NATIONAL RESEARCH UNIVERSITY
HIGHER SCHOOL OF ECONOMICS

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BASIC RESEARCH PROGRAM
WORKING PAPERS

SERIES: ECONOMICS
WP BRP 220/EC/2019

Technology Adoption in Agrarian Societies: the Effect of Volga Germans in Imperial Russia*

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September 10, 2019

Abstract

This paper examines technology adoption in pre-industrial societies. We use the case of a technologically advanced and spatially concentrated German minority in Saratov province of the Russian Empire to study adoption patterns among Russian peasants in late 19^{th}–early 20^{th} century. We find that distance from German colonies predicts the prevalence of heavy ploughs, fanning mills and wheat sowing among Russians, who traditionally sowed rye and plowed with wooden ard (*sokha*). We show a significant rise in labor productivity in agriculture resulting from the adoption of heavy ploughs. However, we find no evidence for the adoption of non-codified knowledge like blacksmithing, carpentry, textile manufacture, tanning and other artisan skills. Hence, the adoption of advanced tools does not necessary induce the diffusion of skills required to produce those tools. This may well be the key to the problem of slow technological convergence.

Keywords: technology adoption, economic development, agriculture, Russian Empire

JEL codes: N33, N53, I15, O15

*The article was prepared within the framework of the Basic Research Program at the National Research University Higher School of Economics (HSE University), Center for Institutional Studies and supported within the framework of a subsidy by the Russian Academic Excellence Project "5-100".

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"The heart of the whole process of economic development is intellectual: it consists in the acquisition and application of a corpus of knowledge concerning techniques, that is, ways of doing things."

– Landes (1980), p. 111

"But if new techniques are regularly transferred from industrial countries [to less developed ones], how will the learning process in the design and the production of capital goods take place? Reliance on borrowed technology perpetuates a posture of dependency and passivity. It deprives a country of the development of precisely those skills which are needed to design and construct capital goods that are properly adapted to her own needs."

– Rosenberg (1970), p. 568

1 Introduction

The adoption of innovative equipment and advanced know-how from the technological frontier is a key ingredient in catch-up growth. Identifying potential barriers to technology adoption is of special importance for understanding productivity differences, both across and within nations.[1]

In this paper we exploit the historical case of Saratov province in the late Russian Empire to study in detail the adoption of advanced agricultural technologies. Until the late 18th century, the province was a sparsely populated frontier along the Volga river acquired as a result of the southward expansion of the Russian Empire. In 1764-1767, the region experienced a substantial inflow of migrants from the German lands devastated during the Seven Years' War. The migrants were attracted by the privileges that Russian government guaranteed to foreign settlers, such as exemption from taxes and military conscription, religious freedom, and administrative autonomy. Up to 3,000 families settled in the province and began to modernize the local economy by introducing numerous innovations in wheat production, flour milling, and small-scale manufacturing (Koch, 2010). Despite the fact that colonies were located on less productive agricultural lands, over time they became the local technological frontier with the highest population density in the whole Middle Volga region.[2] Germans possessed more iron ploughs, fanning mills[3], reapers and other agricultural equipment per household than their Russian neighbors. Consequently, labor productivity in agriculture, measured by wheat yield per household, was about 2.5 times higher in the German colonies. Highly-skilled artisans like blacksmiths, carpenters, textile workers, cobblers, and tanners were also much more numerous in German villages.

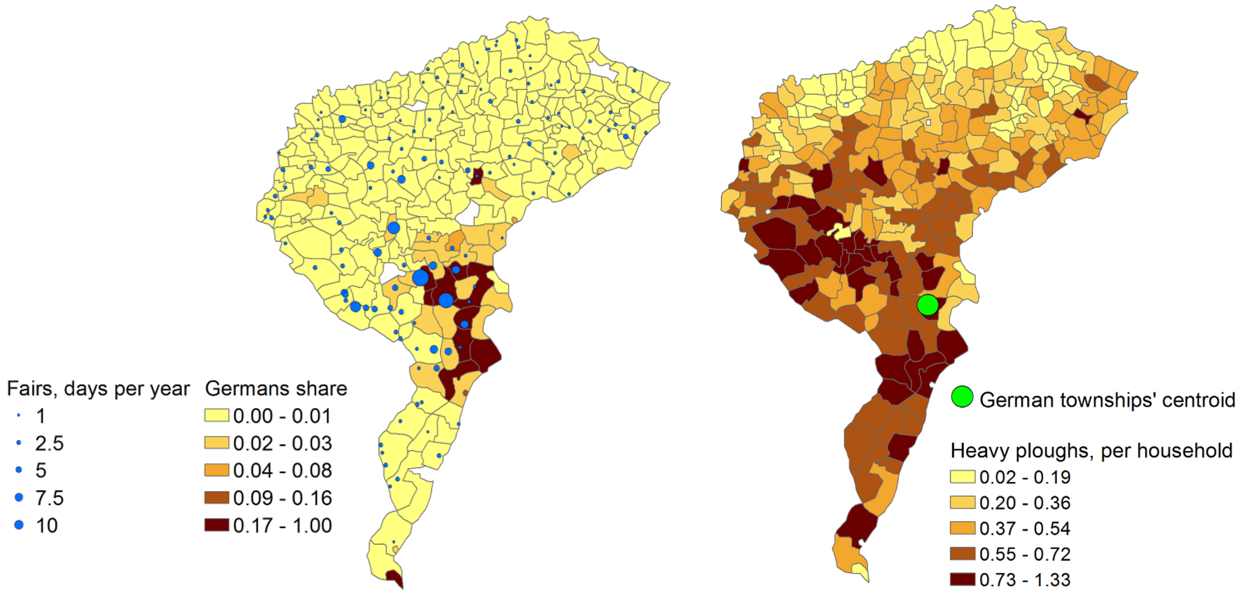
Using highly disaggregated data on 280 Russian townships (*volost'*) of Saratov province in the late 19th–early 20th centuries, we find strong empirical evidence for the adoption of advanced agricultural equipment. Russians living closer to the German colonies had a higher number of heavy ploughs and fanning mills per household, and cultivated wheat instead of rye more often than those living farther away. In a preferred specification,

[1] As Arrow (1969) put it in a seminal paper: "If one nation or class has the knowledge which enables it to achieve high productivity, why is not the other acquiring that information?" (p. 33).

[2] By 1897, the German population of Saratov province reached 166,000 people, which implies population growth rates of around 2.15%. Because the settlement policy was terminated soon after the arrival of the first colonists, the growth was due to natural causes exclusively (Kabuzan, 2003).

[3] A mechanical device for separating grains from the chaff and dirt.

each 50 km decrease in the distance from the German townships increased the number of heavy ploughs per hundred Russian households by 12.5, the number of fanning mills by 10, and the share of arable land sowed with wheat by 10 percentage points. Figure 1a demonstrates the location of German townships and Figure 1b the unconditional spatial pattern of heavy plough diffusion. We hypothesize that the main mechanism for the adoption of agricultural tools and wheat seeds were fairs, which were predominantly located on the boundaries of German and Russian townships (see Figure 1a).



(a) Share of German population and fairs

(b) Heavy ploughs per household

Figure 1: Location of German colonies, fairs and adoption of heavy ploughs

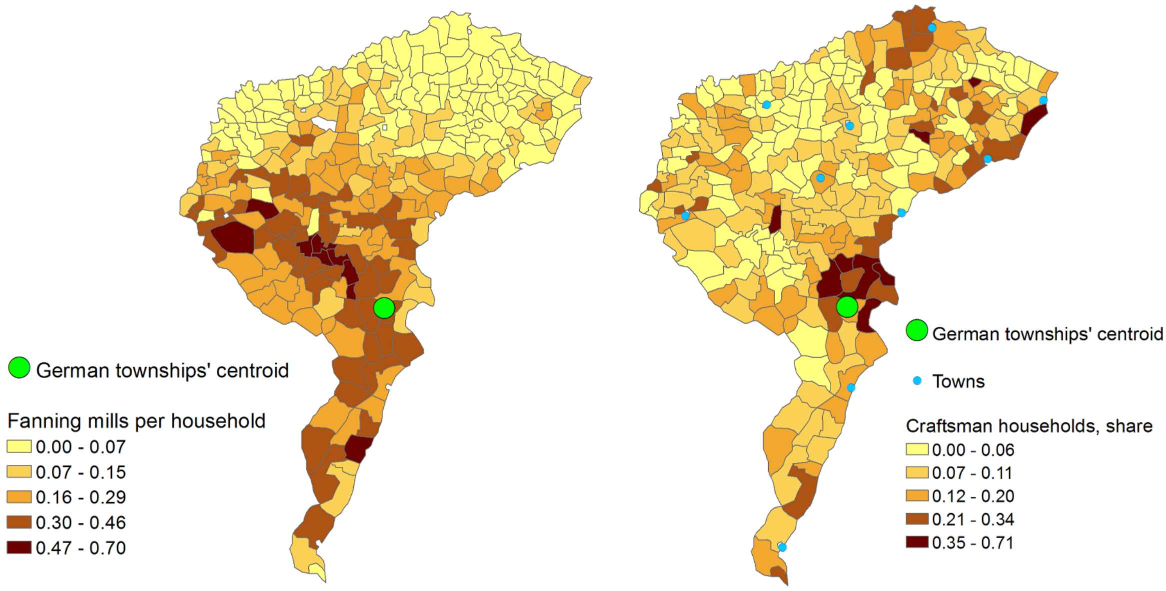
The left map shows the share of Germans in each *volost* of the Saratov province according to the 1897 census, and the location and duration of fairs. The right map shows the number of heavy ploughs per hundred households in a *volost*, and the centroid of German colonies, calculated according to the data on the left map.

