average price of wheat relative to pastoral products fell by around 15 percent, and imports of wheat grew more than fivefold from 1,411-8,952 thousand quarters.[3] Traditional suppliers in Prussia and Russia were replaced with new suppliers in Argentina, Canada and the United States, such that the share of wheat imports from the New World rose from 17-43 percent. In the next three decades from 1871–1901, the average price of wheat relative to pastoral products fell by a further 26 percent, and imports of wheat increased by an additional 77 percent. With continuing reductions in transatlantic transport costs from the steam ship and railway, the share of Britain's wheat imports from the New World more than doubled from 43-95 percent.

We next establish a substantial reallocation of economic activity following this trade shock: (i) within agriculture from arable to pastoral farming; (ii) between agriculture and other sectors; and (iii) between high and low-wheat suitability locations within Britain. Over the period from

[2]Historians have argued that the income distributional effects of this trade shock contributed to the decline and fall of the British aristocracy (Cannadine 1990) and the outbreak of First World War (Offer 1991).

[3]The price index for pastoral products includes eleven pastoral products, as discussed further below, and in Online Appendix F2.1. A quarter corresponded to a quarter of a ton, which equalled 8 bushels of 8 gallons each (64 gallons), where a gallon was a volume of water weight of ten troy pounds (3.74 kilograms).

1871 (the first year of the agricultural census) to 1901, acreage of cereal grains declined by 29 percent, while acreage of permanent pasture rose by 35 percent. Between 1851 and 1901, the share of agricultural laborers in employment declined by more than 20 percentage points in Eastern locations with the highest levels of wheat suitability, compared to a fall of less than 10 percentage points in Western locations with the lowest levels of wheat suitability.

To tighten the connection between this reallocation of economic activity and the Grain Invasion, we estimate event-study specifications using our exogenous measure of wheat suitability. We include parish and year fixed effects to control for time-invariant unobserved heterogeneity across locations and secular trends over time. We include interactions between observed parish characteristics and year dummies to control for other determinants of parish growth rates. In the first half of the 19th-century, we find no differences in trends between high and low-wheat-suitability locations. In the second half of the 19th-century following the Grain Invasion, we find a relative economic decline in high-wheat-suitability locations compared to low-wheat-suitability locations. By the end of our sample period in 1901, we estimate a relative decline of population and property values of 18 and 24 percent, respectively.

We next develop a new quantitative theoretical model to account for these empirical findings and evaluate their implications for the distribution of real income. We model parishes as small open economies that face exogenous prices of traded goods determined on world markets. We consider three production sectors: agriculture, manufacturing and services. Within agriculture, we distinguish between arable farming (cereal grains) and pastoral farming (grazing). Markets are competitive. Goods are produced using labor and land. Each parish is endowed with a continuum of land plots that are heterogeneous in terms of their productivities for alternative land uses. Land is owned by landlords who are geographically immobile. Workers are geographically mobile and have idiosyncratic preferences for each location.

We calibrate the model's parameters using data from our historical setting and estimates from the related empirical literature. Our framework allows for incomplete specialization and structural transformation, both across sectors and disaggregated agricultural goods. Therefore our framework is able to rationalize our observed data on arable and pastoral land use, sectoral employment, and property values across locations and over time as equilibrium outcomes. Given these observed data on the model's endogenous variables, we show how the model can be inverted to recover unobserved location characteristics in each year: relative productivity in arable and pastoral farming within agriculture; relative productivity in the agricultural, manufacturing and services sectors; and relative amenities across locations. We allow each of these unobserved characteristics to change across locations and over time, such that our model controls for other determinants of economic activity, including manufacturing productivity growth driven by technological innovation, and changes in amenities from the disease environment.

We use the model to undertake a counterfactual for the Grain Invasion, which corresponds to an exogenous fall in the price of arable products on world markets. We follow an exact-hat algebra approach, in which we use the observed values of the model's endogenous variables in an initial year to control for unobserved location characteristics. We undertake these counterfactuals using both the observed fall in the relative price of arable products from 1846–1871 after the Repeal of the Corn Laws, and its subsequent fall from 1871–1901 following the continuing integration of New World producers into global markets. These counterfactuals isolate the general equilibrium impact of the Grain Invasion, holding constant other determinants of economic activity, including the prices of other traded goods, productivities and amenities.

In response to a fall in the price of arable products, the model predicts a reallocation of land from arable to pastoral use within the agricultural sector; a reallocation of employment away from the agricultural sector towards manufacturing and services; and a reallocation of population away from locations with higher initial shares of arable land use. We find that these reallocations in our counterfactuals (where only the price of arable products changes) are sizable relative to the observed reallocations in the data (which include other shocks, such as changes in productivities and amenities across locations and over time).

From 1846-1901, we find a counterfactual increase in worker expected utility of 4.13 percent, which includes the impact of both trade liberalization (the Repeal of the Corn Laws) and changes in the terms of trade (the fall in the world price of arable products from the increased integration of the New World into global markets). Comparing the two sub-periods of 1846–1871 and 1871–1971, we find increases in expected worker utility of comparable magnitude of around 2 percent for each subperiod. This pattern of results suggests that both the initial Repeal of the Corn Laws and the subsequent deepening integration of the New World into global markets contributed towards the impact of the Grain Invasion.

We find that these relatively modest aggregate welfare gains are combined with much larger income distributional consequences. As in conventional trade theories, the reallocation of economic activity within and across sectors changes the relative demand for different factors of production, and leads to changes in relative factor prices. In contrast to those conventional theories, the impact of the Grain Invasion on factor prices is uneven across locations within England and Wales, depending on their initial specialization across sectors and across disaggregated goods within agriculture. We find that the change in the rental rate ranges from reductions of 10 percent in locations with high wheat suitability to rises of 10 percent in locations with low wheat suitability. Overall, our results highlight the role of international trade shocks in shaping structural transformation, and highlight the role of geography as an important dimension along which the income distributional effects of international trade occur.

Our paper relates to several strands of existing research. First, we contribute to a long line of research on the distributional consequences of international trade shocks, including Stolper and Samuelson (1941), Mayer (1974), Mussa (1974), Neary (1978), Goldberg and Pavcnik (2005), Trefler and Zhu (2005), Goldberg and Pavcnik (2007), and Borusyak and Jaravel (2021). We exploit exogenous variation from the New World Grain Invasion and micro data on a rich range of outcomes over a long historical time period. Second, we contribute to recent research using historical data and exogenous sources of variation to provide new evidence on classic questions in international economics, including López-Córdova and Meissner (2003), Donaldson (2018), Juhász (2018), Barjamovic et al. (2019), Xu (2022), and Greenland et al. (2024). We use the natural experiment provided by the Grain Invasion to provide new evidence on the distributional consequences of international trade.

Third, our work relates to the recent empirical literature on the local labor market effects of international trade shocks, including Topalova (2010), Autor et al. (2013), Kovak (2013), Costa et al. (2016), Dix-Carneiro and Kovak (2017), and Caliendo et al. (2019), as reviewed in Redding (2022). Much of this research has focused on the China shock, because of its size, and the fact that it was driven by domestic supply-side reform. We use exogenous exposure to a large-scale trade shock based on agroclimatic suitability for wheat cultivation.

Fourth, our paper is also related to recent research on quantitative spatial models, including Redding and Sturm (2008), Allen and Arkolakis (2014), Ahlfeldt et al. (2015), Donaldson and Hornbeck (2016), Redding (2016), Allen et al. (2017), Desmet et al. (2018), Monte et al. (2018), and Caliendo et al. (2019), as reviewed in Redding and Rossi-Hansberg (2017). One strand of this research examines the relationship between structural transformation and trade, including Bustos et al. (2016), Sotelo (2020), Fajgelbaum and Redding (2022), Peters (2022), Farrokhi and Pellegrina (2023), Eckert and Peters (2023) and Nagy (2023). We use the natural experiment of the Grain Invasion to provide evidence on the relationship between structural transformation and trade. We interpret our empirical findings through the lens of a quantitative spatial model that can be used to assess the income distributional consequences of this trade shock.

Fifth, our paper is related to a large economic history literature on the Repeal of the Corn Laws and the Grain Invasion from the New World, including Graham (1892), Nicholson (1904), Williamson (1990), O'Rourke et al. (1996), O'Rourke (1997), Taylor (1999), Schonhardt-Bailey (2006), Sharp and Weisdorf (2013), O'Rourke and Williamson (2001), Chepeliev and Irwin (2021) and Bräuer and Kersting (2024). Most of this research has focused on the implications of this trade shock for the distribution of income across factors (land and labor) and sectors (agriculture and manufacturing). In contrast, we examine the uneven geographical incidence of this trade shock, and the close connection between structural transformation and rural depopulation, using our quantitative spatial general equilibrium model.

The remainder of the paper is structured as follows. Section 2 introduces the historical background to the Repeal of the Corn Laws and the Grain Invasion. Section 3 summarizes our data sources and definitions. Section 4 presents reduced-form evidence on the impact of this international trade shock across sectors and locations. Section 5 develops the theoretical model that we use to rationalize these empirical findings. Section 6 quantifies the model and reports the results of our counterfactuals for the Grain Invasion. Section 7 summarizes our conclusions.

2 Historical Background

Regulations on wheat imports in Britain under the Corn Laws date back to medieval times.[4] From 1670–1815, the law specified a small "nominal" duty payable when the domestic price was high and a "pivot level" for the domestic price below which larger duties were payable. In the first half of the 18th century, Britain was largely self-sufficient in grain, and the import duties were suspended in times of scarcity, which limited their impact on the domestic price of wheat. However, following the onset of the industrial revolution in the 1760s and rapid population growth, the Corn Laws became of increasing relevance, as Britain developed into a growing net importer of wheat, with Prussia and Russia the traditional sources of supply.

In the aftermath of the French Revolution, Britain and France were almost continuously at war during the Revolutionary and Napoleonic Wars from 1792–1815. This widespread conflict and Napoleon's continental blockade restricted Britain's access to wheat imports from traditional suppliers in continental Europe and led to a rise in the domestic price of wheat and an expansion in domestic wheat production.[5] In Figure 1, we show the price of wheat relative to a price index for pastoral products from 1701–1901, using the farm price data from Clark (2004).[6] Both prices are normalized to take the value one in 1701, such that the figure shows changes in relative prices over time. The substantial year-on-year fluctuations in part reflect variation in weather conditions and the harvest. Over the wartime period from 1792–1815 as a whole, the relative price of wheat was 10.8 percent higher than during the years before 1792.

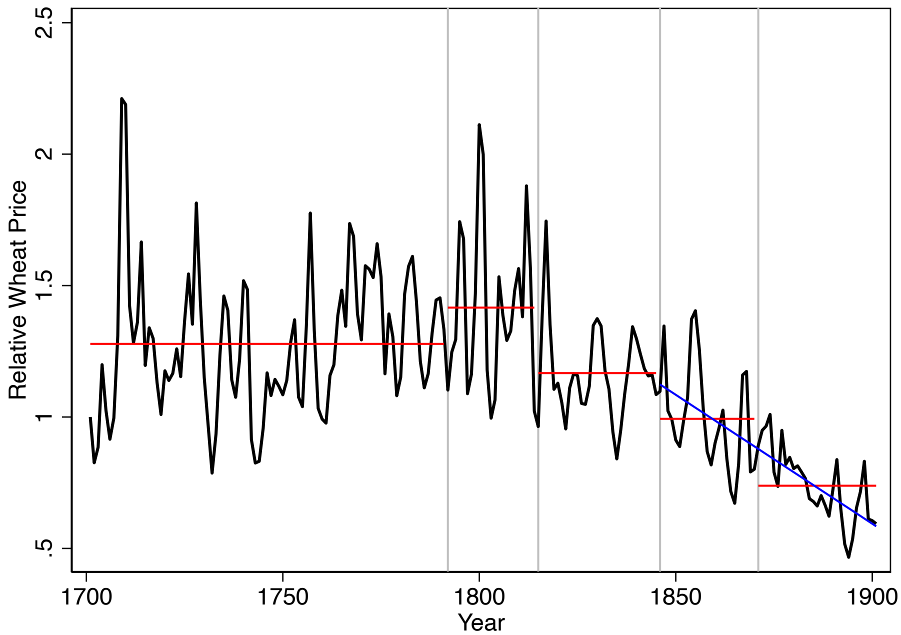
Following victory in 1815, the Tory (conservative) government of Lord Liverpool became concerned about the potential for an influx of cheap imported grains to cause a collapse in the domestic price of wheat and an agricultural crisis. To prevent such a crisis, his government passed the Corn Law of 1815, which prohibited wheat imports when prices were under 82.5 shillings per quarter, and admitted wheat free of duty above this level. As a result, with a few exceptions of some months during the years 1816–19, British ports were closed to imports of wheat until

[4]For historical discussions of the Corn Laws, see for example Nicholson (1904) and Lord Ernle (1912).

[5]See in particular Galpin (1925). For an analysis of the impact of the continental blockade on industrial development in France, see Juhász (2018).

[6]The pastoral price index is based on the price of eleven pastoral products: hay, cheese, butter, milk, beef, mutton, pork, bacon, tallow, wool and eggs, as discussed in Online Appendix F2.1.

Figure 1: Relative Price of Wheat from 1701–1901



Note: Price of wheat relative to a pastoral price index using the farm price data from Clark (2004); Pastoral price index is based on the price of eleven pastoral products: hay, cheese, butter, milk, beef, mutton, pork, bacon, tallow, wool and eggs; Gray vertical lines show the years 1792, 1815, 1846 and 1871. Red horizontal lines show means before 1792, from 1792–1815, 1815–1846, 1846–71, and 1871–1901. Straight blue line shows a linear trend from 1846-1901.

1825. Over the period from 1815–1846, the average domestic relative price of wheat in Figure 1 remained around 91.3 percent of its level before 1792.

In the early 1830s, domestic harvests were plentiful, and hence domestic prices remained relatively low, which ensured that discussion of the Corn Laws remained muted. In contrast, from 1837 onwards, poor domestic harvests led to a rise in the domestic price of wheat, and an increase in political protest against the Corn Laws. Supported by the growing constituency of manufacturers, and influenced by the intellectual case for free trade as espoused in Ricardo (1817), the Anti-Corn Law League developed into an influential nationwide movement, which was led by Richard Cobden and John Bight from 1838 onwards. Around the same time, the economic recession of 1838 was the stimulus for the formation of the Chartist Movement, which campaigned for greater democratic representation of the interests of working people.

In response to this growing discontent, the Tory Prime Minister Robert Peel attempted an initial set of reforms in 1842, which reduced the level of import duties. Following continuing failed harvests in Europe during the 1840s (the "Hungry Forties"), and with the beginning of the Irish Potato Famine in 1845, political pressure for further reform intensified. Finally, in a move that split his own Tory party, Robert Peel's government repealed the Corn Laws in 1846.[7] Repeal

[7] Although this repeal is frequently interpreted as a political concession by an existing elite to forestall greater political change, a growing historical literature argues that Peel's decision was influenced by a threefold combination

gradually reduced import duties to 1 shilling per quarter in February 1849, with the remaining nominal duty ultimately removed in 1869. Over the period from 1846–1871, the average domestic relative price of wheat in Figure 1 fell to 77.7 percent of its level before 1792 (corresponding to 85 percent of its level from 1815–1846).

This Repeal of the Corn Laws left British markets open to the New World Grain Invasion in the second half of the 19th century.[8] With improvements in the speed, reliability and capacity of steam ships, transatlantic freight rates fell by around 1.5 percent per annum from around 1840 onwards, with a cumulative decline of around 70 percent points from 1840–1914 (see North 1958, Harley 1988, and Pascali 2017). After the end of the American Civil War in 1865, the U.S. railroad network expanded into the interior, connecting the grain-growing regions of the mid-West to international markets (see Fogel 1964 and Donaldson and Hornbeck 2016). Similar expansions of the railroad network in Argentina and Canada integrated their arable hinterlands with world markets (see Adelman 1994).