In addition, we empirically document that the adoption of heavy ploughs resulted in the higher labor productivity of Russian peasants – an additional plough per hundred households resulted in extra 10.5 kilograms of wheat per household per annum. Alternatively, increasing the number of ploughs from the minimum value of 2 per hundred households to the maximum value of 89 added about 900 kg of wheat yield per household per annum.

However, we find no evidence for the diffusion of the skills required to produce and maintain advanced agricultural tools. In all specifications, the distance from the German colonies does not predict the share of Russian households engaged in craftsmanship (*promysly*), or the number of smithies, carpentry workshops, textile factories, shoe workshops, tanneries, carriage and wheel factories per thousand Russian households. The data clearly suggests that highly-skill occupations were predominantly concentrated among German villages even after 150 years after their arrival (see Figure 2b).

We interpret these findings as evidence for the "costly adoption" hypothesis, which states that the adoption of advanced tools does not imply the diffusion of skills.

In the discussion of 20th century industrialization, Gerschenkron (1962) famously argued that backward economies could achieve rapid growth by adopting frontier tech-



(a) Fanning mills per household

(b) Craftsman households

Figure 2: Adoption of fanning mills and non-adoption of artisanal skills

The left map shows the number of fanning mills per hundred households in a *volost*, and the centroid of German colonies. The right map shows the share of households involved in various craftsmanship (*promysly*), the centroid of German colonies, and the location of towns.

nologies from developed countries. This implies that productivity differences across countries should gradually diminish.[4] However, more than a century after the Second Industrial revolution, there is no evidence of an unconditional convergence for the world as a whole (Jones, 2016). Numerous studies have been exploring this puzzle,[5] including studies on technology adoption.[6] We use the historical setting of the Volga Germans in the Russian Empire to highlight the importance of "tacit" knowledge and skills.

Rogers (1962) distinguishes between the "hardware" and "software" components of every technology. The "hardware" of a technology is a physical object or tool. The "software" of a technology is the disembodied knowledge which is necessary to design, produce, utilize, and maintain the "hardware".[7] Different technologies combine hardware and software in different proportions, which may substantially affect the costs of their dissemination. Whereas tools can be easily traded, the transfer of disembodied knowledge is usually associated with communication costs. These costs are particularly high if knowledge is non-codified or "tacit", and specific apprenticeship institutions are required to facilitate its transmission (de la Croix et al., 2018). In the absence of such institutions lagging economies will not be able to take full advantage of the frontier technologies because of the prohibitively high costs of knowledge dissemination.

This leads us to the formulation of the "costly adoption" hypothesis, which predicts that success in adoption depends on the relative weights of the "hardware" and the

[4]This prediction is, of course, also follows from the Solow growth model.

[5]See Hall and Jones (1999); Acemoglu and Zilibotti (2001); Caselli (2005) among many others.

[6]A seminal paper in this literature is Griliches (1957). See also Barro and Sala-I-Martin (1997); Caselli and Coleman (2001); Benhabib and Spiegel (2005); Comin and Hobijn (2010); Comin and Mestieri (2018) for the theory and empirical patterns of cross country technology diffusion.

[7]Despite one tends to think of technology predominantly as a "hardware", sometimes it could be entirely represented by a "software", for example, crop rotation systems or recipes.

"software" components of a technology. This hypothesis is especially relevant for the pre-industrial era when communication channels were limited to personal interactions and confined by geographic accessibility. Testing the "costly adoption" hypothesis requires a unique natural experimental setting in which "advanced" and "lagging" groups share the same geographical, climatic and institutional environment, display similar occupational structure and reside in geographical proximity to each other to enable some cultural exchange between them. The case of the German colonies in Saratov province is exactly the type of setting required for this exercise.

The analysis takes advantage of several particularly appealing features of the empirical setting. Firstly, Saratov province was a relatively small and geographically homogeneous region – about 85,000 square kilometers.[8] This allows us to rule out almost all environmental factors that might account for the variation in the outcome variables. [9]

Secondly, we study the adoption process exclusively among Russian peasants. Our goal is not to explain the differences between Russians and Germans, but to study the variation in technologies and productivity across *Russian* townships only. This enables us to hold constant many cultural and institutional factors that might confound the outcome variables.

Thirdly, the German population of Saratov province was spatially concentrated and persistent throughout the period. After the initial inflow the province did not experience German immigration except for occasional settlers. Moreover, there were no population outflows to other Russian provinces or abroad until the late 19^{th} century, and no significant movement within the province – in 1913, the Germans resided in the same locations as in 1769 (Kabuzan, 2003). This allows us to consider the German inflow as a "treatment" in a unique natural experiment.

Finally, this historical setting allows us to distinguish between the main drivers of productivity, namely tools and skills. The unique data set contains various direct and proxy measures for both, which allows us to separately observe the adoption of advanced equipment, the (non)-diffusion of skills, and their effects on productivity.

We show that the "hardware" of technology (advanced tools) introduced by a skilled minority was successfully adopted by the comparatively backward majority, which resulted in higher labor productivity. However, the underlying "software" of the technology (skills and know-how) was not subject to adoption even after many decades of mutual trade.

To ensure the causal interpretation of the results, we consider several alternative explanations for the observed negative correlation between the distance from the Germans and the adoption of tools among the Russians. Reverse causality is extremely unlikely because both qualitative and quantitative evidence point in the same direction, namely that Germans brought with them superior tools and skills and did not borrow them from Russians. An omitted variable bias is a possibility that we overcome with an instrumental variable (IV) estimation. It is plausible that Russian peasants who already possessed advanced tools settled near the Germans.[10] Hence, their technological sophistication in comparison to other Russians was not the result of adoption, but

[8]Slightly greater than modern day Austria (82,500 sq. km) and slightly smaller than the State of Minnesota (86,900 sq. km).

[9]We also explicitly control for climatic variables in the regression analysis to make sure the results are not driven by environmental factors.

[10]This explanation, however, rests on the assumption of free movement of Russian peasant labor, which is difficult to justify, at least until 1906. See Section 5.6 for details.

of some other factor unaccounted for in the baseline OLS regression. We exploit the fact that the German colonists were the last movers in the colonization of Saratov province and settled on the worst agricultural lands. We use potential caloric yield as an instrumental variable for the distance from the German colonies and confirm our OLS estimations. To check the validity of the exclusion restriction, we collect additional data on 91 counties neighbouring Saratov province and located approximately in the same latitude range, but which did not experienced German immigration. We show that potential caloric yield does not predict heavy plough prevalence and wheat growing in this placebo sample.

The third alternative explanation is the self-selection of Russian peasants into the adoption process based on their personal characteristics, like willingness to take risk, patience, or work ethic. We cannot rule out this possibility with the available data. However, this potential self-selection does not invalidate our main conclusion, namely that the adoption of tools does not imply the diffusion of skills. If heavy plough adopters were indeed more entrepreneurial, they would have been inclined to adopt blacksmithing, carpentry or other artisanal skills as well. However, this is not what we observe in the data.

The paper contributes to three strands of the literature on economic history and comparative development. The first one is the empirical literature on the effects of highly-skilled minorities and upper-tail human capital on technological progress and growth. Hornung (2014) finds substantial long-term effects of the skilled Huguenot minority on the productivity of textile manufactures in Prussia. Valencia Caicedo (2019) shows that Jesuit missionaries in modern-day Argentina, Brazil, and Paraguay affected the human capital and long-term income of local population through several channels including technology adoption in agriculture. Rocha et al. (2017) and Droller (2018) find similar effects of European settlers for Brazil and Argentina respectively, and Wantchekon et al. (2015) for colonial Benin. Natkhov (2015) shows how Russian settlers in the North Caucasus affected human capital and the long-term development of the indigenous population, and Arbatli and Gokmen (2016) demonstrate the persistent positive effect of the skilled Armenian and Greek minorities on the Muslim population of the Ottoman Empire. In contrast to these studies, however, we are able to disentangle the effect of the skilled minority showing that the adoption of advanced tools, rather than skills, was the main driver of the productivity increase among natives.

Second, we contribute to the growing body of literature on Russian economic history. Recent studies have focused mostly on the institutional determinants of agricultural productivity in late Imperial Russia (Dennison, 2011; Markevich and Zhuravskaya, 2018; Castaneda Dower and Markevich, 2018), the long-term effects of serfdom (Buggle and Nafziger, 2017), the role of communes (Nafziger, 2010), or the political economy of the Russian peasantry (Nafziger, 2011). Little has been known about technological change in the Russian agricultural sector prior to the Bolshevik revolution, especially in connection with the adoption of foreign know-how. Our paper fills this gap with micro-level data that allows us to hold constant institutional and cultural factors, and focus exclusively on the role of technology adoption in explaining labor productivity in agriculture.

Finally, our paper can be viewed as a preliminary empirical test of the emerging institutional theory of knowledge dissemination. de la Croix et al. (2018) develop a formal model of the person-to-person exchange of ideas. They argue that the differential speed of technological progress in preindustrial societies can be explained by various types of institutions, like family, clan or guilds, which organize who learns from whom. Specifically, they show that the institution of guilds facilitated the diffusion of tacit knowledge and artisanal skills in Western Europe in contrast to family and clans in the rest of the world, which largely accounts for the European primacy in technological progress in the centuries before the Industrial Revolution.

We add to the continuum of institutions (family, clan, guilds, and markets) an extreme case of the absence of any institution for knowledge transmission. We empirically show that this institutional vacuum inhibited the dissemination of useful knowledge from the skilled German minority to the Russian majority. Occasional trade contacts through fairs allowed only for the adoption of tradable tools, but were insufficient for the diffusion of advanced skills.

This historical case can be generalized to other time periods and places, implying that barriers for the diffusion of tacit knowledge and skills are likely to be an important explanation for "why the whole world isn't developed" (Easterlin, 1981).

The rest of the paper is organized as follows. Section 2 provides the historical background to the settlement of Saratov province. Section 3 characterises the German colonies in Saratov province as a local technological frontier. Section 4 takes an extended look at the data that we employ in the empirical analysis. Section 5 describes our empirical strategy. Section 6 reports our main results on the adoption of advanced agricultural technology among Russian peasants and its effect on agricultural productivity. Section 7 presents evidence on the possible mechanism of adoption. Section 8 concludes.

2 Saratov Province: Historical Background

This section briefly introduces our region of study, Saratov province, in the late 19th – early 20th centuries, with a focus on the geography and the history of settlement.

2.1 Geography and Population

Saratov province was located in the south-east of European Russia, on the right bank of the Volga river.[11] Its territory stretched from north to south, along the Volga river, for about 550 kilometers, and from east to west (in the widest part) for about 300 kilometers, making an area of 84,500 square kilometers. Administratively, the province was divided into 10 counties (*uezd*) and 289 townships (*volost'*).

Until the early 18th century, Saratov province was a sparsely populated frontier acquired as the result of the southward expansion of the Russian Empire. The provincial city Saratov was founded in the late 16th century as a fort to secure the southeastern boundary of the Russian state from repeated raids by nomads. The status of town was granted to Saratov in 1708. By the beginning of the 19th century, Saratov became an important shipping port on the Volga river.

According to the 1897 Imperial Census, there were 2.4 million people in the province with about 140,000 living in Saratov. Less than 13% of the total population resided in

[11] The former territory of Saratov province nowadays is divided between Saratov, Penza, and Volgograd oblasts of the Russian Federation.

urban areas; the literacy rate was about 23.8%, below the average level for European Russia (25.2%). While Russians constituted an overwhelming majority (76.8%), several spatially concentrated ethnic groups made up the rest of the provincial population. Germans constituted 7% of the total population, Ukrainians 6.2%, and Tatars around 4%.

None of these groups can be regarded as the indigenous population of the region, since all of them settled the area in the course of gradual colonization. In medieval times, the territory was controlled by the Mongol Empire, and later by its successor, the Golden Horde with a number of large settlements located along the Volga river. Severely depopulated after the decline of the Golden Horde, the vast empty steppe of the Middle and Lower Volga region became a home for various nomadic tribes. Only in the late 17th–early 18th centuries when the south-eastern frontier of the Russian state became safe enough, did it start to attract Russian landowners and their peasants.

2.2 Early Colonization: Tatars and Russians

Historical evidence indicates that the first settlers in the region were Tatars from Kasimov, Kazan, and Astrakhan, who were granted land plots in exchange for military service in the late 17th century. The settlers had the right to choose desirable plots themselves provided that the chosen land was previously unclaimed (the Saratov Provincial Zemstvo, 1891a). As a result, the Tatar population became predominantly concentrated in the north-eastern part of Saratov province – in Khvalynsk and Kuznetsk counties.

Russians founded the first fortresses in the Middle Volga region in the late 16th century. However, regular rural settlements appeared in the area only in 1680-1690s, when the first defense line was built (Chekalin, 1892). Before that time, the constant military threat of raids, which often resulted in the enslavement of the population and cattle rustling, made regular agricultural activity impossible.

By the beginning of the 18th century, with the gradual decline of the nomadic threat, large uninhabited territories, still mostly uncontrolled by the Moscow state, started to attract considerable numbers of fugitive peasants from the Russian inner-lands and Old Believers who were persecuted by the Orthodox Church.[12] The newcomers whose primary occupation was agriculture chose more beneficial places of settlement to maximize their potential yield. At the same time, the Moscow government began to grant the nobility (*pomeschiki*) large land plots in the Middle Volga. This process was supported by the resettlement of peasants from the forest heartland and the enserfment of fugitive settlers whose villages lay on the entitled land.

By the late 19th century the steppe frontier had been transformed from the sparsely settled "wild field" (*dikoe pole*) into densely populated area, which produced a bulk of agricultural output of the Empire (Markevich and Mikhailova, 2013).

[12]Until that time most Russian peasants still lived in the forest heartland – the area between Volga and Oka rivers. After Russia gradually defeated various nomadic tribes, it took the peasants several generations to adapt to the new environmental conditions of the open steppe. Thus, the peasant population of the steppe regions surpassed that of the forest heartland only in the first half of the 19th century (Moon, 1997).

2.3 Later Colonization: Ukrainians and Germans

The beginning of salt mining at Lake Elton (about 300 kilometers south of Saratov) in the 1740s attracted a lot of Ukrainians who engaged in salt delivery from the lake to the markets of Saratov and the recently founded Kamyshin. To foster migration, the government granted Ukrainian traders (*chumacks*) land plots in Kamyshin and Tsarytsin counties, which resulted in the consolidation of the Ukrainian minority in Saratov province.[13]

By the middle of the 18th century, large parts of the province remained empty, which motivated the government to launch another large scale settlement policy. In 1762, Catherine the Great, born a German princess, issued a manifesto inviting foreigners to migrate to Russia. The settlement policy was actively promoted in European states and attracted about 30,000 migrants predominantly from the German-speaking states. Despite the fact that colonists had been promised the right to freely choose their place of settlement in any part of the Russian Empire, the government prescribed the establishment of German colonies in the sparsely populated area on both banks of the Volga river (Klaus, 1869; Koch, 2010). By the end of the 19th century, this area would constitute parts of Saratov and Samara provinces.[14] The soil quality and climatic conditions in the newly colonized area were poorer than in the neighboring areas occupied by Russian and Ukrainian settlers.