In response to these reductions in international transport costs, there was an influx of cheap New World Grain into European markets, as illustrated in Figure 2. The red line indicates UK wheat production; the black line denotes UK wheat consumption (production plus imports); and the difference between the two lines shows UK wheat imports (broken down by major sources of supply). Before the Repeal of the Corn Laws in 1846, wheat imports were small, and largely originated from traditional sources of supply in Europe. Following the Repeal of the Corn Laws, we observe an increase in wheat imports, which accelerates after the end of the American Civil War. From 1871 onwards, Argentina, Australia, Canada, and the United States all emerge as major New World sources of supply for wheat. In response to this Grain Invasion, the average domestic relative price of wheat in Figure 1 fell to 57.8 percent of its level before 1792 (corresponding to 74 percent of its level from 1846-1871), with the evolution of the relative price after 1846 well approximated by a downward linear trend (blue line). The counterpart of this domestic price decline is a progressive reduction in domestic wheat production in Figure 2, which intensifies from 1871 onwards in what was referred to at the time as the "great agricultural depression."

3 Data

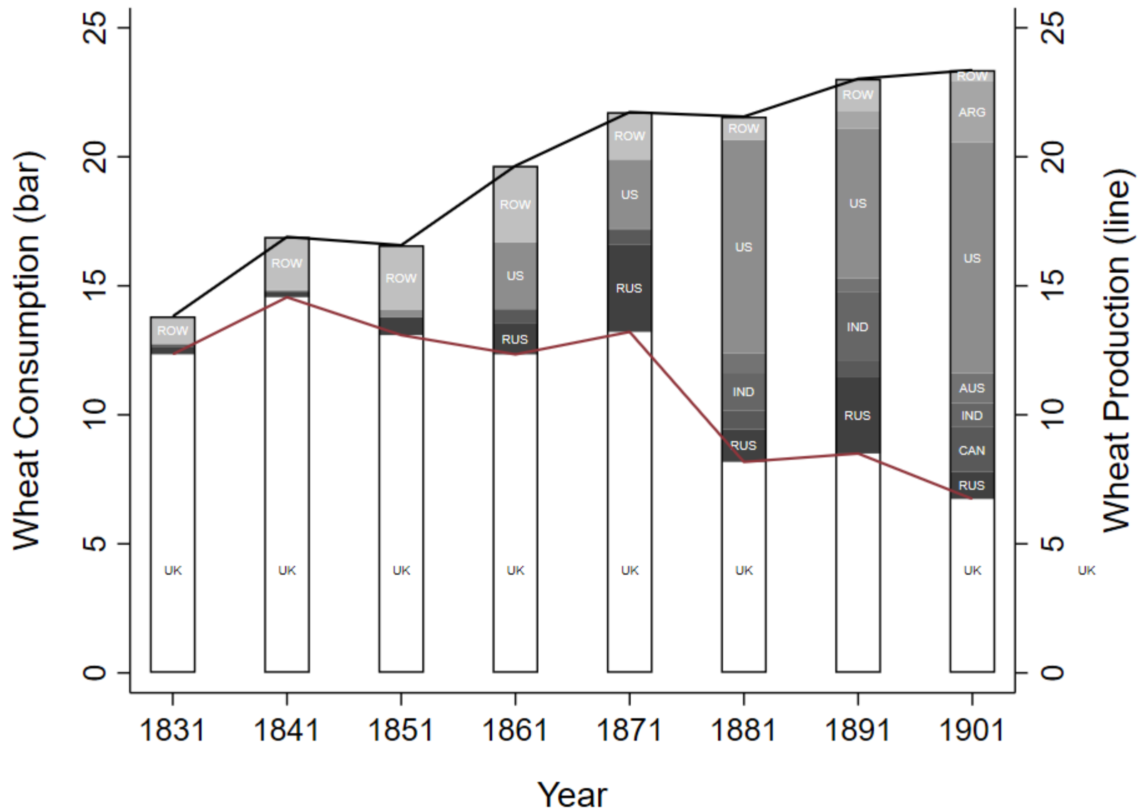
We construct a new spatially-disaggregated dataset on population, employment by sector, property values (rateable values), and poor law transfers for England and Wales from 1801–1901.[9] Our

of political interests, ideologies and ideas, including in particular Irwin (1989) and Schonhardt-Bailey (2006).

[8]In contrast, a number of continental European countries responded to this Grain Invasion with increased levels of protection, as discussed in Trentmann (2008).

[9]We focus on England and Wales, because the Scottish population census is enumerated separately, and we have neither rateable value data nor individual-level population census data for Scotland.

Figure 2: United Kingdom Consumption, Production and Imports of Wheat from 1831–1901



Note: Consumption, production and imports of wheat (quantities) in millions of quarters for the United Kingdom based on its 1901 boundaries (England, Wales, Scotland and Ireland); consumption is the sum of domestic production and imports; imports from different source countries indicated by the gray shading and white letters: ARG (Argentina); AUS (Australia); CAN (Canada), IND (India), ROW (Rest of World), RUS (Russia), and US (United States); Source: Sharp (2010).

main source of data is the population census, which we augment with a number of other sources of data, as summarized below, and discussed in further detail in Online Appendix F.

Spatial Units: Data are available at three main levels of spatial aggregation: parishes (11,448), poor law unions (575) and counties (53). Parishes were historically the lowest level of local government in England and Wales, responsible for the provision of public goods, including poor relief (welfare transfers) since the Poor Law Act of 1601. Parish boundaries are relatively stable during the 19th century, but experience substantial changes after 1901, and hence we end our sample in 1901. We construct constant parish boundary data every census decade from 1801–1901 using the classification from Shaw-Taylor et al. (2010), as discussed further in Online Appendix F1.2.

Following the Poor Law Amendment Act of 1834, parishes were grouped into poor law unions, which became an intermediate tier of local government, responsible for the administration of poor relief for the parishes within their boundaries. These poor law unions correspond closely to registration districts in the population census and we use these two terms interchangeably. Both parishes and registration districts aggregate to counties (e.g., Warwickshire), which were historically the upper tier of local government in England and Wales, responsible for the administration of justice, taxes, and parliamentary representation. Parishes have an average area of 13 kilometers squared and 1851 population of 1,590, which compares to an average area of 262 kilometers squared and 1851 population of 26,401 for registration districts, and an average area of 2,553 kilometers squared and 1851 population of 404,262 for counties.

We focus on parishes as our units of analysis for two main reasons. First, registration districts typically aggregate neighboring rural and urban parishes together, whereas we are concerned with the reallocation of economic activity from rural to urban areas. Second, parishes allow us to measure variation in agroclimatic conditions at a finer level of spatial disaggregation, taking into account local differences in soil conditions and topography, whereas registration districts average out this variation. In some of our empirical analysis, we distinguish between rural and urban parishes, where we define these two groups using K-means clustering based on initial population density in 1801, as discussed further in Online Appendix F4.

Parish Population: We construct population data from the parish-level records of the population census of England and Wales, which is enumerated every decade from 1801–1901.

Employment by industry: The population census of England and Wales reports detailed information on occupation from 1851 onwards. We use this information to construct employment data for the three aggregate sectors of agriculture, manufacturing and services for each parish.

Individual-Level Data: Individual-level records from the population census of England and Wales are available digitally for 1851–1861 and 1881–1901 through the Integrated Census Microdata Project (I-CeM).[10] We use these individual-level records to track people across locations and sectors over time. Building on the record-linking techniques developed for the United States in Abramitzky et al. (2021), we match individuals across the different waves of the population census. Our matching procedure uses a combination of the age, gender, county of birth and name of each individual to select a unique match across consecutive Census waves. Our use of only these matching variables ensures that the matching process is not influenced by individuals' choices of location and sector after birth. We focus on men, because women often changed their last name upon marriage during our historical time period.

In Online Appendix G, we provide further details on the matching process, including match quality and balance statistics for the matched and unmatched samples. The availability of information on county of birth contributes to high match quality, since counties within England and Wales are relatively small geographically. For each consecutive pair of census waves, we match around 30 percent of the population. We thus obtain the following matched samples: 5,323,072 (1851–61), 3,686,306 (1861–81), 7,527,280 (1881–1891), and 12,151,542 (1891–1901). Additionally,

[10] The individual-level records for the 1801–1841 and 1871 population censuses are not available digitally.

the population census reports both current county and county of birth. Therefore, we use this information to construct a separate measure of bilateral migration since birth, which does not require name matching across census waves, and includes both men and women.

Rateable Values: We measure the value of land and buildings in England and Wales using rateable values, which correspond to the market rental value of property for tax purposes. In particular, these rateable values are "The annual rent which a tenant might reasonably be expected, taking one year with one another, to pay for a hereditament, if the tenant undertook to pay all usual tenant's rates and taxes ... after deducting the probable annual average cost of the repairs, insurance and other expenses" (Stamp 1920). With a few minor exceptions, they cover all categories of property, including public services (such as tramways, electricity works etc.), government property (such as courts, parliaments etc.), private property (including factories, warehouses, wharves, offices, shops, theaters, music halls, clubs, and all residential dwellings), and other property (including colleges and halls in universities, hospitals and other charity properties, public schools, and almshouses). They also include both agricultural and non-agricultural land. All categories of properties were assessed, regardless of whether or not their owners were liable for income tax. The main exemptions are roads, canals, railways, mines, quarries, Crown property occupied by the Crown, and places of divine worship. We construct rateable values for each parish for the years for which these are available from 1815–1896 by digitizing the data reported in the publications of the Houses of Parliament (see Online Appendix F1.4).

Poor Law Transfers: The poor law corresponded to a system of welfare transfers for the poor, dating back to the 1601 Poor Relief Act, as discussed in Boyer (1990) and Renwick (2017). Originally, these welfare transfers were administered at the parish level, and provided money and resources for those in need, typically referred to as "outdoor relief." After the 1834 New Poor Law Act, parishes were grouped into Poor Law Unions (registration districts), and there was a move towards housing poor law recipients in designated workhouses, typically referred to as "indoor relief." Nevertheless, substantial amounts of outdoor relief continued to be given, even after 1834. We construct data on the number of paupers relieved for each registration district for 1841, 1851, 1860, 1870, 1881 and 1891 by digitizing the data reported in the publications of the Houses of Parliament (see Online Appendix F1.5).

Agricultural Prices, Production and Trade: We use data on the prices of wheat, arable products and pastoral products for English agriculture from Clark (2004). We obtain data on total wheat imports and wheat imports from different exporting countries for the United Kingdom from Sharp (2010) and Sharp and Weisdorf (2013).

Agricultural Production: We use county-level data on agricultural land use in acres from the Agricultural Returns of the United Kingdom from 1871–1901. Agricultural acreage is reported for a number of different categories: (i) wheat; (ii) other corn crops (e.g., barley, oats and rye);

(iii) permanent pasture or grass not broken up in rotation; (iv) clover, sanfoin and grasses under rotation; (v) green crops (potatos, turnips and swedes, mangold, carrots, cabbage, kohl-rabi and rape, and vetches); and (vi) bare fallow (land remaining uncropped for a season and kept free of vegetation). We also use data on cultivated land area for a number of different crops from the 1801 crop census, as used in Caprettini and Voth (2020), and the 1836 Tithe Surveys. We construct our exogenous measure of exposure to the Grain Invasion using data on the suitability of climate and soil conditions for the cultivation of wheat from the United Nations Food and Agricultural Organization Global Agro-Ecological Zones (GAEZ) dataset, as used in Costinot et al. (2016). Consistent with 19th-century farming practices in England and Wales, we use the measure of wheat suitability for low-input and rain-fed cultivation.

4 Reduced-Form Evidence

In this section, we present reduced-form evidence on the impact of the Grain Invasion. In Subsection 4.1, we introduce our exogenous measure of location exposure to the Grain Invasion, based on the suitability of agroclimatic conditions for the cultivation of wheat. In Subsection 4.2, we provide evidence on the relationship between structural transformation away from agriculture and wheat suitability over time. In Subsection 4.3, we examine reallocation between arable and pastoral products within agriculture over time. In Subsection 4.4, we provide further evidence on timing using an event-study specification. In Section 4.5, we use our individual-level census data to directly examine mobility decisions in response to this international trade shock.

4.1 Grain and Grazing Regions

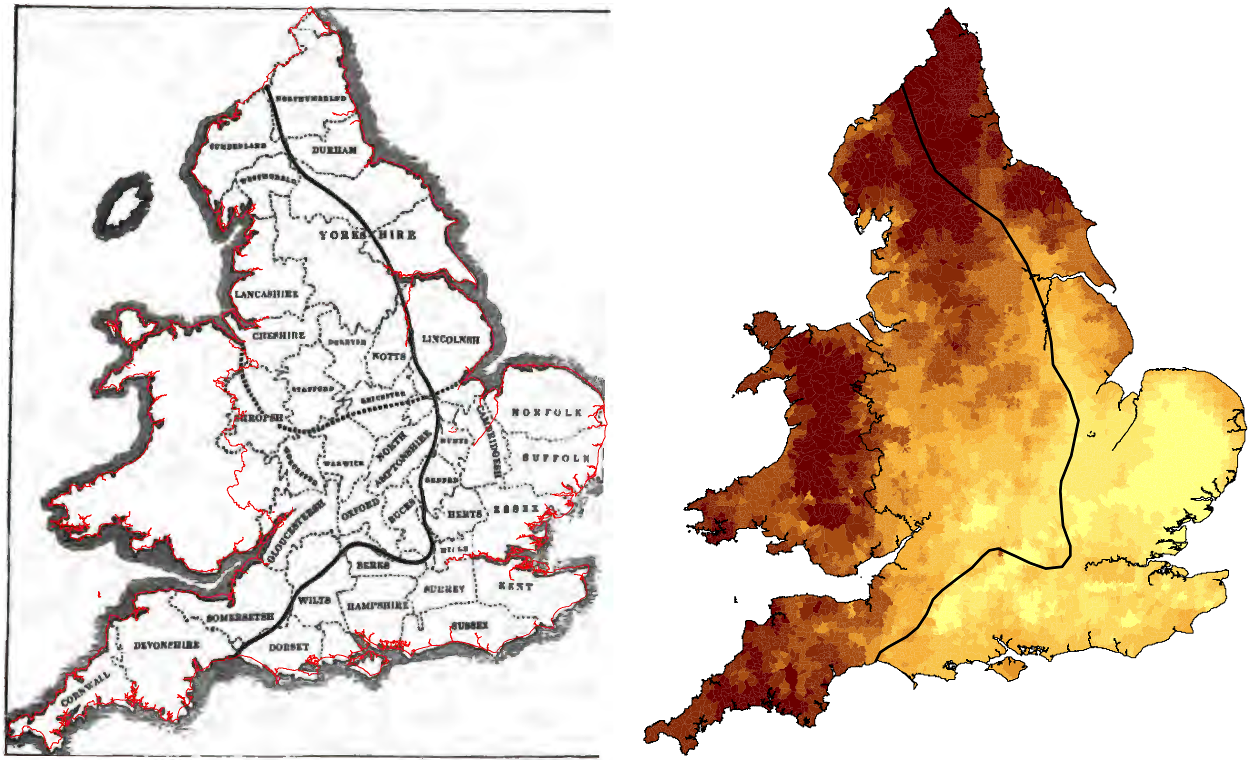
An advantage of our empirical setting is that there is a marked difference in agroclimatic conditions between the Western and Eastern parts of England and Wales.[11] In particular, the warm ocean current of the North Atlantic Drift and the prevailing winds from the South-West generate greater cloud cover, more precipitation, and lower average temperatures in Western areas. Many of the more mountainous areas of England and Wales are also concentrated in these Western areas (such as the Welsh mountains and the Lake District), with a line of hills (the Pennines) running approximately down the middle of England. As a result, these more rugged Western areas typically have thinner and more barren soils.