The spatial distribution of the population within Saratov province on the eve of the German migration supports the hypothesis that the German settlers were channeled to the empty lands which had remained unpopulated during the previous stages of colonization. Map 1 in On-line Appendix demonstrates population densities across the counties of Saratov province in 1765.[15] Population density sharply decreases from north to south. Kamyshin county, a major destination for German migration, is marked with the second lowest population density, around 1.6 per squared km and the total population was 19,729.[16] In 1769, the German population in Kamyshin county was 9,631, which constituted almost 49% in relation to the initial non-German population. According to the fourth peasant census of 1781, population growth in Kamyshin county was the highest among the counties of Saratov province – 156% compared to the average growth of 44% for the other provinces. Such numbers can be attributed to the large German migration in-flow.

2.4 Determinants of Colonization Patterns

Given the historical evidence, we can expect that earlier settlers took the first-mover advantage and occupied more fertile lands with more favorable climatic conditions. Consequently, late-movers were left with a narrower range of settlement alternatives to choose from.

[13]"In 1730-1750, the government settled substantial numbers of Cossacks and Ukrainians, who until the twenties of the present century had been obliged to transport and trade salt, to the southern part of the Kamyshin district." (the Saratov Provincial Zemstvo, 1891b, p. 43).

[14]In 1851, the districts on the left bank of the Volga to which the German colonies belonged were transferred to the newly created Samara province.

[15]Population numbers come from the third peasant census (*podushnaya perepis*) conducted in 1762-1764 in the Russian Empire and compiled from the archival sources by Kabuzan (1990).

[16]The lowest population density of 0.97 per squared km was in Tsaritsyn county.

In Table 1, we check the validity of the historical and ethnographic records by regressing the shares of each ethnic group on the number of geographical variables at the township level.[17] The set of explanatory variables includes the average potential caloric yield, the standard deviation of potential caloric yield, terrain ruggedness, and a dummy for townships being on the bank of the Volga.

We find that Tatars and Russians, as first movers, occupied territories with significantly higher potential yields. For late-movers, the coefficient on potential yields is negative and significant, indicating that Ukrainians and Germans occupied territories that had remained unclaimed at the earlier stages of colonization and, consequently, were less suited for agriculture.

In Table 12 in Online Appendix, we employ alternative measures of climatic conditions, such as the mean and standard deviation of the average annual temperature, and the mean and standard deviation of annual precipitation. We obtain similar results – whereas average annual temperature is mostly insignificant, the coefficients on annual precipitation are negative both for Ukrainians and Germans, and highly significant for Germans. Moreover, terrain ruggedness is significantly negative for Russians and significantly positive for Germans.

These results provide suggestive evidence that the pattern of ethnic settlement was in large part determined by variations in geographic and climatic conditions, which can be regarded as orthogonal to the socio-economic characteristics of the colonizing group. Furthermore, we can conclude that the Germans did not have any natural advantage over Russians in potential agricultural productivity.

3 The History of German Migration to the Volga Region

This section briefly summarizes the historical background of German migrations to Russia, and describes the colonies in the Middle Volga region.

3.1 The Colonization Policy of Catherine the Great

In the late Russian Empire, most of the German population belonged to three spatially concentrated groups: Baltic Germans, Volga Germans, and Black Sea Germans, located in several districts of southern Ukraine. In the Baltic provinces of Estonia, Livonia, and Courland, Germans had constituted an elite minority before the region was annexed by the Russian Empire in the 18th century. In contrast, the Volga and the Black Sea Germans were mostly peasants and artisans who arrived from various German lands under specific migration policies initiated by the Russian government.

The Volga region was the destination of the first German migration inflow. In 1763, Catherine the Great launched a state-sponsored settlement policy inviting Europeans to immigrate to the Russian Empire. This policy granted potential settlers a wide range of privileges, such as temporary tax exemption, permanent exemption from military conscription, the right to self-government, religious freedom, and native language schools. The settlement policy achieved considerable success in the German-speaking

[17] See Section 4 for details on data sources.

states, especially those most devastated by the Seven Years' War, such as Kessel and Darmstadt (Koch, 2010).[18] The demand for out-migration was so high that some states, for example, Austria, forbade enrollment in the Russian colonization program. In 1766, the policy run out of funds and was terminated.

The first decades of the Volga colonies were marked by persistent disorder and devastation stemming from crop failures, the lack of experience in agriculture in arid zones among the colonists, and corruption by imperial officials. Shortly after the Volga colonization was labelled as unsuccessful, the government reconsidered its recruitment strategy, toughened the terms of settlement and launched the second wave of colonization to the Black Sea region (Klaus, 1869).

3.2 Population Movement in German Colonies

Two characteristics of the German colonies in Saratov province are crucial for our identification strategy. The first one is the absence of additional migration inflows after 1766, and the second one is the persistent spatial distribution of the German population within the Saratov province.

From around 27,000 German migrants who reached the Volga region by 1767, the population dropped to around 23,000 in a decade, as a consequence of epidemics, crop failures, nomad raids, and the Pugachev rebellion (Koch, 2010). Nevertheless, in subsequent decades the population recovered and substantial growth persisted throughout the next century (see Figure 4 for population dynamics in Volga German colonies). After the termination of the migration policy in 1766 the region would not see German migration inflows in the future except for occasional settlers (Klaus, 1869). Thus, a natural increase entirely accounts for population growth among the Volga Germans. The migration outflow from the German colonies started only in the mid-1860s and was caused by increasing land tension. Two major destinations of the German out-migration inside Russia were Samara province and the Caucasus. After many of the German privileges were revoked in the mid-1870s, thousands of the Volga Germans emigrated to North and South America.[19]

The original 44 colonies in Saratov province, or "mother colonies", established between 1764 and 1767, were located in the territories that later would constitute 10 townships in 4 counties of the province.[20] Persistent population growth among the German population made the territorial expansion of the German enclave inevitable. In the mid-1850s, Ilovlinskaya township was established on the lands granted by the government to the colonists to ease growing land tension (the Saratov Provincial Zemstvo, 1891b). In 1897, 99% of the population of Ilovlinskaya township were Germans. With

[18] The source regions of German out-migration are presented on Figure 8 in On-Line Appendix.

[19] In the US Russian Germans concentrated mostly in the Great Plains area. Baltensperger (1983) shows that they brought with them agricultural experience in a arid environment of the Russian steppe (crop diversification and use of small grains), which contrasted sharply with the humid-land agricultural system, emphasizing corn and livestock, dominant among the Midwest farmers. Although, in order to compete in the marketplace the immigrants quickly adopted local agricultural practices, they also retained a number of elements from their Russian experience like highly diversified cropping system. Also Khramova (2012) documents word borrowing from Russian language among Germans of the Russel County in Kansas.

[20] Those townships are Kamenskaya, Linyovo-Ozerskaya, Norkskaya, Oleshinskaya, Semyonovskaya, and Sosnovskaya in Kamyshin county; Medveditskaya in Atkarsk county; Yagodno-Polyanskaya in Saratov county; Sareptskaya in Tsarytsyn county.

the exception of this newly established township and the cities, a century and a half later, no other township in Saratov province was more than 1% German. This indicates that the spatial distribution of the German population was fairly persistent and no migrations took place within Saratov province.[21] Map 2 presents the spatial distribution of the German population in Saratov province.

3.3 German Colonies as a Local Technological Frontier

Koch (2010) asserts that a high percentage of non-farmers among the original 27,000 settlers was a key factor in their survival. The government's failure to provide the colonists with sufficient physical capital essential for living (for example, houses and agricultural equipment) was partly compensated for by the knowledge and skills of German craftsmen. In a comparatively short time, the Volga Germans introduced a number of innovations concerning both manufacturing and agriculture previously unknown to the Russians at least in the Volga region.

> "The smiths among the farmers introduced the forge to the Volga, and five years before the colonists harvested their first good crop they were building German moldboard plows to replace crude *sokhas*."[22] (Koch, 2010, p. 65)

The Volga Germans pioneered flour milling, tobacco growing, tanning, weaving, saw milling, and the manufacturing of a wide range of agricultural equipment including fanning mills and wagons. At first, local artisans exclusively served the needs of German communities. With the increase in demand from their Russian neighbors Germans gradually developed comparatively large industries that started to supply both regional and national markets. An example of German commercial success was the milling enterprises of the Schmidt and Borel families, supplying flour and grain nationwide including to Finland and the Baltic provinces.[23]

Ethnographic evidence clearly suggests that Russian peasants residing in close proximity to the German colonies adopted German ploughs and other agricultural equipment. For example, in Bobrovka village of Topovskaya township, peasants "used to plow with a *sokha* a century ago, but later, when the Germans settled nearby, learned from them to use a heavy plough and abandoned their *sokhas*." (the Saratov Provincial Zemstvo, 1891b, p. 119) A survey of peasant economies in Saratov province in 1859 shows that Russians appreciated the skills and knowledge of German artisans:

> "Russian peasants tend to attach blades to scythes themselves; however, in the villages located closer to the German colonies, Russians often entrusted

[21] Such a settlement persistence of the Volga Germans stands in a stark contrast with the German migrants of later waves. For example, after migrating to Chernigov province in the 1770s, the Hutterites resettled twice. First they moved within the Chernigov province in the beginning of the 18th century. In 40 years, they resettled to Taurida province.

[22] *Sokha* is a traditional light wooden ard widespread among Russian peasants since the thirteenth century. It usually had two tines. Sokha was comparatively cheap in production and required only one horse for ploughing. However, it could not efficiently plow dense soil and turn the land over the way heavy mouldboard ploughs did.

[23] Photo 1 in the Online appendix shows the Borel's mill near the village of Nizhnaya Dobrinka in Kamyshin county, which has survived until today. Apart from the mill powered by steam engines and employing more than 200 workers, the Borel family possessed a small fleet on the Volga which allowed them to transport the flour by river to central Russia and further to the west. Our reading in the history of the family revealed that they descended from French Huguenots settled in Germany in the 17th century (Shelgorn, 1909).

it to Germans, since the Germans attach blades to scythes more skilfully and firmly. " (the Central Statistics Office, 1859, p. 128)

Table 2 presents a quantitative comparison of German and Russian townships by the mean values of various types of development, human capital, and technology measures.[24]

One of the most striking results from the table is that despite Germans settling worse agricultural lands (less potential caloric yield, more terrain ruggedness, less precipitation) they were more successful in almost every measure of development. For example, the population density in German colonies was almost twice that in Russian townships (respectively 58 and 32 per sq. kilometer). Germans had a higher number of livestock per household than Russians, and a higher number of advanced agricultural implements per household (heavy ploughs, fanning mills, reapers). The prevalent crop in German agriculture was wheat in contrast to rye which was the Russian staple.[25].

Furthermore, highly skilled occupations were much more prevalent in German townships. About 27% of German households were employed in craftsmanship of one sort or another (*promysly*), whereas only 7% of Russian households were. Blacksmiths, carpenters, textile workers, shoe makers, tanners and other non-agricultural workers were much more widespread among Germans than among Russians. Also German townships hosted large fairs, which lasted on average 6.5 days per year.

In sum, both the ethnographic and quantitative evidence suggest that German colonies in Saratov province can be viewed as a local technological frontier. The unique historical and geographical setting of this "natural experiment", and the availability of detailed low resolution data, provides an opportunity to study the adoption of advanced techniques and skills in pre-industrial societies. In the next section we describe the data digitized for the very first time. Relying on these unique sources, in Section 6 we reveal whether adoption took place and what components of technology – tools, knowledge, or both – were adopted and how.

4 Data

We combine several published and archival sources to construct a unique dataset on population, human capital, the structure of the economy, technologies, and economic output in Saratov province at the township (*volost*) level in the late 19th – early 20th centuries. The total number of townships in our dataset is 280, excluding ten county capitals (*uezdnye goroda*). This number is defined according to the administrative-territorial division of Saratov province in 1897. Subsequent changes in the number of townships, all of which implied either division or renaming, were adjusted to the earlier administrative boundaries. A GIS shapefile of townships of Saratov province was digitized from the original map published in Tezyanov (1904).

[24]See Section 4 for data sources. Table 11 in Online Appendix presents the extended version of the table and reports standard deviations.

[25]However, identical values for the shares of land under crops – about 66% of arable land – indicate that both Germans and Russians employed three-field crop rotation system. Under this system, two thirds of the arable land (66%) were sown, and one third was left fallow. This agricultural technology goes back at least to the late Middle Ages in Europe (North and Thomas, 1973; Cipolla, 1976), and at least to the end of the 17th century in Russia (Milov, 1998).

Outcome Variables. We employ three sets of outcome variables capturing different components of technology. First, we distinguish tools from knowledge; second, we differentiate between types of knowledge on the degree of its observability to an outsider.

The first group of outcomes measures advanced agricultural technology embodied in agricultural equipment. It includes the number of heavy iron ploughs, fanning mills, and reapers per household. The source for this set of outcomes is a series of publications called *"Lists of the settlements of Saratov province"* issued by the Saratov Provincial Zemstvo (1914). Each publication comprises demographic and agricultural data at the levels of peasant communes and townships for each county of Saratov province in 1913.

The second group of outcomes measures technology as disembodied knowledge that can nevertheless be easily observed and, therefore, adopted by an outsider. In our dataset, it is represented by the share of arable land sowed by wheat and barley. We also use the share of land under crops as a measure of the crop rotation system. All the variables come from the *"Agricultural census of 1917"* (the Saratov Provincial Statistics Bureau, 1919). The ongoing First World War and the peasant unrest of 1917 impeded the collection of data in a number of provinces. For example, in the neighboring Samara province, approximately 9,221 households dropped out of the census, which constituted about 2% of the total number of households in the province. In Saratov province, only 316 households (less than 0.07%) did not take part in the census, which makes data on Saratov province much more reliable (the Central Statistics Office, 1923).

The third group of outcome variables measures technology as disembodied knowledge that cannot be easily observed by an outsider. Those include the percentage of households engaged in craftsmanship (*promysly*) (also from the 1917 agricultural census), the number of forges, carpentry workshops, textile factories, shoe workshops, tanneries, wheel and cart factories per 1,000 households in the 1880s come from the study of economic activities in the settlements of European Russia conducted by the Central Statistical Committee (1883).

Finally, we digitized data on wheat yields in 1914 to estimate the effect of adopted technologies on agricultural productivity. The data were retrieved from Voznesensky (1915) and were originally measured in yield per area (*pood* per *desyatina*). To obtain the estimates of output per unit of labor, we multiplied the yield per area by the sown area and divided by the number of households.

Explanatory Variables. Our main explanatory variable is distance from a township centroid to the centroid of the ten German colonies measured in kilometers. Calculations of centroids and distances are performed using ArcGIS software.

Population density and livestock per household measure the economic prosperity of the population and come from the Saratov Provincial Zemstvo (1914). Literacy rates are defined as the share of population who completed any type of education (the Saratov Provincial Zemstvo, 1888).

We extensively control for the cultural heterogeneity of population. Data on religious composition come from the 1897 Imperial Census. The results of the Census were published in a series of volumes, and each volume contained the data for a single province. However, the lowest level of aggregation available in the published sources is the county (*uezd*). To collect data at the township level, we used the Census records from the Russian State Historical Archive funds in Saint Petersburg.[26]

[26] RGIA. F. 1290. Op. 11. D. 2041-2075.

Ethnographic evidence suggests that heavy ploughs were well-known to Ukrainians in contrast to Russians (Zelenin, 1907). Since Ukrainians as later settlers resided in proximity to Germans, failure to control for the Ukrainian population could lead to a bias in our adoption estimations. We used the information on the prevalent ethnicity in a commune reported in *Lists of the settlements* to estimate the share of the Ukrainian population in a township.

Geography. To rule out environmental factors in the adoption of technology, we control for a wide range of geographic and climatic controls. The measure of potential caloric yield that we employ as an instrumental variable was constructed by Galor and Ozak (2016). Data on terrain ruggedness come from Shaver et al. (2019). Data on average temperature and annual precipitation were retrieved from Fick and Hijmans (2017).

Placebo Dataset. To perform a number of placebo tests we assembled an additional county-level dataset for neighboring provinces located roughly in the same latitudes as Saratov, but which did not experienced German migration inflow. The dataset covers 106 counties in 10 provinces: Don ($n = 9$), Kaluga ($n = 11$), Kursk ($n = 15$), Orel ($n = 12$), Penza ($n = 10$), Ryazan ($n = 12$), Simbirsk ($n = 8$), Stavropol ($n = 5$), Tambov ($n = 12$), Tula ($n = 12$). The set of variables include the number of heavy ploughs per capita, the share of arable land sowed with wheat, the population density in 1917 (all from the *"Agricultural census of 1917"*), the share of private serfs in 1858 from Buggle and Nafziger (2017), the ethnic structure of the population from the 1897 Imperial Census and geographic controls (ruggedness, average temperature and annual precipitation).