In contrast, the Eastern parts of the country are in the rain shadow of these mountains, with lower cloud cover, less precipitation, and higher average temperatures. These Eastern areas are also more low-lying, with thicker and more fertile soils, in part because of the accumulated sediment from the water erosion of the more mountainous areas to the West. For these combined

[11] See, for example, the classic volume on the physical geography of Britain by Goudie and Brunsden (1995).

reasons of climate, terrain and soil, Western locations are more suitable for grass (and hence the grazing of cattle and sheep), while Eastern locations are more suitable for the cultivation of corn (historically mainly wheat, but also barley, maize, and rye).

Figure 3: Caird's Western-Grazing and Eastern-Corn Counties and Wheat Suitability (UN GAEZ)



(a) Reproduction of Caird's Original Map (b) Wheat Suitability (UN GAEZ)

Note: Panel (a) shows a reproduction of Caird's (1852) original map; the thick black line shows his division between the grazing and the corn counties; the thin red line shows the outline of England and Wales used to georeference the original map; Panel (b) shows Low-Input, Rain-Fed Wheat Suitability from the United Nations Global Agro-Ecological Zones (UN GAEZ); lighter shading corresponds to greater suitability for wheat cultivation.

This difference in agroclimatic conditions has been reflected in longstanding differences in agricultural land use between Western and Eastern regions. In his seminal mid-19th century study of the state of English agriculture, Caird (1852) drew a line approximately down the middle of England that separated the "grazing counties" of the West from the "corn counties" of the East, as shown in a reproduction of his original map in Panel (a) of Figure 3.

As a check on this categorization, we superimpose the Caird line on a map of low-input, rain-fed wheat suitability from the United Nations Global Agro-Ecological Zones (GAEZ) data in Panel (b) of Figure 3.[12] Although this GAEZ measure is computed for the period 1961–1990, these differences in relative agroclimatic conditions between the Western and Eastern parts of

[12]We provide further evidence on the relationship between arable/pastoral farming and agroclimatic suitability for the cultivation of wheat using the 1836 Tithe maps for unenclosed land in Section B2 of the Online Appendix.

England and Wales have been stable for centuries.[13] As shown in the figure, we find a close correspondence between the Caird line and wheat suitability as measured by UN GAEZ. Despite the clear differences between Western and Eastern areas, we also find some heterogeneity in wheat suitability within each of these parts of England and Wales, which we exploit using our spatially-disaggregated parish-level data. In particular, for each parish, we compute mean wheat suitability across 5 arc-minute pixels within its geographical boundaries.

4.2 Structural Transformation

We now use this exogenous measure of wheat suitability based on agroclimatic conditions to provide evidence on the impact of the Grain Invasion on the distribution of economic activity across sectors and regions. We begin by confirming that West-East location within England and Wales is accompanied by systematic differences in agricultural practices. In particular, arable farming (including corn cultivation) is more input intensive than pastoral farming (including the grazing of cattle and sheep). Whereas cattle and sheep can be left to graze in fields and pastures, corn cultivation involves a number of horticultural tasks, such as plowing, sowing, weeding, harvesting and threshing.

In Figure 4, we display the shares of farmers (red) and agricultural laborers (blue) in employment in 1851 (solid lines) and 1901 (dashed lines) against West-East location, as measured by the Eastings of the British National Grid (BNG) of the Ordnance Survey (OS).[14] In each case, we show the fitted values from kernel (Epanechnikov) regressions (dark lines) and the 95 percent confidence intervals (light gray shading). We find that the share of farmers in employment is relatively flat and in fact declines as one moves further Eastwards. In contrast, the share of agricultural laborers in employment rises as one moves further Eastwards, consistent with these more Easterly locations specializing in more labor-intensive corn cultivation.

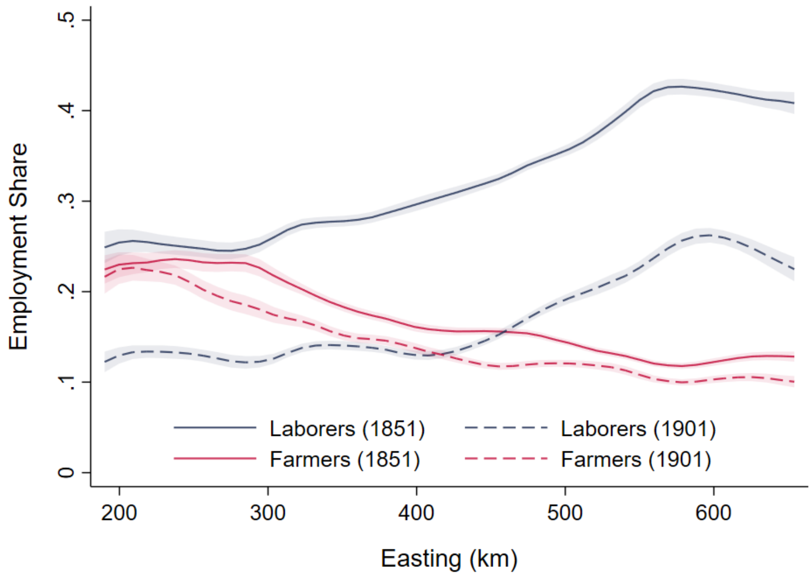
Between 1851 and 1901, there is a decline in the share of farmers in employment. Over the same period, however, there is a much larger decline in the share of agricultural laborers in employment, with the largest declines observed for locations with Easting of more than 400 (where Birmingham has an Easting of 408). As a result, the West-East gradient in the share of agricultural laborers in employment becomes shallower over time. Therefore, we find greater structural transformation away from agriculture in Eastern-corn locations than in Western-grazing locations following the Grain Invasion in the second half of the 19th century.[15]

[13] Despite this stability in relative agroclimatic conditions, there was an increase in overall temperature levels during the medieval warm period (900–1300 CE) and a decrease in overall temperature levels during the little ice age (1300–1850 CE), as discussed for example in Fagan (2019).

[14] The first year for which employment by industry is available in the population census is 1851. To provide a benchmark for the interpretation of the Eastings, the Guildhall in the center of the historical City of London has an Easting of 532 kilometers.

[15] For further evidence on structural transformation in England and Wales during the 19th century, see Online

Figure 4: Employment Shares of Agricultural Laborers and Farmers in 1851 and 1901 by Easting



Note: Kernel (Epanechnikov) regressions of employment shares on Easting across parishes in England and Wales; dark lines show fitted values and lighter shading shows 95 percent point confidence intervals; Eastings are based on the British National Grid (BNG) of the Ordnance Survey (OS) and measure East-West location, where the Guildhall in the center of the City of London has an Easting of 532 kilometers.

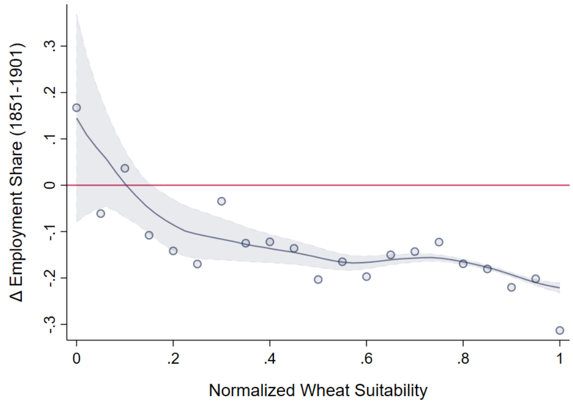
In Figure 5, we tighten this connection between structural transformation and wheat suitability, by displaying the changes in the shares of sectors in employment from 1851–1901 against our wheat suitability measure (normalized to lie between 0 and 1).[16] In each case, we show the fitted values from kernel (Epanechnikov) regressions (dark lines) and the 95 percent confidence intervals (light gray shading). As shown in the top-left panel, there is a much greater overall decline in agricultural employment in high-wheat-suitability locations. Comparing the top-left and top-right panels, this greater decline in agricultural employment is mainly driven by a larger reduction in employment of agricultural laborers, consistent with a decline in corn cultivation that is intensive in the employment of these agricultural laborers.

In the bottom-left panel, we show that there is little relationship between the change in manufacturing's share of employment and wheat suitability. This finding confirms that the more rapid decline in agriculture in high-wheat-suitability locations is not driven by a general equilibrium "Dutch Disease"' effect from a more rapid expansion of manufacturing as part of either the first industrial revolution from 1760 onwards or the second industrial revolution from 1870 onwards. This finding is also consistent with the fact that the expansion in manufacturing during the industrial revolution was concentrated in the new large industrial cities of Manchester and

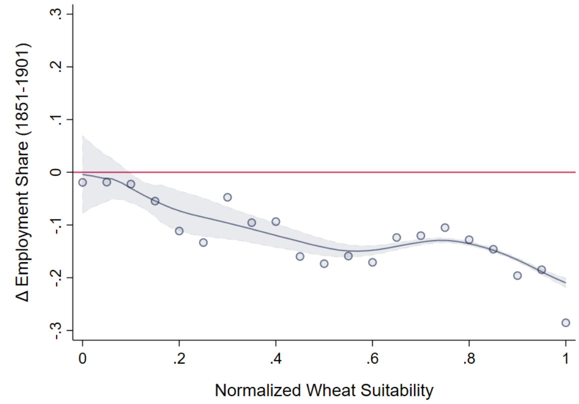
Appendix F4.

[16]The changes in the shares of these four sectors in employment do not sum to zero, because agricultural laborers are part of agriculture, and we omit some sectors, such as construction.

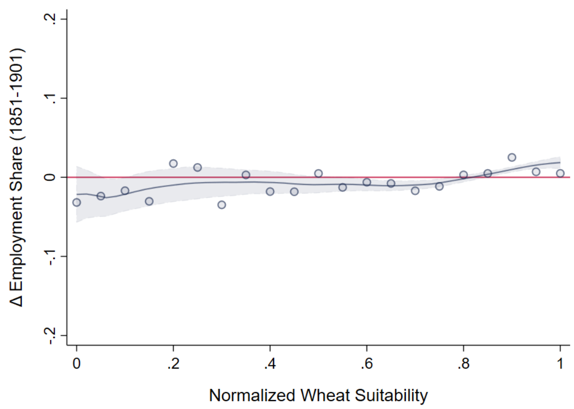
Figure 5: Change in Employment Shares from 1851–1901 by Wheat Suitability



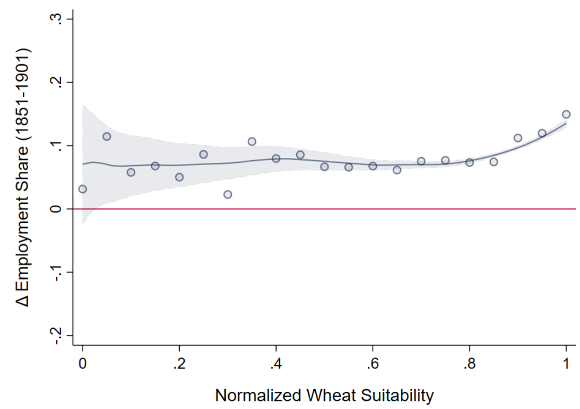
(a) Agriculture



(b) Agricultural Laborers



(c) Manufacturing



(d) Services

Note: Kernel (Epanechnikov) regressions of the change in sectoral employment shares on wheat suitability (normalized to lie between 0 and 1) across parishes in England and Wales; dark lines show fitted values and lighter shading shows 95 percent point confidence intervals.

Birmingham, and in the existing urban center of London, which are located in areas with very different levels of wheat suitability (low, medium and high, respectively).

Finally, as shown in the bottom-right panel, we find a more rapid rise in the share of services in employment in high-wheat-suitability locations. This pattern of results is in line with the idea that the reduction in employment opportunities for agricultural laborers as a result of the Grain Invasion increased the relative importance of local services as a source of rural employment, including in particular personal services for the gentry and aristocracy that historically dominated rural economic life in Britain.[17]

Taken together, this pattern of results is consistent with the negative trade shock from the

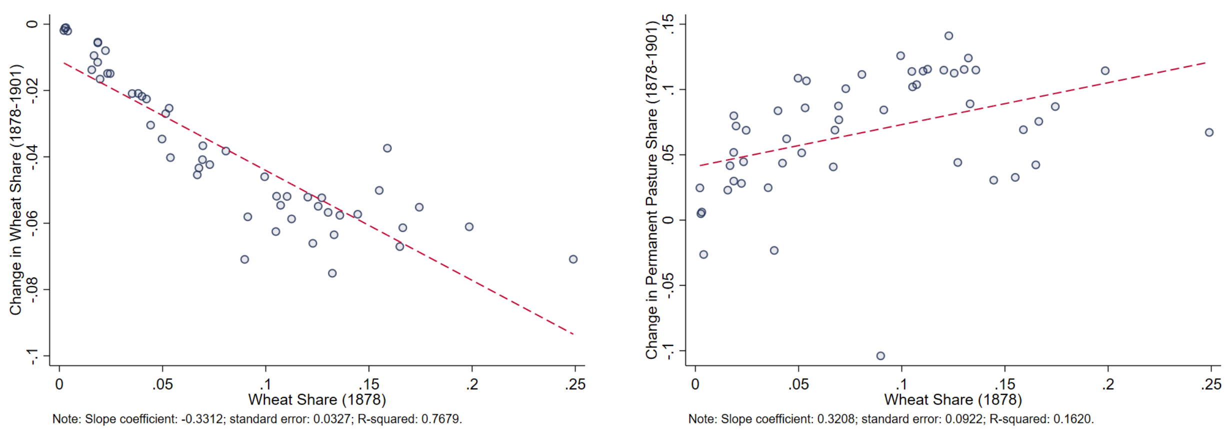
[17] As late as 1876, around 80 percent of all land in Great Britain was held by estates consisting of more than 1,000 acres (see Table 1.1. in Cannadine 1990).

Grain Invasion in the second half of the 19th century disproportionately affecting Eastern-corn locations. These empirical findings are in line with a large historical literature on the "great agricultural depression" in Britain following the Grain Invasion of the late-19th century, which emphasizes that Eastern-corn locations were more heavily hit, and discusses rural depopulation from agricultural laborers leaving the land, land sales by the great estates in response to declining rents, agricultural bankruptcies, and a switch from arable to pastoral farming.[18]

4.3 Reallocation Within Agriculture

In this subsection, we provide further evidence in support of our mechanism that the trade shock from the Grain Invasion disproportionately affected locations that were more suitable for corn cultivation than the grazing of cattle and sheep. In particular, we use our county-level data on the acreage of agricultural land allocated to different uses from the Agricultural Returns of the United Kingdom. We focus on the period from 1878 (the first year for which wheat cultivated area is reported as a separate category) to the end of our sample in 1901.

Figure 6: Reallocation of Agricultural Land from Wheat Cultivation to Permanent Pasture



(a) Change in Wheat Share of Agricultural Land 1878–1901

(b) Change in Permanent Pasture Share of Agricultural Land 1878–1901

Note: Panel (a) shows change in wheat share of agricultural land from 1878–1901 against initial wheat share of agricultural land in 1878; Panel (b) shows change in permanent pasture share of agricultural land from 1878–1901 against initial wheat share of agricultural land in 1878; in addition to wheat and permanent pasture (for grazing of animals), agricultural land area also includes other corn crops (e.g., barley, oats and rye), clover, sanfoin and grasses under rotation, green crops (potatos, turnips and swedes, mangold, carrots, cabbage, kohlrabi and rape, and vetches), and bare fallow (land remaining uncropped for a season and kept free of vegetation).

In Panel (a) of Figure 6, we display the change in wheat's share of agricultural land area from

[18] See Fletcher (1961) and Perry (1973) on the great agricultural depression; Graham (1892), Longstaff (1893) and Board of Agriculture and Fisheries (1906) on rural depopulation; see Thompson (1963) and Cannadine (1990) on the break-up of the great estates; and Perry (1972) on the geography of agricultural bankruptcies and the switch from arable to pastoral farming.