5 Empirical Strategy

In this section we describe the empirical strategy employed to test the "costly adoption" hypothesis. In our analysis, we exclude the German townships from the sample to explore variation in technologies and productivity *only* among the Russian majority. We proceed in three steps. First, we investigate the prevalence of advanced tools and skills in Russian townships depending on the proximity to German colonies. Second, we employ an instrumental variable approach to deal with possible endogeniety, and a set of placebo regressions to test the exclusion restriction. Third, we estimate the effect of technology adoption on agricultural productivity in Russian townships. The following subsections describe each step in more details.

5.1 Baseline Equation

To estimate the adoption of technologies among the Russian population, we estimate the following regression equation:

$$Technology_{ij} = \beta_0 + \beta_1 DistGermans_{ij} + \beta_2 PopDens_{ij} + \beta_3 Lit_{ij} + \beta_4 \boldsymbol{X_{ij}} + \mu_j + \varepsilon_{ij}, \quad (1)$$

where $Technology_{ij}$ denotes one of the outcomes measuring the prevalence of advanced agricultural tools, crop varieties, and artisanal skills in township i in county j, namely heavy iron ploughs, fanning mills, and reapers (all of them per 100 households); wheat, barley, and the total land under crops (as % of arable land); the share of households employed in craftsmanship (*promysly*), and number of forges, carpentry shops, textile factories, shoe shops and tanneries per 1,000 households in a township.

$DistGermans_{ij}$ is our main explanatory variable that represents distance to a township centroid from the centroid of German townships measured in kilometers. The coefficient of interest is β_1, which shows the effect of geographical proximity to the German colonies on the prevalence of advanced technologies and skills in non-German townships.

Other factors that might affect the adoption of technology are captured with population density, literacy, livestock per household, the religious and ethnic composition of the population (shares of Ukrainians, Tatars, Jews and Old Believers), dummies for a railroad and a navigable river in a township, and terrain ruggedness. Specific factors at a county level are captures by county fixed effects with μ_j. We also cluster standard errors at the county level in all specifications.

5.2 Identification Strategy

There are a number of competing explanations for the association between distance from German townships and the prevalence of advanced tools among Russians.

The first, and the easiest one to rule out, is reverse causality. Hypothetically, it is possible that German peasants borrowed heavy ploughs from Russians and not the other way around. However, this explanation does not hold up to the empirical evidence, both quantitative and qualitative. The number of heavy ploughs per household was almost two times higher in German townships than in Russian ones. For other tools and crops, the ratios are similar (see Table 2 and Section 3.3). It is extremely unlikely that a borrower will possess a larger number of tools than the originator who mastered the production technology. Moreover, as shown in same Table 2, Russians had almost no forges and carpentry shops where ploughs and other tools can be produced. Finally, vast ethnographic evidence suggest that heavy ploughs were not known to Russians and were adopted from other ethnic groups.[27]

The second possible explanation is an omitted variable bias. It may be the case that both the location of the German colonies and the prevalence of advanced tools among Russians were caused by some other factor unaccounted in our regression model. For instance, Russian peasants with heavy ploughs might have settled near German colonies for reasons related to climate and soil type. One way to rule out this possibility would be to explicitly measure the spread of heavy ploughs among the Russian peasants before the German migration. However, the absence of such data does not allow us to proceed this way.[28] Instead, we rely on an instrumental variable strategy.

We exploit the fact that the German colonists were the last movers in the colonization of Saratov province. As shown in Section 2.4, the earlier settlers – Tatars and Russians – enjoyed a first-mover advantage and settled much better lands, while the Germans were forcibly settled in areas less suitable for agriculture. Hence, distance to German settlements is strongly negatively correlated with potential caloric yield – the correlation coefficient is -0.91, meaning that land closer to German settlements was less

[27] "If anywhere among Velikorus (Russians) heavy plough can be found, it should be considered as a late cultural adoption." (Zelenin, 1907, p. 128)

[28] We can only refer to the same body of ethnographic sources which strongly suggest that heavy iron plough was mostly unknown to Russian peasantry in the 18$^{\text{th}}$ century (Zelenin, 1907).

productive for agriculture.[29] We use potential caloric yield as an instrumental variable for distance from the German colonies and estimate the following first stage regression:

$$DistGermans_{ij} = \alpha_0 + \alpha_1 PotentialYield_{ij} + \alpha_2 PopDens_{ij} + \alpha_3 Lit_{ij} + \alpha_4 \boldsymbol{X_{ij}} + \mu_j + \epsilon_{ij}, \quad (2)$$

The identifying assumption here is that potential caloric yield affects the adoption of technology among Russians only through the distance from the German colonies. To provide supportive evidence for the plausibility of this assumption we collect additional data on 91 counties neighbouring Saratov province and located approximately in the same range of latitudes, but which did not experience German immigration (for details on provinces and data sources see Section 4). If the exclusion restriction holds, we should not observe a significant effect of potential caloric yield on the prevalence of heavy ploughs and the share of wheat cultivated by Russian peasants in these neighbouring counties. The specification for this test is as follows:

$$HeavyPloughs_i = \gamma_0 + \gamma_1 PotentialYield_i + \gamma_2 PopDens_i + \gamma_3 \boldsymbol{X_i} + \nu_i, \quad (3)$$

where $HeavyPloughs_i$ is the prevalence of heavy ploughs in a county i, $PotentialYield_i$ is the potential caloric yield, $PopDens_i$ is population density, and a set of controls $\boldsymbol{X}$ include terrain ruggedness, the share of private serfs in 1858 as a measure of institutional legacy, and the shares of Ukrainians, Belorussians, and Tatars among a county's population. The coefficient of interest, γ_1, is expected to be insignificant if the exclusion restriction holds.

Finally, the third alternative explanation for the correlation between distance from the Germans and the prevalence of advanced tools is the self-selection of Russian peasants into the adoption process. Adoption of new technology is a risky enterprise, especially in traditional agriculture. It is possible that Russian peasants who were more entrepreneurial and willing to take risks deliberately settled the areas around German colonies to be closer to the source of tools and know-how. We can not rule out this possibility with the available data. However, there are two reasons to believe this does not invalidate our results. First, the explanation is based on the implicit assumption of the free movement of Russian peasant labor. This assumption is very problematic. Peasants were not allowed to move until the emancipation in 1861. After the emancipation they were tied to the commune until Stolypin's land reform in 1906. The share of Russian peasants who left the commune by the year 1913 in Saratov province was only 10.1% (Chief Administration of Agriculture and Land Engineering, 1916). Even if all of them settled near the Germans, it could not explain away the observed spatial pattern of heavy plough diffusion. Second, the entrepreneurial traits of those Russians who, presumably, deliberately settled closer to Germans could indeed introduce an upward bias to the coefficient on distance. But the bias should be universal for all tools and skills. However, we do not observe any diffusion of advanced skills like smithing, carpentry, textile work, or tanning. Hence, our main conclusion, that the adoption of tools does not imply the diffusion of skills, holds even under very strong assumption of free movement of Russian peasant labor.

[29]The potential caloric yield index constructed by Galor and Ozak (2016) reflects variations in potential (rather than actual) crop yields across the globe, as captured by calories (per hectare per year). The measure hinge on estimates of potential crop yield under low level of inputs and rain-fed agriculture, and agro-climatic conditions that are orthogonal to human intervention (such as temperature and precipitation).

5.3 Model of Productivity

The third step is to explore the effect of technology adoption on labor productivity. We estimate the following specification:

$$lnYield_{ij} = \beta_0 + \beta_1 HeavyPloughs_{ij} + \beta_2 PopDens_{ij} + \beta_3 Lit_{ij} + \beta_4 \boldsymbol{X_{ij}} + \mu_j + \varepsilon_{ij}, \quad (4)$$

where $lnYield_{ij}$ is the natural logarithm of wheat yield per household in township i in county j. Our key explanatory variable in this specification, $HeavyPloughs_{ij}$, is the number of heavy ploughs per 100 households, and β_1 is the coefficient of interest. The rest of the covariates are identical to equation (1). Equation (4) is an estimation of the standard production function with output per capita on the left hand side and inputs per capita on the right hand side.

6 Main Results

6.1 Baseline OLS Regressions

Tables 3, 4 and 5 report the main results from regression (1).

In Table 3, the outcome variable is the number of heavy iron ploughs per 100 households. Column 1 shows that distance from German townships is negatively correlated with the number of heavy ploughs – the unconditional relationship is highly significant with a large t-statistics of -5.67 and economically significant coefficient.

In column 2, we control for a set of development covariates including population density, literacy, and livestock per household as a proxy for wealth. More wealthy Russian townships were significantly more likely to adopt heavy ploughs. The effect is robust to the inclusion of additional controls. The effect of literacy, however, disappears once we add controls.[30]

In columns 3-5 we gradually add railroads, shares of other ethnic and religious groups, terrain ruggedness, a river dummy and county fixed effects. The coefficient on the distance from German townships remains remarkably stable across specifications – a standard deviation increase in the distance from the German colonies decreases the number of heavy ploughs by 0.705 standard deviations. In terms of real measures, each 50 km increase in distance from the German townships decreases the number of heavy ploughs per 100 Russian households by approximately 12.5 (Figure 5). Map 3 reports an unconditional spatial distribution of heavy plough adoption – it is apparent that heavy ploughs spread approximately concentrically around German townships.

In Table 4 the outcome variables are the prevalence of other agricultural tools and crops, which were more widespread among Germans. Columns 1 and 2 present the results for fanning mills, and reapers, both per 100 households. We find a highly significant and negative effect of distance from the German townships on the adoption of fanning

[30] This result is consistent with the well-established fact that in pre-industrial societies literacy played a minor role in spreading of technologies since most "useful knowledge" was non-codified and embodied in workers' brains rather than in books (Cameron, 1975; Mitch, 1993; Mokyr and Voth, 2010).

mills. Moving 50 km closer to German townships adds approximately 10 fanning mills per 100 Russian households with all other factors held constant (see Figure 5).[31]

In Column 2, the coefficient on distance is negative but statistically insignificant. We explain this result by the fact that the number of reapers per 100 households in German townships was quite low, much lower than of heavy ploughs and fanning mills (29.4 against 75.1 and 41.6 respectively) and, therefore, reapers had lower potential for adoption among Russians. As in the case of heavy ploughs we find no evidence of the association between literacy and the adoption of advanced agricultural equipment, and we do find evidence of a positive association between wealth measured as livestock per household and the adoption of both fanning mills and reapers.

The "costly adoption" hypothesis also predicts that easily observable agricultural techniques should be subject to adoption by outsiders. We treat the percentages of wheat and barley among all crops sown as an instance of such an easily observable technique. In columns 3 and 4 we find the same spatial pattern of adoption for wheat and barley. The coefficients on distance are negative and significant. A one standard deviation increase in distance decreases wheat crops by 0.577 standard deviations, and barley crops by 0.463 standard deviations. Alternatively, each 50 km increase in the distance from the German townships leads to a 10 percentage point decrease in the share of arable land sowed with wheat and a 0.9 percentage point decrease in barley. Such a striking difference in the magnitudes of these effects can be explained by the low spread of barley in the German townships, with an average of only 3.2% of all crops.

Our results could be questioned if we observed the same spatial pattern for the agricultural technology that had been widespread among Russians before the German migration. The three-fields crop rotation system was well known to Russians by at least the end of the 17th century. This fact can be exploited in a placebo test – if our hypothesis is correct, we should not observe the same spatial pattern in the share of land under crops as in the number of heavy ploughs. This is what we found. In Column 5 – the coefficient on the distance from German townships is statistically indistinguishable from zero.

Finally, Table 5 reports the results for highly-skilled occupations as dependent variables. These are non-observable techniques the adoption of which is associated with the high communication costs of skill transmission. We measure this costly adoption of know-how with the share of households engaged in various types of craftsmanship (*promysly*), the number of smithies, carpentry workshops, textile factories, shoe shops, and tanneries per 1,000 households. The results support the "costly adoption" hypothesis – we do not find any evidence for the adoption of these highly-skilled occupations. The spatial pattern for craftsmenship is shown on Map 5.

6.2 Instrumental Variable Regressions

To rule out potential endogeneity concerns, we now proceed with the instrumental-variables estimation. Table 6 reports the results of the estimation. The first stage coefficients on potential caloric yield are presented in the bottom panel. We observe a positive and highly significant association between potential caloric yield and the

[31] The unconditional spatial distribution of fanning mills is presented on Map 4. We again observe the concentric pattern around German townships with the adoption of fanning mill declining with distance.

distance from German townships – a one standard deviation increase in distance entails a 0.413 standard deviation increase in potential caloric yield. The first stage F-statistics of 73.35 substantially surpasses the conventional critical value of 10.

The second stage coefficients the distance from the German townships support previous OLS results. We confirm the significant effect of the distance from the German townships on the adoption of heavy ploughs, fanning mills, and wheat – moving 50 km closer to German townships increases the number of heavy ploughs per 100 households by 20, the number of fanning mills per 100 households by 12, and the percentage of wheat crops by 14 percentage points. These results are very close to the OLS estimations.

We did not find evidence for the adoption of reapers and barley. Concerning barley, the significance of the coefficient on distance has disappeared compared to OLS regressions. These results confirm that techniques which were not widespread among the Germans themselves were not subject to adoption by the Russian population.

6.3 Testing the Instrument's Validity

Here we test the exclusion restriction as described in Section 5.2. We collected data on 106 counties in 10 provinces neighboring Saratov province and located in the same latitude range, but which did not experience an inflow of German colonists. The dependent variables are the number of heavy ploughs per household and share of arable land sowed with wheat. The main explanatory variable is potential caloric yield. We expect to see no relationship between potential yield and technology adoption in provinces without German colonies.

Table 7 reports OLS estimates of the placebo regressions. Across all the specifications, there is no significant effect of potential crop yield on heavy plough use and wheat production. We gradually include different sets of controls to demonstrate the robustness of our findings. The simple regression reported in Column 1 shows an insignificant coefficient and a very small R^2 value of 0.0001. In Column 2, we control for ruggedness, and in Column 3 for population density. We include a measure of the institutional legacy of serfdom, namely the share of private serfs before the emancipation reforms. In Column 4 we include the ethnic and religious composition. In Column 5 we regress the share of arable land under wheat on the same set of variables and again find no effect of potential crop yield.

The statistical significance of the share of Ukrainians in a county is consistent with the historical and ethnographic evidence which mention that Ukrainians grew wheat and employed heavy ploughs in agriculture to a larger extent than Russians (Zelenin, 1907).

We conclude that potential caloric yield does not have an effect on heavy plough use and wheat growing in provinces with no German colonies. Hence, the identifying assumption is plausible, and we can interpret the IV coefficients in Table 6 as a causal effect of German colonists on technology adoption among Russians.

6.4 Technology Adoption and Labor Productivity

The third step of our analysis is to test whether the adoption of heavy ploughs resulted in higher labor productivity in Russian townships. Table 8 reports the results of the estimation of Equation 4. The outcome variable is log wheat yield per household.

In Column 1 we find that heavy plough prevalence among Russian peasants has a positive and highly significant effect and explains about 27% of the variation in wheat production. The inclusion of the standard set of controls – development level in Column 2, population composition in Column 3, and geography in Column 4 – does not invalidate our result. The observed relationship is also robust to the inclusion of county fixed effects in Column 5. Although the magnitude of the coefficient diminishes, it remains statistically significant at the 1% level and large in terms of economic effect – a one standard deviation increase in the adoption of heavy ploughs increases agricultural productivity by 0.282 standard deviations (Figure 7). In terms of real measures, an additional plough per 100 households results in 10.5 kilograms of wheat per household. Alternatively, increasing the number of ploughs from the minimum value of 2 per 100 households to the maximum value of 89 adds about 900 kg of wheat yield per household.

This result is striking and suggests that the migration of skilled minorities may induce positive spillovers and be beneficial for local populations even with a slow or zero rate of cultural assimilation.

7 Fairs as a Potential Mechanism

What was the mechanism for the adoption of technology by Russian peasants from German colonists, given their separate settlements and the sporadic everyday interaction between the two cultural groups? Map 6 demonstrates the location and duration of fairs measured as the sum of fair days over a year in Saratov province. It is apparent that the intensity of fairs was higher on the boundary between German and Russian townships, which may indicate to fairs as a potential mechanism of technology transmission.

According to Mironov (1981), fairs constituted more than a half of the total turnover on the domestic market. In rural areas the role of fairs was paramount – since only 7% of rural population had access to retail trade, peasants participated either as buyers or sellers in 99% of all the fairs. Fairs were usually tied to religious holidays. Over a year, the number of fairs peaked twice: in May and June, when Easter, Ascension, and Pentecost were celebrated; and after the farming season, in September and October, on the Nativity of Mary, the feast of the Cross, and the Orthodox feast of John the Apostle. In early summer, peasants were buying crops, horses, and agricultural tools; in autumn, peasants sold their harvest and bought consumption goods.