1878–1901 against its initial share in 1878. Each blue dot corresponds to a county in England or Wales and we also show the regression relationship between the two variables. As shown in the figure, we observe a decline in wheat's share of agricultural land in all counties, which ranges up to 8 percentage points. Consistent with the Grain Invasion disproportionately affecting corn-growing regions, we find that counties with the highest initial wheat shares (up to 25 percentage points) experience the greatest declines in wheat's share of the agricultural land. The regression relationship is negative and statistically significant at conventional critical values, with a slope coefficient of -0.331 (standard error of 0.033) and a regression R-squared of 0.77.[19]

In Panel (b) of Figure 6, we display the change in permanent pasture's share of agricultural land area from 1878–1901 against the initial share of wheat in agriculture land area in 1878. For the vast majority of counties, we observe an increase in permanent pasture's share of agricultural land area. Furthermore, we find that counties with the highest initial wheat shares experience the greatest increases in permanent pasture's share of agricultural land area. The regression relationship is positive and statistically significant at conventional critical values, with a slope coefficient of 0.321 (standard error 0.092) and a regression R-squared of 0.16.

The results of this subsection provide further support for our mechanism, and suggest that our findings are not capturing a common decline in all agricultural activities. In this analysis, we use variation within the agricultural sector, and hence difference out any shock that is common across all agricultural activities. Therefore, it is hard to explain these results in terms of an expansion of the manufacturing sector that leads to a decline in the agricultural sector as a whole. These results also cast doubt on some other potential explanations for a decline in agricultural employment, such as mechanization in arable farming. If the decline in agricultural employment were driven by technological advances that increased the productivity of arable farming, we would expect to observe an increase in the arable land share, whereas we find the opposite pattern of a decrease in this arable land share.[20]

Overall, we find changes in land use within the agricultural sector that are consistent with the idea that the Grain Invasion disproportionately affected corn-growing regions and led to a reallocation of economic activity within agriculture towards the grazing of cattle and sheep.

[19]This regression relationship does not simply capture mean reversion for all agricultural goods. If we instead regress the change in permanent pasture's share of agricultural land from 1878–1901 against its initial share in 1878, we find a quite different pattern of results, with a coefficient that is positive (0.031) and not statistically significantly different from zero (standard error 0.049), with a regression R-squared of 0.01.

[20]An explanation for the decline in agricultural employment based on technological advances that increased the productivity of arable farming also sits awkwardly with agricultural bankruptcies that were more severe in areas with greater wheat suitability, as discussed in Perry (1972) and shown in Online Appendix B5.

4.4 Event-Study Evidence

We now provide further evidence connecting the relative economic decline of high-wheat-suitability locations to the Grain Invasion, by using an event-study specification to examine the timing of this decline and to control for other determinants of economic activity.

4.4.1 Econometric Specification

We consider the following event-study specification for the relationship between log economic activity in a parish and wheat suitability:

$$\log L_{jt} = \sum_{\tau=-40}^{\tau=70} \beta_\tau \left(\mathbb{W}_j \times \mathbb{I}_\tau \right) + \sum_{\tau=-40}^{\tau=70} \left(X_j \times \delta_\tau \right) + \eta_j + d_t + u_{jt}, \tag{1}$$

where j indexes parishes; t indicates census year; we linearly interpolate between census years 1841 and 1851 to include 1846 in the regression sample as the year in which the repeal of the Corn Laws occurred; L_{jt} is an economic outcome of interest; $\mathbb{W}_j$ is an indicator variable that is one if a parish has above-median wheat suitability and zero otherwise; τ denotes treatment year, which equals year minus 1846; the excluded category is treatment year $\tau = 0$ (1846); $\mathbb{I}_\tau$ is an indicator variable that is one for treatment year τ; X_j are controls for observable parish characteristics that could affect parish growth rates; δ_t are time-varying coefficients on these controls; η_j is a parish fixed effect; d_t is a census-year dummy; and u_{jt} is a stochastic error. In our baseline specification, we report standard errors clustered by registration district, which allows the error term to be serially correlated across parishes within registration districts and over time.[21]

In this specification, the parish fixed effects (η_j) allow for time-invariant unobserved heterogeneity that can be correlated with wheat suitability. The census-year dummies (d_t) control for secular changes in economic activity across all parishes over time. The treatment coefficients (β_τ) on the interaction terms between wheat suitability ($\mathbb{W}_j$) and the treatment year indicators ($\mathbb{I}_\tau$) have a "difference-in-difference" interpretation, where the first difference compares parishes with above and below-median wheat suitability, and the second difference undertakes this comparison between treatment year zero (1846) and other census years. Since our model predicts that low-wheat-suitability locations are affected in general equilibrium by a reallocation of economic activity away from high-wheat-suitability locations, these treatment coefficients (β_τ) capture relative changes in economic activity between the two groups of locations. General equilibrium effects that are common across all locations, and which are included in our quantitative spatial model below, are here absorbed into the census-year dummies.

[21] As robustness checks, we report standard errors clustered by county, a more conservative procedure to account for spatial autocorrelation (Müller and Watson 2024) and standard errors clustered two-way by 560 registration districts and 100 quantiles of wheat suitability to allow for serial correlation across levels of wheat suitability motivated by Adão et al. (2019).

The main effect of each of our controls for observable parish characteristics (X_j) is captured in the parish fixed effect. The time-varying coefficients on these controls (δ_t) allow for heterogeneity in parish trends depending on these observed parish characteristics. We include a wide range of controls for other potential determinants of parish growth (X_j), including (i) travel time to the nearest market town (to control for access to urban centers); (ii) travel time to the nearest coalfield (to capture access to coal as a natural resource); (iii) Easting and Northing of the parish centroid (to control for geographical location); (iv) an indicator that is one for Wales (to allow for differences in growth between England and Wales); (v) distance to London and distance to Manchester (to capture proximity to these two concentrations of urban population); (vi) an indicator that is one for urban parishes based on the 1801 distribution of population densities (to allow for differences in growth between urban and rural areas).[22]

In our baseline specification, we report results using the conventional two-way fixed effects estimator. However, a recent empirical literature has highlighted that the interpretation of this two-way fixed effects estimator can be problematic in the presence of treatment heterogeneity and a variable timing of the treatment. Although we have a common timing of the treatment (the Grain Invasion in the second half of the 19th century), Online Appendix B6.3 demonstrates the robustness of our results to the use of alternative difference-in-differences estimators, including Borusyak et al. (2024), De Chaisemartin and d'Haultfoeuille (2020), Callaway and Sant'Anna (2021) and Sun and Abraham (2021). In our empirical application, we find a similar pattern of results across all of these different estimators.

4.4.2 Population Results

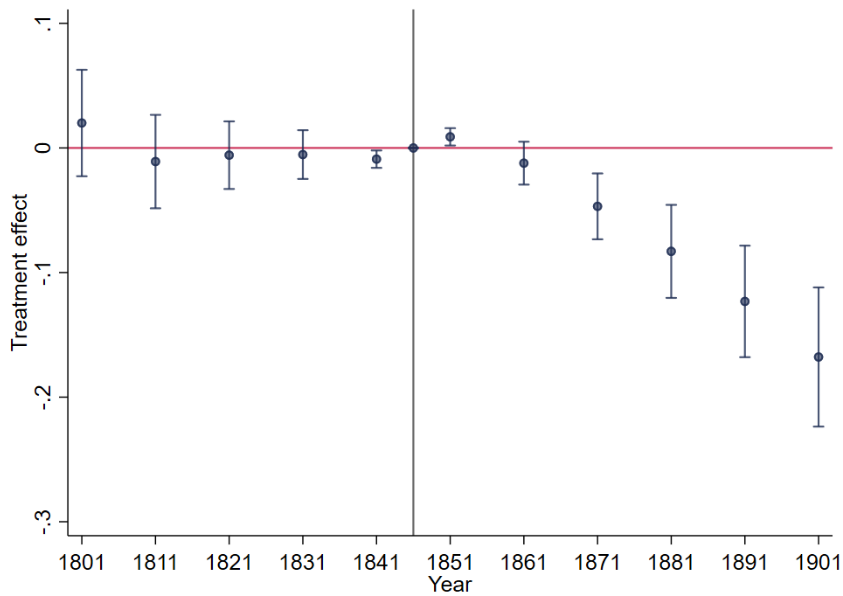
We begin by estimating our event-study specification (1) using our parish-level population data, which are available every census decade from 1801-1901. Given the inclusion of the parish fixed effects, and the fact that parish geographical area is time invariant, this specification also has an equivalent interpretation in terms of population density. Figure 7 displays the estimated treatment coefficients (β_τ) from our baseline specification including all of our controls for observable parish characteristics (X_j) interacted with census-year dummies. The vertical bars correspond to the 95 percent confidence intervals clustered by registration district, while the vertical red line shows the Repeal of the Corn Laws in 1846.

In the early decades of the 19th century, we find that high and low-wheat-suitability locations have similar population trends, with estimated coefficients that are close to zero and statistically insignificant. In contrast, in the second half of the 19th century, we observe a relative decline in population in locations with high wheat suitability. The timing of this estimated treatment effect

[22]See Appendix F4 for further details on the construction of the urban indicator and our measures of travel time to the nearest market town and coalfield.

accords closely with the timing of the Grain Invasion. In Figure 2, the large-scale expansion in wheat imports, and the emergence of major New World suppliers such as the United States, both begin in 1851, which is exactly when the estimated treatment effect in Figure 7 starts to trend downwards. The immediately preceding years are sometimes referred to as the "Age of High Farming" in Britain (e.g., Caird 1852), as a period of relative agricultural prosperity before the Grain Invasion. The estimated treatment effect grows in absolute magnitude over the second half of the 19th century, which is consistent with the continuing decline in the relative price of wheat over this period, as shown by the downward blue trend in Figure 1. By 1901, we find a relative decline in population of around 18 percent in high-wheat-suitability locations.[23]

Figure 7: Estimated Treatment Effects of Wheat Suitability for Log Population



Note: The figure shows the estimated treatment effects (β_t) from the differences-in-differences specification (1) using interactions between years and an indicator variable that is one for parishes with above-median wheat suitability and zero otherwise; 1846 is the excluded year; vertical lines show 95 percent confidence intervals based on standard errors clustered by registration district. The specification conditions on parish and year fixed effects, and interactions between year and (i) travel time to the nearest market town; (ii) travel time to the nearest coalfield; (iii) distance to London and distance to Manchester; (iv) Easting and Northing of the parish centroid; (v) an indicator that is one for Wales; (vi) an indicator that is one for urban parishes based on the 1801 distribution of population densities.

The timing of the estimated treatment effect in Figure 7 is also hard to reconcile in terms of other potential explanations such as the expansion of manufacturing during the first industrial revolution or mechanization in agriculture. The first industrial revolution began earlier around

[23]While we show 95 percent confidence errors based on standard errors clustered on registration districts in Figure 7, we find a similar pattern of results using standard errors clustered by parish, standard errors clustered two-way on registration districts and 100 bins for quantiles of wheat suitability using an approach based on Adão et al. (2019), standard errors clustered by county, and standard errors clustered for spatial autocorrelation using the approach of Müller and Watson (2024). In Figure B.16 of Online Appendix B6.3, we demonstrate the robust of our results to using other approaches to compute standard errors and including different sets of controls.

1760, with key innovations in the cotton industry and steam technology occurring in the second half of the 18th century. Similarly, mechanization in agriculture began earlier, with the first mechanical threshing machine invented in 1786, and the Captain Swing riots against automation occurring in the 1830s. Yet we find no evidence of differences in pre-trends between high and low-wheat-suitability locations in Figure 7 in the first half of the 19th century.

The timing of the treatment effect in Figure 7 is also hard to explain in terms of the second industrial revolution from 1870 onwards, which was associated with the expansion of the machine tools industry, the diffusion of the railway and telegraph, and electrification. The decline in relative population in high-wheat-suitability locations begins in 1851, which is two decades before the onset of the second industrial revolution. Additionally, much of the reallocation away from agriculture is towards services rather than manufacturing, as shown in Figure 5 above, which is hard to reconcile with an explanation based on the second industrial revolution. In Online Appendix B6.1, we provide further evidence that our results are not capturing industrialization by including a control for predicted employment growth, which uses parish industry employment shares in the early-19th century interacted with aggregate industry employment growth over the course of the 19th century. As in our baseline specification, we find no evidence of differences in trends in the first half of the 19th century, and a relative decline of population in locations with high wheat suitability in the second half of the 19th century.

Our finding of a change in relative population levels in response to the Grain Invasion at first sight contrasts with evidence of little population response to the China trade shock (e.g., Autor et al. 2013). But there are a number of reasons why the population response could be greater in our empirical setting. First, 19th-century Britain had rapid population growth and a relatively young population, both of which could facilitate changes in relative population levels. Our findings of a population response are consistent with the contemporary literature on rural depopulation, including Graham (1892), Longstaff (1893) and Board of Agriculture and Fisheries (1906). More broadly, most people lived in rural areas in the past, whereas few of us do so today.[24] Second, real income per capita was closer to subsistence levels, and poor law relief was a more primitive welfare system than in the United States today, both of which could generate a greater population response.[25] Third, our parish spatial units are much smaller than the U.S. commuting zones used for the China trade shock. In our individual-level population census data, we find that more than two thirds of migrations between parishes involve movements of less than 50 kilometers, as shown in Figure G.3 in Online Appendix G3. Migrations over these short distances

[24]Substantial population reallocations are observed in the United States for earlier historical time periods, including the migration of African-Americans from the South to the North, as examined in Wilkerson (2011).

[25]Some of the change in relative population levels could be achieved through international migration. Consistent with this mechanism, the emigration rate in England (higher-wheat suitability) is greater than in Wales (lower-wheat suitability) in the second half of the 19th century, but the magnitude of the difference is relatively small (Wilcox 1969).

would typically fall within the boundaries of U.S. commuting zones, and hence would not show up in changes in the relative populations of these commuting zones. We work with parishes as our spatial units, because they capture local variation in wheat suitability, and are the relevant spatial units in a historical setting in which most people lived where they worked, and most migration occurred between rural areas and nearby towns and cities.[26]

We find a similar pattern of event-study estimates across a wide range of different specifications. First, we re-estimated our baseline specification including separate treatment-year interactions with indicators for low-wheat suitability (bottom tercile) and high-wheat suitability (top tercile), where the excluded category is the middle tercile. As shown in Figure B.13 in Online Appendix B6.2, we find that low-wheat-suitability locations experience a weakly statistically significant *increase* in population relative to those with medium-wheat suitability, while high-wheat-suitability locations experience a statistically significant *decrease* in population relative to those with medium wheat suitability. Therefore, we find a consistent pattern of results throughout the distribution of wheat suitability.

Second, we re-estimated our baseline specification, augmenting it with interactions between treatment years and an indicator for above-median grass suitability. In Figure B.14 in Online Appendix B6.2, we show the estimated coefficients on both wheat suitability (in blue) and grass suitability (in green). Consistent with our results capturing the Grain Invasion, we find a similar pattern of estimated coefficients for wheat suitability, with negative and statistically significant treatment effects in the second half of the 19th century. In line with our earlier findings of a reallocation from arable to pastoral farming in Section 4.3 above, we find positive and statistically significant treatment effects for grass suitability in the second half of the 19th century.

4.4.3 Property Values and Poor Law Relief

We next re-estimate our baseline event-study specification (1) using our data on property values instead of population. These property values correspond to the market rental value of land and buildings for tax purposes and summarize the relative economic value of locations. Data are available for the years of 1815, 1843, 1852, 1865, 1870, 1881 and 1896. Again we linearly interpolate between 1843 and 1851 to include 1846 in the sample as the year in which the Repeal of the Corn Laws occurred. As shown in Figure B.17 in Online Appendix B6.4, we obtain a similar pattern of results for property values as for population. By the end of the 19th century, we estimate a relative decline in property values of around 24 percent in high-wheat-suitability locations compared to low-wheat-suitability locations.

Finally, we estimate our event-study specification (1) using data on poor law relief, as a mea-

[26]Consistent with local migration, Eckert and Peters (2023) find that most structural transformation from agriculture to manufacturing and services in the 19th-century United States occurred within counties.

sure of welfare relief that captures local economic distress. Our poor law relief data are available for 1841, 1851, 1860, 1870, 1883 and 1891 at the level of registration districts. We match parishes to registration districts and cluster the standard errors on registration districts to take account of the fact that poor law relief is measured at a more aggregate level. Again we linearly interpolate to include 1846 in the sample as the year in which the Repeal of the Corn Laws occurred. Following Repeal, we find a statistically significant increase in welfare relief in high-wheat-suitability locations relative to low-wheat-suitability locations, as shown in Figure B.18 in Online Appendix B6.4. This pattern of results is consistent with an increase in local economic distress in response to this trade shock. We find that the estimated treatment effect for poor law relief declines somewhat in absolute magnitude by the last two decades of the 19th century, which is consistent with the population reallocation estimated above helping to dissipate some of this local economic distress in high-wheat-suitability locations.

Taking the results of this section as a whole, we find strong evidence of a relative economic decline in high-wheat suitability locations following the Repeal of the Corn Laws and the Grain Invasion in the second half of the 19th century.

4.5 Individual-level Census Data

We next use our individual-level census data to directly examine the response of individual mobility decisions to this international trade shock.

We use our matched samples of individuals between each pair of consecutive census years. We treat the first pair of census years from 1851–61 as a pre-period, using the fact that the Grain Invasion increases in magnitude following the expansion of the railroad network into the mid-West after the end of the American Civil War in 1865. We pool the remaining pairs of census years from 1861–1881, 1881–1891, and 1891–1901 as a post-period. We use the matched data between each pair of consecutive census years to compute several mobility measures: (i) an indicator that is one if an individual moves to another census registration district; (ii) indicators that are one for rural-urban or urban-urban migrations between registration districts respectively; (iii) an indicator that is one if an individual moves two-digit occupation; and (iv) an indicator that is one if an individual moves one-digit industry.

Our historical time period is characterized by relatively high levels of mobility. On average, between pairs of consecutive census years, we find a probability of moving parish of around 0.4; registration district of about 0.3; county of around 0.2; two-digit occupation of above 0.6; and one-digit sector of over 0.5. As a check on these results from name matching across census waves, we find an average probability on living outside the county of birth of around 0.4 in each census year, again confirming substantial mobility.[27]

[27]Using individual-level records from the 1940 U.S. population census, which report current county and country

To examine the relationship between this mobility and the Grain Invasion, we estimate the following regression specification:

$$M_{ijt} = \sum_{t \in \mathbb{T}} \beta_t \left(\mathbb{W}_j \times \mathbb{I}_t \right) + \sum_{t \in \mathbb{T}} \left(X_j \times \delta_t \right) + \eta_j + d_t + u_{ijt} \tag{2}$$

where an observation is an individual i located in parish j in census year t; M_{ijt} is an indicator that is one if an individual moves (either location, occupation or sector) between a pair of consecutive census years and zero otherwise; the excluded category is the pre-period 1851–61, such that β_t and δ_t are estimated for the post-periods relative to the pre-period; the other variables are defined as in previous subsections; and we include the same set of controls for interactions between observable parish characteristics and year dummies as in our parish-level specification above. To ensure comparability with our parish-level results above, we weight the observations on individuals such that all parishes have the same weight. We report standard errors clustered by registration districts, which allows the error term to be serially correlated across individuals within registration districts and across census years within registration districts.

In Panel A of Table 1, we report the estimation results using the following four measures of spatial mobility: (i) mobility across registration districts in column 1, (ii) mobility across counties in column 2, (iii) rural-urban migration in column 3, (iv) urban-urban migration in column 4. In line with our earlier findings of a change in relative population levels, we find a larger increase in spatial mobility over time in locations with high wheat suitability than in those with low wheat suitability. As shown in column 1, the probability of outmigration at the registration district level rises increases by 1.5 percentage points in high-wheat-suitability locations relative to low-wheat-suitability locations in 1861-1881 relative to the excluded category of 1851-61, and increases by 5.3 percentage points in 1891-1901 relative to this excluded category. This effect is large relative to the average outmigration probability of 0.30 for registration districts. As shown in column 2, we also find some increase in outmigration probabilities in the later three periods relative to the excluded category for counties. But this increase is smaller than for registration districts, consistent with most mobility occurring within counties. From columns 3 and 4, this increase in outmigration is mostly driven by movements from rural to urban areas, consistent with the negative impact of the Grain Invasion largely falling on rural areas.[28]

We find that this increase in mobility between locations is mirrored by increases in mobility between occupations and sectors. We consider the following four additional mobility measures: (i) occupational mobility across 2-digit occupations within registration districts in column 1; (ii) a

five years previously, Hornbeck (2023) finds that 17 percent of people moved counties over that five-year period, where U.S. counties are substantially larger than those in England and Wales. Taken together, England and Wales have approximately the same total land area as the U.S. state of Georgia.

[28] In Online Appendix G3, we provide further evidence on bilateral patterns of migration away from areas with higher wheat suitability towards those with lower wheat suitability.

Table 1: Wheat Suitability and Spatial/Occupational Mobility

Panel A: Spatial mobility	Districts	Counties	Rural-urban	Urban-urban
Wheat suitability × 1861-1881	.0147	.0235	.0133	.0001
	(.0066)	(.0064)	(.0050)	(.0029)
Wheat suitability × 1881-1891	.0214	.0093	.0118	-.0016
	(.0076)	(.0058)	(.0047)	(.0030)
Wheat suitability × 1891-1901	.0527	.0121	.0195	.0204
	(.0143)	(.0098)	(.0085)	(.0065)
Observations	9,759,420	9,759,420	9,759,420	9,759,420

Panel B: Occupational mobility	Occupations only	Occupations/locations	Agriculture	Industries
Wheat suitability × 1861-1881	-.0109	.0139	.0254	.0129
	(.0060)	(.0060)	(.0089)	(.0062)
Wheat suitability × 1881-1891	.0004	.0199	.0226	.0233
	(.0052)	(.0059)	(.0086)	(.0060)
Wheat suitability × 1891-1901	-.0125	.0355	.0170	.0174
	(.0077)	(.0088)	(.0088)	(.0061)
Observations	5,385,948	5,385,948	1,426,520	5,385,948

Note: Standard errors are reported between parentheses and are clustered at the level of registration districts. The unit of observation is an individual at a given time t. All specifications condition the analysis on parish fixed effects, time fixed effects and controls for observable parish characteristics interacted with time dummies: (i) travel time to the nearest market town; (ii) travel time to the nearest coalfield; (iii) distance to London and distance to Manchester; (iv) Easting and Northing of the parish centroid; (v) an indicator that is one for Wales; (vi) an indicator that is one for urban parishes based on the 1801 distribution of population densities.

measure of joint mobility (changing *both* 2-digit occupation and registration district) in column 2; (iii) a measure of mobility out of agriculture (including both farmers and agricultural laborers) in column 3; (iv) mobility across 1-digit sectors in column 4. We find that overall mobility between 2-digit occupations increases in high-wheat-suitability locations relative to low-wheat suitability locations between the pre-period and post-periods. But this increase in overall occupational mobility is driven entirely by people moving both occupation and registration district (an increase of 3.6 percentage points by 1891-1901 in column 2). In contrast, the probability of moving occupation alone within registration district *falls* (a decrease of 1.25 percentage points by 1891-1901 in column 1). A share of this mobility across occupations and locations can be explained by a movement out of agriculture, as shown in column 3 (an increase of 1.7 percentage points by 1891-1901), and more generally by movement across 1-digit industries, as shown in column 4 (an increase of 1.74 percentage points by 1891-1901).

Overall, our estimates using the individual-level census data confirm our findings using parish population above and support the conclusions of the historical literature on rural depopulation. We find that the Grain Invasion increased outmigration from high-wheat-suitability locations, with the largest increases occurring for rural-urban migration.

5 Theoretical Framework

We next develop our quantitative spatial model to rationalize these empirical findings and evaluate the distributional consequences of the Grain Invasion.[29]

We consider an economy that consists of a set of small open economies indexed by $i, j \in \mathcal{J}$, which correspond to the parishes in our data. There are three aggregate sectors indexed by $k \in \{A, M, S\}$: Agriculture (A), Manufacturing (M), and Services (S). The agricultural sector includes two disaggregated goods $g \in \{G, F\}$: arable products (G for "grain") and pastoral products (F for "field"). Arable, pastoral and manufacturing goods are traded on world markets, with their local prices exogenously determined by world market prices and transport costs. Services (including housing) are non-traded, with their local prices endogenously determined by the equality of local demand and supply.

To examine the long-run impact of the Grain Invasion, our baseline specification considers a static specification of worker location decisions.[30] The economy is populated by a measure of $\bar{N}_t$ workers. Each worker is endowed with one unit of labor that is supplied inelastically. Workers are geographically mobile and have idiosyncratic preferences for locations. Each worker chooses their preferred location given their idiosyncratic preference draws.

Each location i is endowed with a continuum of land plots indexed by $\varphi \in L_i$, where L_i corresponds to land area. Land is owned by local landlords. After observing idiosyncratic productivity shocks for each sector in each land plot, the local landlord decides whether to allocate it to agriculture, manufacturing or services. After allocating a land plot to agriculture, the local landlord observes idiosyncratic productivities for the disaggregated goods within the agricultural sector, and decides whether to use the land plot for arable or pastoral farming. Whereas conventional trade model typically feature complete specialization across sectors (as in Fajgelbaum and Redding 2022), this specification with nested idiosyncratic productivity shocks allows for incomplete specialization across sectors and disaggregated goods, as observed in our data.

We interpret land in the model as capturing land and buildings in the data. In our baseline specification, we assume an inelastic supply of land, but we report an extension with a constant elasticity supply function for land and buildings in Online Appendix E3. We allow locations to differ in amenities, average productivities by sector, average productivities by disaggregated good within agriculture, land area, and bilateral trade costs. We allow all of these location characteristics besides land area to change over time. To streamline notation, we suppress the implicit

[29]See Online Appendix C for the derivation of all theoretical results in this section of the paper.

[30]In Online Appendix E1, we consider an extension of our theoretical model to incorporate migration dynamics following Artuç et al. (2010) and Caliendo et al. (2019).

dependence on time t from now onwards, except where otherwise indicated.

5.1 Preferences

We assume a nested preference structure, in which preferences are first defined over sectors, and then over disaggregated goods within the agricultural sector. In the upper tier of utility, the preferences of a worker ψ who chooses to live in location i depend on consumption of the goods produced by each sector k (C_{ki}), residential amenities (B_i), and an idiosyncratic preference shock ($b_i(\psi)$). We assume for simplicity a constant elasticity of substitution (CES) functional form:

$$u_i(\psi) = B_i b_i(\psi) \left[\sum_{k \in \{A,M,S\}} (\beta_k C_{ki})^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \qquad 0 < \sigma < 1, \tag{3}$$

where the parameter β_k controls the relative weight of each sector in consumer utility; the idiosyncratic preference shock ($b_i(\psi)$) is specific to a pair of worker and location, and captures all of the idiosyncratic factors that can influence the location decisions of individual workers.[31]

In the lower tier of utility, the consumption index for the agricultural sector (C_{Ai}) is defined over the consumption of arable (C_{Gi}) and pastoral (C_{Fi}) products. We assume for simplicity the following Cobb-Douglas functional form:

$$C_{Ai} = C_{Gi}^{\beta_G} C_{Fi}^{\beta_F}, \qquad \beta_G + \beta_F = 1. \tag{4}$$

Our assumption of CES preferences in the upper tier follows a large macroeconomics literature on structural transformation following Baumol (1967). This literature typically assumes inelastic demand across sectors ($0 < \sigma < 1$), such that faster productivity growth in a given sector reallocates employment towards other sectors. Our assumption of Cobb-Douglas preferences in the lower tier is primarily motivated by our quantitative application, for which only limited historical expenditure survey data are available. But this specification also satisfies the intuitive property that demand is more elastic across products within the agricultural sector than across sectors. For both tiers of utility, we assume homotheticity, again mainly for data availability reasons. In Online Appendix E2, we generalize our theoretical model to allow for non-homothetic preferences following Comin et al. (2021). Although non-homotheticity introduces a new expenditure channel for distributional effects, geography remains an important dimension along which the income distributional effects of trade occur.

We assume that idiosyncratic preferences are drawn independently across individuals and locations from a Fréchet distribution: $F(b) = e^{-b^{-\chi}}$, where $\chi > 1$. We normalize the scale parameter to one, because it enters the model isomorphically to common amenities (B_i). The shape

[31] Although we model the worker idiosyncratic shock in terms of preferences, there is a closely-related formulation in terms of an idiosyncratic shock to worker productivity.

parameter χ controls the dispersion of idiosyncratic preferences, and hence the responsiveness of location decisions to economic variables relative to idiosyncratic preferences.

Landlords have the same preferences as workers, except that we abstract from idiosyncratic preferences for landlords, because they are geographically immobile, and hence these idiosyncratic preferences would not affect equilibrium allocations in any way.

5.2 Prices and Expenditure Shares

The dual consumption goods price index (P_{Ci}) is defined over the price of the goods produced by each sector (P_{ki}) and takes the following conventional form:

$$P_{Ci} = \left[\sum_{k \in \{A,M,S\}} \left(P_{ki}/\beta_k \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}, \tag{5}$$

where the agricultural price index is defined over the prices of the arable and pastoral goods:

$$P_{Ai} = P_{Gi}^{\beta_G} P_{Fi}^{1-\beta_G}. \tag{6}$$

No arbitrage determines the local prices of the traded arable, pastoral and manufacturing goods (P_{ki}) as a function of the world market price (P_k^*) and domestic transport costs from location i to world markets in that sector (τ_{ki}):

$$\begin{aligned} P_{ki} &= \tau_{ki} P_k^*, \quad \text{if} \quad C_{ki} > Q_{ki} \quad k \in \{G, F, M\}, \\ P_{ki} &= P_k^* / \tau_{ki}, \quad \text{if} \quad Q_{ki} > C_{ki}, \end{aligned} \tag{7}$$

where Q_{ki} is production of good k in location i. In contrast, the local prices of non-traded services are determined by the equality between local demand and local supply.

Expenditure minimization implies the following shares of sectors in consumer expenditure:

$$x_{ki} = \frac{\left(P_{ki}/\beta_k \right)^{1-\sigma}}{\sum_{m \in \{A,M,S\}} \left(P_{mi}/\beta_m \right)^{1-\sigma}}. \tag{8}$$

5.3 Production Technology

Markets are assumed to be perfectly competitive. Goods are produced using labor and land under conditions of constant returns to scale. We make the natural assumption that pastoral farming has the highest land intensity, followed by arable farming, with manufacturing and services having lower land intensities. We assume Cobb-Douglas production technologies for simplicity. Expressing these technologies in the intensive form, output per unit of land ($q_{ki}(\varphi)$) depends on employment per unit of land ($n_{ki}(\varphi)$) and productivity ($z_{ki}(\varphi)$, $a_{gi}(\varphi)$) as follows:

$$\begin{aligned} q_{ki}(\varphi) &= \vartheta_k n_{ki}(\varphi)^{1-\alpha_k} z_{ki}(\varphi)^{\alpha_k}, & 0 < \alpha_k < 1, \ k \in \{M, S\}, \\ q_{gi}(\varphi) &= \vartheta_g n_{gi}(\varphi)^{1-\alpha_g} z_{Ai}(\varphi)^{\alpha_g} a_{gi}(\varphi)^{\alpha_g}, & 0 < \alpha_g < 1, \ g \in \{F, G\}. \end{aligned}$$

where $\vartheta_k \equiv \alpha_k^{-\alpha_k} (1-\alpha_k)^{-(1-\alpha_k)}$; $z_{ki}(\varphi)$ captures productivity differences across the aggregate sectors of agriculture, manufacturing, and services; $a_{gi}(\varphi)$ captures productivity differences across the disaggregated arable and pastoral goods within the agricultural sector. Although the distinction between land and labor-augmenting technology is not consequential under our assumption of Cobb-Douglas production technologies, we model technology as land-augmenting to simplify the characterization of the distribution of the wage-rental ratio.

We assume that land plots are heterogeneous in productivity for each alternative use, depending for example on terrain and soil. Productivity for the aggregate sectors (z_{ki} for $k \in \{A, M, S\}$) is drawn independently for each land plot from the following Fréchet distribution: $F_{ki}(z) = e^{-T_{ki} z^{-\theta}}$. Similarly, productivity for each disaggregated good $g \in \{G, F\}$ within the agricultural sector is drawn independently for each land plot from the following Fréchet distribution: $F_{gi}(a) = e^{-E_{gi} a^{-\epsilon}}$. The scale parameters ($T_{ki}$, E_{gi}) control absolute advantage and the shape parameters (θ, ϵ) regulate comparative advantage.

We assume that landlords first observe the sectoral productivity draws (z_{Ai}, z_{Mi}, z_{Si}) and decide which land plots to allocate to agriculture, manufacturing, and services. Having chosen to allocate a land plot to agriculture, landlords observe the productivity draws for each disaggregated agricultural good (a_{Gi}, a_{Fi}), and decide whether to allocate that agricultural land plot to arable or pastoral farming. We use this timing assumption to capture the idea that uncertainty about agricultural conditions (e.g., climate) is typically only fully realized after land already has been allocated to agricultural use.[32]

An implication of these assumptions is that locations are typically incompletely specialized across alternative land uses for positive and finite values of the average productivity parameters T_{ki} and E_{gi}. The reason is that support of the Fréchet productivity distribution is unbounded from above. Therefore, with a continuum of land plots in each location, there is a positive measure of land plots with arbitrarily high productivity for each land use. We allow for zero land use for some economic activities in some locations by considering the limiting case in which these average productivity parameters converge towards zero ($T_{ki} \rightarrow 0$ and $E_{gi} \rightarrow 0$).

5.4 Production within Agriculture

We first characterize the allocation of land between arable and pastoral farming conditional on having chosen to use land agriculturally, before turning next to the allocation of land between agriculture, manufacturing, and services.

Each agricultural land plot φ is allocated to the disaggregated good $g \in \{G, F\}$ that offers the highest rental rate ($r_{gi}(\varphi)$), given the realizations for agricultural productivity ($a_{gi}(\varphi)$). With

[32] Although we make this timing assumption, we could equivalently assume a nested extreme value specification for sectoral productivity (z_{ki}) and agricultural productivity (a_{gi}).

a common wage across goods and sectors within locations (w_i), we can equivalently characterize this decision in terms of the good that offers the lowest wage-rental ratio ($\omega_{gi}(\varphi)$). Using the first-order conditions for cost minimization and zero profits, the equilibrium wage-rental ratio for given realizations of agricultural and sector productivity is:

$$\omega_{gi}(\varphi) \equiv \frac{w_i}{r_{gi}(\varphi)} = \frac{1}{z_{Ai}(\varphi)a_{gi}(\varphi)} \left(\frac{w_i}{P_{gi}} \right)^{\frac{1}{\alpha_g}} . \tag{9}$$

Using the Fréchet distribution for agricultural productivity (a_{gi}) and equation (9) to solve for the distribution of the equilibrium wage-rental ratio, the probability that an agricultural land plot is allocated to disaggregated good g in location i (ℓ_{gi}^A), and the share of agricultural land used for disaggregated good g in location i, is:

$$\ell_{gi}^A = \frac{L_{gi}}{L_{Ai}} = \frac{E_{gi} \left(P_{gi}/w_i \right)^{\epsilon/\alpha_g}}{\sum_{o \in \{G,F\}} E_{oi} \left(P_{oi}/w_i \right)^{\epsilon/\alpha_h}}, \tag{10}$$

where the superscript A indicates that this share is defined as a share of agricultural land.

The share of agricultural land allocated to each good g (ℓ_{gi}^A) in equation (10) is increasing in the average productivity (E_{gi}) and local price for that good (P_{gi}), and decreasing in the average productivity and local price for the other good. Other things equal, locations with higher equilibrium wages (w_i) have lower arable shares of agricultural land, because arable farming (G) is labor-intensive relative to pastoral farming (F), such that $\alpha_G < \alpha_F$. The agricultural productivity dispersion parameter ϵ regulates the sensitivity of agricultural land shares to prices and wages relative to idiosyncratic agricultural productivity.

With a Fréchet distribution for agricultural productivity, the expected wage-rental ratio is the same across the two disaggregated goods within the agricultural sector, and is determined by productivity (z_{Ai}, E_{gi}), prices (P_{gi}), the common wage (w_i), and factor intensities (α_g):

$$\frac{1}{\omega_{Ai}} \equiv \mathbb{E}_a \left[\frac{1}{\omega_{gi}} \right] = z_{Ai} \gamma_\epsilon \left[\sum_{g \in \{G,F\}} E_{gi} \left(P_{gi}/w_i \right)^{\epsilon/\alpha_g} \right]^{\frac{1}{\epsilon}} , \tag{11}$$

where $\gamma_\epsilon \equiv \Gamma\left(\frac{\epsilon-1}{\epsilon}\right)$; $\Gamma(\cdot)$ is the Gamma function; $\mathbb{E}_a[\cdot]$ is the expectation over the distribution for idiosyncratic agricultural productivity (a) conditional on land with a given sectoral productivity (z_{Ai}) being used agriculturally.

The intuition for this equalization of the expected wage-rental ratio is as follows. If a location has lower costs and higher prices for one of the disaggregated goods, agricultural land plots with lower realizations for agricultural productivity are allocated to that good. With a Fréchet distribution for agricultural productivity, this composition effect exactly offsets the lower costs and higher prices, such that the expected wage-rental ratio conditional on agricultural land being used for a good is the same across the two disaggregated goods.[33]

5.5 Production Across Sectors

The allocation of land plots across agriculture, manufacturing, and services is determined in a similar way. Each land plot φ is allocated to the sector that offers the highest rental rate ($r_{ki}(\varphi)$), or lowest wage-rental ratio ($\omega_{ki}(\varphi)$), given the realizations for sectoral productivity ($z_{ki}(\varphi)$). From the first-order conditions for cost minimization and zero profits, the equilibrium wage-rental ratio in each sector is given by:

$$\omega_{ki}(\varphi) \equiv \frac{w_i}{r_{ki}(\varphi)} = \frac{1}{z_{ki}(\varphi)\mathcal{P}_{ki}}, \tag{12}$$

where $\mathcal{P}_{ki}$ corresponds to prices adjusted for wages and factor intensities:

$$\begin{aligned} &\mathcal{P}_{ki} \equiv \left(\frac{P_{ki}}{w_i}\right)^{\frac{1}{\alpha_k}}, \qquad k \in \{M, S\}, \\ &\mathcal{P}_{Ai} \equiv \gamma_\epsilon \left[\sum_{g\in\{G,F\}} E_{gi} \left(\frac{P_{gi}}{w_i}\right)^{\frac{\epsilon}{\alpha_g}}\right]^{\frac{1}{\epsilon}}, \qquad \gamma_\epsilon \equiv \Gamma\left(\frac{\epsilon-1}{\epsilon}\right). \end{aligned} \tag{13}$$

Since the sectoral land use decision is made before the realizations for agricultural productivity (a_{gi}) are observed, the relevant wage-rental ratio for the agricultural sector is the expected wage-rental ratio (11), as reflected in the definition of $\mathcal{P}_{Ai}$ in equation (13).

Using the Fréchet distribution for sector productivity (z_{ki}) and equation (12) to solve for the distribution of the equilibrium wage-rental ratio, the probability that a land plot is allocated to sector k in location i (ℓ_{ki}), and the share of land used for sector k in location i, is:

$$\ell_{ki} = \frac{L_{ki}}{L_i} = \frac{T_{ki}\mathcal{P}_{ki}^{\theta}}{\sum_{s\in\{A,M,S\}} T_{si}\mathcal{P}_{si}^{\theta}}. \tag{14}$$

Therefore, the share of land allocated to a given sector (ℓ_{ki}) is increasing in average productivity (T_{ki}) and adjusted prices ($\mathcal{P}_{ki}$) for that sector and decreasing in those variables for the other sectors. The sector productivity dispersion parameter θ regulates the sensitivity of land shares to adjusted prices relative to idiosyncratic sectoral productivity.

With a Fréchet distribution for sector productivity, the expected wage-rental ratio is the same across sectors, as determined by productivity (T_{ki}) and adjusted prices ($\mathcal{P}_{ki}$):

$$\mathbb{E}_z\left[\frac{1}{\omega_i}\right] = \gamma_\theta \left[\sum_{k\in\{A,M,S\}} T_{ki}\mathcal{P}_{ki}^{\theta}\right]^{\frac{1}{\theta}}, \tag{15}$$

[33]This property is analogous to the result in Eaton and Kortum (2002) that average prices conditional on sourcing a good from a country are the same across all source countries.

where $\gamma_\theta \equiv \Gamma\left(\frac{\theta-1}{\theta}\right)$, $\Gamma(\cdot)$ is the Gamma function; and $E_z[\cdot]$ is the expectation over the distribution for sectoral productivity (z).

The intuition is similar as for the equalization of the wage-rental ratio across disaggregated goods within the agricultural sector. If a location has higher adjusted prices for a sector, it allocates land plots with lower realizations for sector productivity to that sector. With a Fréchet distribution for sector productivity, this composition effect exactly offsets the higher adjusted prices, such that the expected wage-rental ratio conditional on land being allocated to a sector is the same across all sectors.

We can solve for all other aggregate variables using this common expected wage-rental ratio, including the expected rental rate:

$$r_i = w_i \mathbb{E}_z\left[\frac{1}{\omega_i}\right]. \tag{16}$$

Using cost minimization, zero profits, and our assumption of a Cobb-Douglas production technology, employment per unit of land used for manufacturing and services is:

$$n_k = \frac{1-\alpha_k}{\alpha_k}\mathbb{E}_z\left[\frac{1}{\omega_i}\right], \qquad k \in \{M, S\}, \tag{17}$$

while employment per unit of agricultural land is a weighted average of the factor intensities in arable and pastoral farming, with the weights given by the shares of agricultural land allocated to each of these two disaggregated goods:

$$n_A = \sum_{g\in\{G,F\}} \frac{L_g}{L_A}\frac{N_g}{L_g} = \sum_{g\in\{G,F\}} \ell_g^A n_g = \sum_{g\in\{G,F\}} \ell_g^A \frac{1-\alpha_g}{\alpha_g}\mathbb{E}_z\left[\frac{1}{\omega_i}\right]. \tag{18}$$

5.6 Population Mobility

Each worker chooses their preferred location given their idiosyncratic preference draws. Using the Fréchet distribution of idiosyncratic preferences, the probability of choosing to live in location i depends on relative amenities (B_i), wages (w_i), and consumption price indexes (P_{Ci}):

$$\lambda_i = \frac{(B_i w_i / P_{Ci})^\chi}{\sum_{m\in\mathcal{J}} (B_m w_m / P_{Cm})^\chi}. \tag{19}$$

With workers having idiosyncratic preferences, each location faces an upward-sloping supply function for workers, such that it must offer a higher amenity-adjusted real wage to attract additional workers with lower realizations for idiosyncratic preferences for that location.

The expected utility of workers depends on amenity-adjusted real income in each location i:

$$\mathbb{E}[u] = \gamma_\chi\left[\sum_{m\in\mathcal{J}} (B_m w_m / P_{Cm})^\chi\right]^{\frac{1}{\chi}}, \qquad \gamma_\chi \equiv \Gamma\left(\frac{\chi-1}{\chi}\right), \tag{20}$$

where recall that $\Gamma(\cdot)$ is the Gamma function.

Therefore, although amenity-adjusted real wages ($B_i w_i / P_{Ci}$) differ across locations, expected utility conditional on choosing a location is equalized. The intuition is again a composition effect. If a location has a higher amenity-adjusted real wage, it attracts workers with lower realizations for idiosyncratic preferences. With a Fréchet distribution for idiosyncratic preferences, this composition effect exactly offsets the higher amenity-adjusted real wages, such that expected utility conditional on choosing a location is the same across all locations.

5.7 Market Clearing

Total expenditure in each location i (X_i) equals the sum of the income of workers ($w_i N_i$) and the income of landlords ($r_i L_i$):

$$X_i = w_i N_i + r_i L_i, \tag{21}$$

where N_i is the measure of workers that choose to live in location i; L_i is land area; and we abstract from trade imbalances.[34]

Market clearing for non-traded services requires that local revenue equals local expenditure in that sector in each location:

$$P_{Si} Q_{Si} = x_{Si} X_i. \tag{22}$$

Labor market clearing within each location requires that total employment equals the sum of employment across the disaggregated agricultural goods, manufacturing, and services:

$$N_i = \sum_{k \in \{G,F,M,S\}} N_{ki}. \tag{23}$$

Labor market clearing across locations requires that total employment in each location (N_i) equals the measure of workers choosing to live in that location:

$$N_i = \lambda_i \overline{N}. \tag{24}$$

Land market clearing implies that the income of landlords is equal to total payments for land use. Using our assumption of Cobb-Douglas production technologies, this land market clearing condition can be written as follows:

$$r_i L_i = \sum_{k \in \{G,F,M,S\}} \frac{\alpha_k}{1-\alpha_k} w_i N_{ki}, \tag{25}$$

where the terms on the right-hand side capture payments for land used for the disaggregated agricultural goods, manufacturing, and services.

[34] We undertake our counterfactuals starting from 1846, when the U.K. had a small trade surplus of 0.17 percent of GDP. In the second half of the 19th century, the U.K.'s trade balance exhibits no clear pattern, and fluctuates between surpluses and deficits, consistent with it being determined by other intertemporal considerations.

5.8 General Equilibrium

The equilibrium spatial distribution of economic activity is determined by (i) model parameters (β_G, β_F, β_A, β_M, β_S, α_G, α_F, α_M, α_S, σ, ϵ, θ, χ); (ii) world prices and transport costs for the traded goods (P^*_G, P^*_F, P^*_M, τ_{Gi}, τ_{Fi}, τ_{Mi}); (iii) productivities (E_{Gi}, E_{Fi}, T_{Ai}, T_{Mi}, T_{Si}); (iv) amenities (B_i); (v) land supplies (L_i); (vi) labor supply ($\overline{N}$).

Given these exogenous primitives, the general equilibrium of the model can be referenced by the following endogenous variables: (i) the local prices of traded goods $\{P_{Gi}, P_{Fi}, P_{Mi}\}$, (ii) the local prices of non-traded services (P_{Si}), (iii) the shares of arable and pastoral farming in agricultural land area (ℓ^A_{Gi}, ℓ^A_{Fi}); (iv) the shares of agriculture, manufacturing, and services in total land area (ℓ_{Ai}, ℓ_{Mi}, ℓ_{Si}); (v) the expected wage-rental ratio (ω_i); (vi) the wage (w_i); (vii) total employment shares (λ_i). Given these equilibrium objects, all other endogenous variables of the model can be determined.

We use the model to evaluate the distributional implications of an international trade shock that is concentrated in a particular sector (arable farming). We model the Grain Invasion as a fall in the world price of arable products (P^*_G) relative to the world prices of pastoral products (P^*_F) and manufacturing goods (P^*_M), which affects the spatial distribution of economic activity in the model through a number of different channels.

First, there is a reallocation within agriculture. The direct effect of the fall in the world arable price (P^*_G) is to reduce the share of agricultural land used for arable farming (ℓ^A_{Gi}) and raise the share of agricultural land used for pastoral farming (ℓ^A_{Fi}) from equation (10).

Second, there is a reallocation between agriculture and non-agriculture. The direct effect of the fall in the world arable price (P^*_G) is to reduce the adjusted agricultural price ($\mathcal{P}_{Ai}$) from equation (13), which implies a decline in the share of land used for agriculture (ℓ_{Ai}) and an increase in the share of land used non-agriculturally (ℓ_{Mi}, ℓ_{Si}) from equation (14).

Third, the reallocation of land away from agriculture, and away from arable farming within the agricultural sector, both imply a decline in agricultural employment. Therefore, the decline in the world arable price leads to structural transformation away from agriculture.

Fourth, locations with higher wheat suitability and larger initial arable land shares are more exposed to this international trade shock, and hence experience larger declines in agricultural employment. This larger reduction in labor demand in areas with higher wheat suitability leads to a decline in wages relative to other locations, which leads to a population reallocation towards other locations. Therefore, the model rationalizes empirical findings of rural depopulation in areas with high wheat suitability and high initial arable land shares.

Fifth, since agriculture is land-intensive, the contraction of the agricultural sector changes relative factor prices. This force operates in the conventional Heckscher-Ohlin model, with land and labor as the two factors of production, and agricultural and non-agriculture as the two sectors. In that conventional framework, a fall in the price of the agricultural good leads to a more than proportionate decline in the price of land and a rise in the wage. This magnified change in factor prices implies that landlords experience a reduction in real income in terms of both goods, whereas workers enjoy higher real income in terms of both goods.

Although this conventional force operates in our framework, the income distributional consequences of this trade shock are considerably more subtle. Our framework distinguishes arable and pastoral farming within the agricultural sector. Therefore, arable farming is only part of the agricultural sector, and is the relatively labor-intensive part, which dampens the impact of the fall in the price of arable products on the price of land.

More fundamentally, in the Heckscher-Ohlin model, the income distributional consequences of trade operate at the aggregate country level. In contrast, we consider a setting with many locations within each country that differ in initial patterns of specialization and are linked through labor mobility. Therefore, in our framework, geography is an important dimension along which the income distributional consequences of trade occur. Locations with higher wheat suitability and larger initial arable land shares experience larger contractions in agriculture, and hence larger reductions in the demand for labor. As labor reallocates away from these areas, this dampens the decline in the wage, but magnifies the decline in the price of land.

Therefore, our framework rationalizes our earlier empirical findings for the Grain Invasion. A decline in the price of arable products on world markets leads to (i) structural transformation away from agriculture; (ii) reallocation within agriculture from arable to pastoral farming; and (iii) rural depopulation that is concentrated in areas with high initial arable land shares. Our framework also highlights the income distributional consequences of the Grain Invasion, both at the aggregate level between land and labor, and at the disaggregate level across locations with high versus low wheat suitability.

6 Quantitative Analysis

We next undertake a quantitative analysis of the model to evaluate the magnitude of these income distributional consequences.[35] Subsection 6.1 calibrates the model's parameters. Subsection 6.2 uses the observed data and the structure of the model to recover unobserved endogenous variables that are inputs into our counterfactuals. We show that our model rationalizes the observed data as an equilibrium outcome, by allowing for unobserved time-varying amenities and sectoral productivities, which control for other determinants of economic activity. Section 6.3 undertakes our counterfactuals for the Grain Invasion (a fall in the exogenous world market price of arable products), holding constant other exogenous determinants of economic activity.

[35] Online Appendix D provides further details on our quantitative analysis of the model.

6.1 Parameterization

We calibrate the model's parameters using historical data for our sample period and estimates from the related empirical literature.[36] We set the elasticity of substitution across sectors equal to $\sigma = 0.5$, which is a central value in the existing macroeconomic literature on structural transformation, and is close to the value of $\sigma = 0.49$ estimated for late-19th-century Argentina in Fajgelbaum and Redding (2022).[37] Our quantitative analysis does not require us to specify values for the CES weights for each sector (β_A, β_M, β_S). Instead, we use the observed data and the structure of our model to solve for implied expenditure shares for each sector and location in the initial equilibrium in the data, which capture these unobserved weights. We calibrate the consumer expenditure share parameters within the agricultural sector using the historical consumer expenditure survey data for Britain at the turn of the 20th century in Allen and Bowley (1935). We set the expenditure share on arable products as $\beta_G = 0.5$ and the corresponding expenditure share on pastoral products as $\beta_F = 1 - \beta_G = 0.5$.

We calibrate the production cost parameters for arable and pastoral farming using national accounts data from Feinstein (1972), together with data on employment and farm size from the population census data for 1851. From the national accounts data, the share of land in production costs for the agricultural sector as a whole was 0.31 in 1855. From the population census for 1851, the ratio of agricultural employment to farm size was around 1.5 times larger in high-wheat-suitability areas than in low-wheat-suitability areas. Therefore, we calibrate the land cost share parameters for arable and pastoral farming (α_G, α_F) such that the model matches these two empirical moments, given the observed aggregate shares of arable and pastoral farming in agricultural land area (ℓ^A_{Git}, ℓ^A_{Fit}). We thus obtain $\alpha_G = 0.25$ and $\alpha_F = 0.34$.

We assume a common share of land in production costs in manufacturing and services ($\alpha_M = \alpha_S = \alpha_N$), such that we focus on differences in land intensity between agriculture and non-agriculture. We calibrate this common value for α_N such that the model's predictions are consistent with the following three empirical moments: (i) our calibrated share of land in production costs for the agricultural sector as a whole of 0.31 in 1855 from Feinstein (1972); (ii) an aggregate share of land in national income of 0.15 in 1855 from Feinstein (1972); (iii) a share of manufacturing and services (including housing) in national income of 0.77 in 1851 from Deane and Cole (1967). Together these three empirical moments imply a common share of land in production costs in manufacturing and services of $\alpha_N = 0.10$.

We calibrate the three productivity dispersion parameters (ϵ, θ, χ) using central values from

[36] See Online Appendix D1 for further discussion of the calibration of model parameters.

[37] Using our assumption of CES preferences and data for a number of different countries and time periods, Bah (2007), Rogerson (2008), Duarte and Restuccia (2010), and Üngör (2017) obtain values for this elasticity of substitution of 0.44, 0.45, 0.40, and 0.47, respectively.

the related empirical literature. We set the agricultural productivity dispersion parameter that controls land use decisions within the agricultural sector equal to $\epsilon = 1.658$ based on the estimates using agricultural land use data in Sotelo (2020). We set the sectoral productivity parameter that controls the allocation of land between sectors equal to $\theta = 1.2$, which ensures greater substitutability of land between alternative uses within the agricultural sector than across sectors. Finally, we set the preference dispersion parameter that determines the migration elasticity across locations equal to $\chi = 2$, which lies in center of the range of estimates of this parameter in Bryan and Morten (2019) and Galle et al. (2023).

6.2 Model Inversion

We next use the observed data and the structure of our model to recover unobserved endogenous variables, such as rental rates and wages for each parish, which are inputs into our counterfactuals below. Given the model parameters and the observed data, we use the equilibrium conditions of the model to solve for the implied values of these unobserved endogenous variables that are consistent with the data being an equilibrium of the model. Throughout the remainder of this subsection, we make explicit the dependence on time.

Proposition 1. ***(Unobserved Endogenous Variables)*** *Given the demand parameters (σ, β_G, β_F), production cost parameters (α_k), productivity and preference dispersion parameters (ϵ, θ, χ) and data by location i and year t on employment by sector (N_{Ait}, N_{Mit}, N_{Sit}), agricultural land shares for arable and pastoral farming (ℓ^A_{Git}, ℓ^A_{Fit}), total land area (L_i), and rateable values ($\mathbb{V}_{it} = r_{it}L_i$), there exist unique values for unobserved rental rates (r_{it}), wages (w_{it}), sectoral land shares (ℓ_{Ait}, ℓ_{Mit}, ℓ_{Sit}), employment in arable and pastoral farming (N_{Git}, N_{Fit}), and sectoral expenditure shares (x_{Ait}, x_{Mit}, x_{Sit}) that are consistent with the observed data being an equilibrium of the model.*

Proof. See Online Appendix D2.1. □

Intuitively, we use the cost minimization, zero profits and land market clearing conditions to solve for the unobserved endogenous variables. We interpret rateable values as the rental rate times the quantity of land ($\mathbb{V}_{it} = r_{it}L_i$), which allows us to recover the unobserved rental rate for each location (r_{it}) from observed rateable values ($\mathbb{V}_{it}$) and land area (L_i). Noting that cost minimization, zero profits and Cobb-Douglas production technologies together imply that land payments are a multiple of labor payments, we next recover the unobserved wage for each location (w_{it}) from observed rateable values ($\mathbb{V}_{it}$) and employment by sector (N_{kit}).

Using this proportional relationship between land and labor payments in each sector, we next recover the unobserved shares of land area used for each sector in each location (ℓ_{kit}) from observed employment by sector (N_{kit}), together with our solutions for rental rates (r_{it}) and wages

(w_{it}). Using this proportional relationship between land and labor payments for each disaggregated agricultural good, we next recover employment in arable and pastoral farming in each location (N_{Git}, N_{Fit}) from the observed agricultural land shares (ℓ^A_{Git}, ℓ^A_{Fit}), together with our solutions for rental rates (r_{it}), wages (w_{it}) and land shares (ℓ_{kit}). Finally, using expenditure minimization, market clearing for non-traded services, and the equality between income and expenditure, we recover the implied expenditure shares by sector for each location (x_{kit}).

We next show that our model incorporates a wide range of determinants of the evolution of the spatial distribution of economic activity over time. We allow for unobserved changes over time in sectoral productivity for each location, agricultural productivity for each disaggregated good and location, and amenities for each location, such that the model exactly matches the observed changes over time in rateable values, employment by sector and agricultural land shares for arable and pastoral farming in the data. Given the observed values of these variables, we use the equilibrium conditions of the model to solve for unique values of amenity and productivity-adjusted prices for which the observed data are an equilibrium of the model.

Proposition 2. ***(Model Inversion)*** *Given the demand parameters (σ, β_G, β_F), production cost parameters (α_k), productivity and preference dispersion parameters (ϵ, θ, χ) and data by location i and year t on employment by sector (N_{Ait}, N_{Mit}, N_{Sit}), agricultural land shares for arable and pastoral farming (ℓ^A_{Git}, ℓ^A_{Fit}), total land area (L_i), and rateable values ($\mathbb{V}_{it} = r_{it}L_i$), there exist unique values of productivity-adjusted prices for each disaggregated agricultural good ($\mathbb{E}_{git}$), productivity-adjusted prices for each sector ($\mathbb{T}_{kit}$), and amenity-adjusted aggregate prices ($\mathbb{B}_{it}$) (up to scale) that are consistent with the data being an equilibrium of the model.*

Proof. See Online Appendix D2.2. □

Intuitively, the observed shares of agricultural land used for arable and pastoral farming (ℓ^A_{git}) in equation (10) reveal relative productivity-adjusted prices for each disaggregated agricultural good ($\mathbb{E}_{git} \equiv E_{git}P^{\epsilon/\alpha_F}_{git}$) given wages ($w_{it}$). Similarly, the shares of overall land area used for each sector (ℓ_{kit}) in equation (14) embody relative productivity-adjusted prices for each sector ($\mathbb{T}_{kit} = T_{kit}P^{\theta/\alpha_k}_{kit}$) given wages ($w_{it}$). Finally, the observed total employment shares (λ_{it}) in equation (19) contain information on relative amenity-adjusted aggregate prices ($\mathbb{B}_{it} \equiv (B_{it}/P_{Cit})^{\chi}$) given wages ($w_{it}$).

Proposition 2 makes clear that our model encompasses many other determinants of the evolution of economic activity over time, besides movements in world relative prices for traded goods. We allow for differential productivity growth by sector and location that can generate uneven industrialization and urbanization across locations. We capture improvements in the domestic transport network that affect trade costs, and hence generate variation in local relative prices for given values of world relative prices. We incorporate differential changes in amenities across locations, which allows for variation in the sanitation and disease environment across locations and over time.

6.3 Counterfactuals

We next use our model to undertake counterfactuals for the Grain Invasion (a fall in the exogenous world price of arable products), holding constant other exogenous determinants of economic activity. We undertake our counterfactuals starting from an initial equilibrium in 1841, before the Repeal of the Corn Laws.

We denote the value of variable in the counterfactual equilibrium by a prime (e.g., x_j'), the value of a variable in the observed equilibrium in the data without a prime (e.g., x_j), and the relative changes in variables between the counterfactual and observed equilibria by a hat (e.g., $\widehat{x}_j \equiv x_j'/x_j$). We show that we can re-write the counterfactual equilibrium conditions in the model in terms of the observed endogenous variables in the initial equilibrium and the counterfactual relative changes in the endogenous variables. Therefore, we can solve for a counterfactual equilibrium without requiring information on the initial level of unobserved location characteristics, such as productivity, amenities and trade costs. Instead, we use the values of the endogenous variables in the initial equilibrium, as observed in the data or recovered from Proposition 1, to control for these unobserved location characteristics.

Proposition 3. ***(Exact-Hat Algebra)*** *Given the demand parameters (σ, β_G, β_F), production cost parameters (α_k), productivity and preference dispersion parameters (ϵ, θ, χ), and data by location i and year t on employment by sector (N_{Ait}, N_{Mit}, N_{Sit}), agricultural land shares for arable and pastoral farming (ℓ^A_{Git}, ℓ^A_{Fit}), total land area (L_i), rateable values ($\mathbb{V}_{it} = r_{it} L_i$), and counterfactual changes in world relative prices for traded goods ($\widehat{P}^*_{Gt}$, $\widehat{P}^*_{Ft}$, $\widehat{P}^*_{Mt}$), the solution for counterfactual changes in the model's endogenous variables does not require information on the level of the location characteristics (E_{git}, T_{kit}, τ_{kit}, B_{it}).*

Proof. See Online Appendix D3.1. □

We undertake our counterfactuals for the Grain Invasion using the observed change in the relative price of arable to pastoral products from the agricultural prices data in Clark (2004). We report three sets of counterfactuals: (i) the change in mean relative arable prices between 1815-1846 and 1871-1901 ($\widehat{P}^*_{Gt} = 0.81$); (ii) the change in mean relative arable prices between 1815-1846 and 1846-1871 ($\widehat{P}^*_{Gt} = 0.92$); and (iii) the change in mean relative arable prices between 1846-1871 and 1871-1901 ($\widehat{P}^*_{Gt} = 0.88$).[38] We use these two sub-periods to examine the initial impact of the Repeal of the Corn Laws before the full integration of New World producers into global markets in the last three decades of the 19th century. We assume a counterfactual change in the world price of arable products ($\widehat{P}^*_{Gt}$), holding constant the exogenous world prices of the other two traded goods of pastoral products ($\widehat{P}^*_{Ft} = 1$) and manufacturing goods ($\widehat{P}^*_{Mt} = 1$), and solving for the counterfactual changes in the endogenous price of non-traded services ($\widehat{P}_{Sit}$).

There are three main differences between our earlier reduced-form regressions and these counterfactuals. First, in our earlier reduced-form regressions, we included controls for other determinants of economic activity, whereas these counterfactuals by construction isolate the impact of the Grain Invasion, holding constant other exogenous determinants of economic activity. Second, our earlier reduced-form regressions estimate relative effects of the Grain Invasion between high-wheat-suitability and low-wheat-suitability locations, where the aggregate effect is captured in the time dummies. In contrast, these counterfactuals capture both relative effects and aggregate general equilibrium effects. Third, while our reduced-form regressions focused on observable variables such as employment and property values, our counterfactuals yield predictions for model-based objects such as real income.

Parishes are unevenly affected by the counterfactual change in the world price of arable products ($\widehat{P}^*_{Gt}$), because they differ in the share of agricultural land used for arable farming (ℓ^A_{Git}) and the share of land used agriculturally (ℓ_{Ait}). From equations (13) and (14), the effect of this world price change ($\widehat{P}^*_{Gt}$) on specialization within agriculture (ℓ^A_{Git}) and the adjusted agricultural price ($\widehat{\mathcal{P}}_{Ait}$) depends on the initial arable share of agricultural land (ℓ^A_{Git}):

$$\widehat{\ell}^A_{Git}\ell^A_{Git} = \frac{\ell^A_{Git}\left(\widehat{P}^*_{Gt}\right)^{\epsilon/\alpha_G}\left(\widehat{w}_{it}\right)^{-\epsilon/\alpha_G}}{\ell^A_{Git}\left(\widehat{P}^*_{Gt}\right)^{\epsilon/\alpha_G}\left(\widehat{w}_{it}\right)^{-\epsilon/\alpha_G} + \ell^A_{Fit}\left(\widehat{w}_{it}\right)^{-\epsilon/\alpha_F}}, \tag{26}$$

$$\widehat{\mathcal{P}}_{Ait} = \left[\ell^A_{Git}\left(\widehat{P}^*_{Gt}\right)^{\epsilon/\alpha_G}\left(\widehat{w}_{it}\right)^{-\epsilon/\alpha_G} + \left(1-\ell^A_{Git}\right)\left(\widehat{w}_{it}\right)^{-\epsilon/\alpha_F}\right]^{\frac{1}{\epsilon}}, \tag{27}$$

where we have used $\widehat{P}^*_{Ft} = 1$ and the direct effects of this world price change ($\widehat{P}^*_{Gt}$) are moderated by general equilibrium effects through endogenous changes in wages ($\widehat{w}_{it}$).

From equation (14), the effect of this change in the adjusted agricultural price ($\widehat{\mathcal{P}}_{Ait}$) on the allocation of land across sectors (ℓ_{Ait}) depends on the initial agricultural land share (ℓ_{Ait}):

$$\widehat{\ell}_{Ait}\ell_{Ait} = \frac{\ell_{Ait}\widehat{\mathcal{P}}^{\theta}_{Ait}}{\sum_{k\in\{A,M,S\}}\ell_{kit}\widehat{\mathcal{P}}^{\theta}_{kit}}, \tag{28}$$

[38] The arable price index includes eleven crops (and is dominated by cereals), while the pastoral price index encompasses eleven pastoral products, as discussed further in Online Appendix F2.1.

where we report the full system of general equilibrium conditions for a counterfactual equilibrium in Online Appendix D3.1. Both the initial shares of arable land in agricultural land (ℓ_{Git}^{A}) and agricultural land in total land (ℓ_{Ait}) are strongly positively related across parishes to our exogenous measure of wheat suitability.[39]

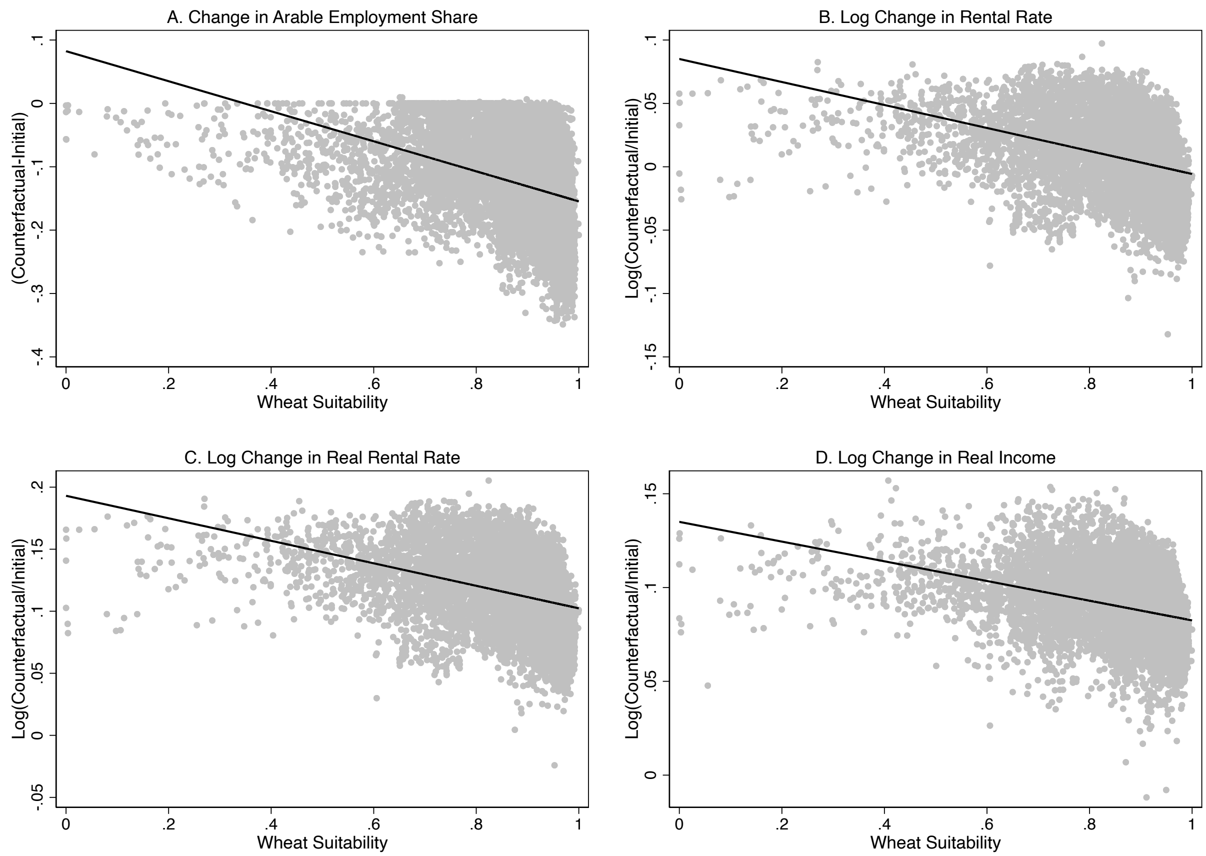
In Figure 8, we display the results of our counterfactuals for the Grain Invasion for the full period 1846-1901. The gray circles display values for each parish and the black lines correspond to the linear regression relationships. In Panel A, we show the change in the employment share of arable farming ($(N'_{Git}/N'_{it} - N_{Git}/N_{it})$) against our measure of wheat suitability. Consistent with our earlier reduced-form findings in Section 4 above, we find that the Grain Invasion leads to substantial structural transformation and that these effects are heterogeneous across locations. The decline in the arable employment share ranges from close to zero in low-wheat-suitability locations to up to 30 percentage points in high-wheat-suitability locations.[40] The linear regression relationship is not a perfect fit for several reasons. First, wheat suitability is not a perfect predictor of initial specialization in arable farming, because for example of the impact of endowments of other natural resources on initial specialization patterns. Second, initial specialization in arable farming is not a perfect predictor of the change in the arable employment share, because of general equilibrium effects through endogenous changes in wages and rental rates.

In Panel B, we show the log change in the rental rate ($\log(\widehat{r}_{it})$) against wheat suitability. We find that the Grain Invasion has marked income distributional consequences across locations, with the change in the rental rate ranging from reductions of 10 percent in locations with high wheat suitability to rises of 10 percent in locations with low wheat suitability. These results contrast with the predictions of the conventional Heckscher-Ohlin model with two goods, two factors and labor immobility, in which a decline in the price of the land-intensive agricultural good necessarily reduces the rental rate. Our framework generates much richer income distributional predictions for two main reasons. First, the decline in the price of arable products leads to a reallocation within agriculture from arable to pastoral farming. Since arable farming is land intensive relative to manufacturing and services, but labor intensive relative to pastoral farming, this reallocation towards pastoral farming mitigates the reduction in the demand for land from the contraction of the agricultural sector as a whole. Second, our framework incorporates labor mobility, such that the labor released from the contraction of the agricultural sector in a given location need not be absorbed by the expansion of the non-agricultural sector in that location, but can be accommodated through population mobility. The resulting reallocation of population

[39] We find regression slope coefficients (standard errors) on wheat suitability of 0.473 (0.038) and 0.089 (0.026) using the arable share of agricultural share (ℓ_{Git}^{A}) and agricultural land share (ℓ_{Ait}) in 1841, respectively.

[40] We find smaller declines in the share of agriculture in total employment, because of reallocation within the agricultural sector from arable to pastoral farming. Nevertheless, we find declines in the share of agriculture in employment of up to 15 percentage points in locations with high wheat suitability.

Figure 8: Distributional Consequences of the Grain Invasion Across Locations (1846-1901)



Note: Counterfactual for the observed decline in the relative price of arable products from 1846-1901 ($\widehat{P}^*_{Gt} = 0.81$); gray circles correspond to parishes in our data; black lines show the linear regression relationship; vertical axes show either the difference or the log difference between the counterfactual value of a variable and its value in the initial equilibrium; horizontal axis shows our exogenous measure of wheat suitability (normalized to lie between 0 and 1).

away from high-wheat-suitability locations magnifies the decline in the price of land in those locations and increases the price of land in low-wheat-suitability locations.

In Panel C, we show the log change in the real rental rate ($\log\left(\widehat{r_{it}/P_{Cit}}\right)$) against wheat suitability. This real rental rate incorporates changes in the consumption price index, both from the reduction in the world market price of arable products, and from endogenous changes in the price of non-traded services. Notably, after taking into account these changes in the cost of living, we find increases in real rental rates for most locations. Again these results contrast with those of the conventional Heckscher-Ohlin model with two goods, two factors and labor immobility, in which a decline in the price of the land-intensive agricultural good necessarily reduces the real rental rate. Again our framework generates different predictions because of both reallocation within the agricultural sector and the redistribution of population away from locations with high-wheat suitability towards those with low-wheat suitability. Additionally, our framework incorporates non-traded services, such that the negative impact on real income of a lower rental rate in high-wheat-suitability locations is dampened by a fall in the price of the non-traded services produced using local factors of production.

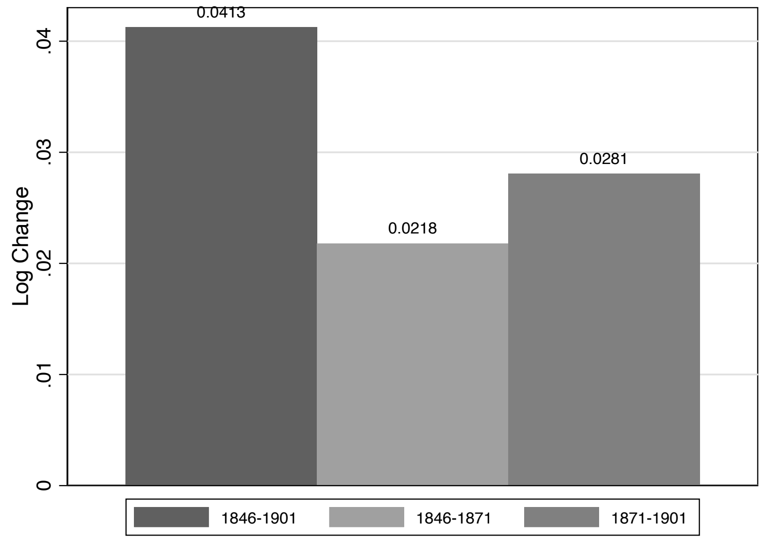
Finally, in Panel D, we show the log change in real income ($\log\left(\left(w_{it}\widehat{N_{it} + r}_{it}L_i\right)/\widehat{P_{Cit}}\right)$) against wheat suitability. This change in real income takes into account changes in the prices of both factors of production (wages and rental rates) and the distribution of population across locations. Again we find substantial distributional consequences, with the change in real income ranging from rises of 15 percent to declines of 5 percent. While the reallocation of population magnifies the changes in real income in response to the Grain Invasion, the fact that land is in perfectly inelastic supply dampens these changes. These findings highlight that international trade shocks (here the Grain Invasion) can have substantial negative impacts on local economic activity (measured here by real income). These declines in real income in the high-wheat suitability locations that are most exposed to the negative shock of the Grain Invasion are offset in general equilibrium by increases in real income in other locations.

In Figure 9, we examine the aggregate effects of the Grain Invasion on worker expected utility. We report the log change in worker expected utility (20) for both the full period and the two sub-periods.[41] From 1846-1901, we find an increase in worker expected utility of 4.13 percent, which includes the impact of both trade liberalization (the Repeal of the Corn Laws) and changes in the terms of trade (the fall in the world price of arable products from the increased integration of the New World into global markets). Although this increase in expected utility is substantial relative to conventional estimates of the aggregate welfare gains from trade for a relatively closed country such as the United States, it is more modest compared to estimates for smaller and more open countries, such as England and Wales. Additionally, while these conventional estimates are computed at the country level, our estimates of these aggregate welfare gains incorporate reallocation across locations within England and Wales.

Comparing the two sub-periods, we find increases in expected worker utility of comparable magnitude of around 2 percent. This pattern of results suggests that both the initial Repeal of the Corn Laws and the subsequent deepening integration of the New World into global markets contributed towards the impact of the Grain Invasion. These findings are in line with the historical narrative, which emphasizes the closing three decades of the 19th century as the period of the great agricultural depression, when the full effects of the New World Grain Invasion were felt. Nevertheless, these aggregate welfare gains for workers in Figure 9 remain small relative to the distributional consequences across locations in Figure 8 above.

[41] The change in worker expected utility for the full period is not exactly the product of the changes for the two sub-periods, because the general equilibrium of the model is non-linear in the change in world arable prices.

Figure 9: Impact of the Grain Invasion on Worker Expected Utility



Note: Counterfactuals for the observed decline in the relative price of arable products from 1846-1901, 1846-1871, and 1871-1901; each bar shows the log change in worker expected utility (20) for the relevant counterfactual.

7 Conclusion

The aggregate and income distributional effects of trade remain one of the most central issues in international economics and lie center stage in current policy debates. We provide new theory and evidence on these issues using exogenous variation from a historical natural experiment. We combine the New World Grain Invasion in the second half of the 19th century together with variation in agroclimatic suitability for wheat across locations within England and Wales. We examine the role of this agricultural trade shock in inducing structural transformation away from agriculture and a redistribution of population from rural to urban areas. We consider an empirical setting with a minimal welfare state and a laissez-faire economy, in which we would expect the mechanisms in our model to apply, as in many developing countries today.

We use a newly-created, spatially-disaggregated dataset on population, employment by sector, property values (value of land and buildings), and poor law relief (welfare transfers) for over 10,000 parishes in England and Wales from 1801–1901. In the first half of the 19th century, we find no evidence of differences in trends between locations with different levels of wheat suitability. In the wake of the Grain Invasion in the second half of the 19th century, we find a relative decline in population and property values, and an increase in pauperism, in high-wheat-suitability locations relative to low-wheat-suitability locations. We show that this pattern holds after controlling for a range of other potential determinants of economic activity, including proximity to natural resources and urban population concentrations.

The timing of these estimated treatment effects aligns closely with the influx in imports of wheat and the emergence of New World suppliers such as the United States. We provide evidence against alternative possible explanations, such as the first or second industrial revolutions. We show that the timing of these alternative explanations is wrong and that much of the reallocation away from agriculture is towards services rather than manufacturing. We look at specialization within agriculture to control for shocks to the agricultural sector as a whole. We find a larger reallocation of land from arable to pastoral farming in high-wheat-suitability locations, consistent with our results capturing the impact of the Grain Invasion. Using individual-level population census data to track mobility over time, we find larger increases in outmigration and rural-urban migration in higher-wheat-suitability locations in response to the Grain Invasion.

We develop a quantitative spatial model to rationalize our empirical findings and evaluate the aggregate implications of this international trade shock. Our framework incorporates incomplete specialization and structural transformation across sectors. We use our model to undertake a counterfactual for a fall in the world price of arable products, holding constant other exogenous variables. Over the second half of the 19th century, we find an increase in expected worker utility of 4.13 percent, which includes the impact of both the initial Repeal of the Corn Laws and the subsequent deepening integration of the New World into global markets. This relatively modest aggregate welfare gain for workers is combined with much larger distributional consequences for landlords across locations, with changes in rental rates ranging from declines of 10 percent to increases of the same absolute magnitude.

Taken together, our findings highlight that trade can play an important role in inducing structural transformation and urbanization, with substantial effects on income distribution.

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