In 1913, Saratov province hosted 247 fairs in 133 rural settlements. The settlement with the longest fair and the largest total duration of fairs over a year was the German colony *Krestovo-Medveditsky-Buyerak* (Frank in German) of Medveditsa township in Atkarsky county. It hosted 3 fairs: from the 8th until the 11th of February, on the feast of Pentecost[32], and from the 5th of September until the 10th of October. Moreover, Medveditsa township bordered three Russian townships that did not host any fairs, which could suggest that population of those townships visited fairs in Krestovo-Medveditsky-Buyerak.

[32] Pentecost is celebrated on the fiftieth day after Easter Sunday, usually at the end of May.

Once we treat fairs as the main mechanism for innovation adoption, it becomes explainable why skills and know-how were not subject to diffusion. The transmission of knowledge requires long-term interpersonal communications, which are difficult to maintain between distinct cultural groups in a traditional agrarian setting. Fairs provided only limited interaction, insufficient to transmit advanced skills which were needed to design, construct and maintain the tools. It seems like the adoption of tools rather than skills was a second best available option in this particular setting.

8 Conclusion

This paper examines the adoption of the advanced agricultural technology introduced by the German minority among the relatively backward Russian majority in Saratov province of the Russian Empire in the late 19th – early 20th centuries. Using highly disaggregated township (*volost*) level data, we examine the variation in the prevalence of advanced tools and skills among the Russian peasants and its dependence on the geographical proximity to the German colonies.

We document that in the areas located closer to the German townships, Russians successfully adopted advanced agricultural equipment, such as heavy ploughs and fanning mills, and easily observable techniques, such as the production of wheat. We observe the significant spatially concentric pattern of technology adoption decreasing with distance. In terms of real measures, moving 50 km closer to German settlements increases the number of heavy ploughs per 100 Russian households by 12.5, the number of fanning mills per 100 Russian households by 10, and the percentage of wheat crops by 10 percentage points. We also show a significant rise in agricultural productivity measured as wheat yield per household associated with the higher number of heavy ploughs per household.

However, we show that no advanced artisanal skills were adopted, most likely because they constitute tacit knowledge that can be transferred only through the long process of deliberate personal interaction. There was no institution to support this kind of knowledge transmission between culturally and linguistically distant groups in a traditional agrarian setting. Occasional trade contacts allowed for adoption of tradable tools and easily observable know-how, but were insufficient for the diffusion of more advanced skills.

There is a long-standing agreement among economists that technology adoption is at the heart of catch-up economic growth. However, there is no consensus on why adoption differs enormously between countries and technologies. This paper suggests that differences in the relative weights of the "hardware" (tools) and "software" (knowledge) components of technology might account for part of this variation. The exact quantification of these components for various types of technologies, and theoretical modeling of the resulting diffusion process would be a fruitful future research avenue.

Acknowledgements

We thank Eren Arbatli, Felipe Valencia Caicedo, Ruben Enikolopov, Cormac O'Grada, Amanga Gregg, Raphael Frank, Hartmut Lehmann, Steven Nafziger, Leonid Polishchuk, Koen Schoors, participants of the PennState Workshop on Russian Economic

History and the 2019 Russian Summer School on Institutional Analysis for valuable comments and suggestions that helped to improve the paper. Maxim Gritsenko provided excellent research assistance. The financial support of the Program of Fundamental Studies of the National Research University Higher School of Economics is gratefully acknowledged.

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9 Tables

Table 1: Determinants of Ethnic Settlements (OLS Regressions)

	(1) Tatars, %	(2) Russians, %	(3) Ukrainians, %	(4) Germans, %
Potential caloric yield (mean)	0.148**	0.244***	-0.347***	-0.362***
	(2.15)	(3.53)	(-5.20)	(-5.48)
Potential caloric yield (std)	-0.068	0.074	-0.039	-0.018
	(-1.11)	(1.21)	(-0.67)	(-0.32)
Ruggedness	0.162**	-0.310***	-0.105*	0.081
	(2.49)	(-4.79)	(-1.67)	(1.31)
Township on Volga	-0.058	0.111	-0.167**	-0.083
	(-0.80)	(1.56)	(-2.40)	(-1.20)
R^2	0.048	0.113	0.099	0.123
Observations	271	271	272	271

Notes: Dependent variables are share of Tatars (column 1), Russians (column 2), Ukrainians (column 3), and Germans (column 4) in the *volost* population. All regressions are run on the *volost* level with robust standard errors clustered at the *uezd* level. Standardized beta coefficients are reported with *t*-statistics in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2: Comparison of German and Russian Townships (Mean Values)

	(1) German townships	(2) Russian townships	(3) Difference (1)-(2)	(4) Whole sample
Population and human capital				
Population, thousands	22.3	6.9	15.4***	8.6
Population density, per sq. km	57.7	31.6	26.1***	35.1
Literacy, %	49.9	5.1	44.8***	7.5
Schools, per 1000 households	3.37	1.00	2.37***	1.15
Agriculture and trade				
Heavy ploughs, per 100 households	75.1	38.8	36.3***	41.8
Fanning mills, per 100 households	41.6	13.6	28.0***	15.2
Reapers, per 100 households	29.4	4.0	25.5***	3.9
Animals per household	16.1	9.9	6.1***	9.4
Wheat, % of all crops	56.9	16.7	40.2***	28.2
Rye, %	28.1	44.0	-15.9***	38.0
Oats, %	3.9	16.2	-12.3***	11.7
Barley, %	3.2	1.0	2.1**	1.6
Land under crops, % of arable land	65.7	65.7	0.0	67.1
Fairs, days per year	8.4	0.58	7.8***	1.4
High-skilled occupations				
Craftsmen, % of households	26.9	7.2	19.6***	10.8
Smithy (forge), per 1000 households	1.4	0.0	1.4***	0.06
Carpentry, per 1000 households	0.54	0.01	0.52**	0.03
Textile factory, per 1000 households	0.99	0.0	0.99***	0.039
Shoe workshop, per 1000 households	1.31	0.02	1.29***	0.054
Tannery, per 1000 households	3.30	0.04	3.26***	0.41
Geography				
Potential yield, calories	1664.0	1872.8	-208.8***	1839.5
Terrain ruggedness	53.6	37.0	16.6***	43.2
Average temperature, Celsius	5.8	5.1	0.75**	5.3
Annual precipitation, mm	427.3	509.5	-82.2***	503.5
N	10	89		276

Notes: Columns (1), (2), (4) report mean values of respected variables. Column (3) reports difference between (1) and (2). Ten German townships are those where Germans constituted more than 99% of population. To obtain the sample of Russian townships we take those where Orthodox constituted more than 99% of population and exclude Ukrainian townships from the sub-sample. Asterisk indicate statistical significance of differences in means according to t-test on the equality of means (null hypothesis).
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3: Diffusion of Heavy Ploughs (OLS Regressions)

	(1)	(2)	(3)	(4)	(5)
	Heavy (iron) ploughs per 100 households				
Distance from German townships	-0.574***	-0.453***	-0.505***	-0.525***	-0.705***
	(-5.67)	(-4.34)	(-4.75)	(-5.44)	(-3.89)
Population density		-0.069	-0.061	-0.057	-0.052
		(-0.85)	(-0.77)	(-0.72)	(-0.62)
Literacy		0.164*	0.115	0.130	0.076
		(1.91)	(1.23)	(1.45)	(0.84)
Animals per household		0.275***	0.299***	0.259***	0.222***
		(3.98)	(4.93)	(4.31)	(3.85)
Railroad		-0.053	-0.065*	-0.074**	-0.019
		(-0.97)	(-2.24)	(-2.38)	(-0.51)
Ruggedness				-0.119	-0.166***
				(-1.69)	(-4.08)
River dummy				-0.066	-0.126
				(-0.69)	(-1.80)
Population composition controls			✓	✓	✓
County fixed effects					✓
R^2	0.330	0.422	0.474	0.488	0.587
Observations	260	252	250	250	250

Notes: Dependent variable is the number of heavy ploughs per 100 households. Ten *volosts* with more than 99% of Germans are excluded from the sample. Population composition controls include shares of Ukrainians, Tatars, Old Believers, Jews, and Germans. All regressions are run on the *volost* level with robust standard errors clustered at the *uezd* level. Standardized beta coefficients are reported with *t*-statistics in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Diffusion of Agricultural Equipment and Crops (OLS Regressions)

	(1) Fanning mills, per 100 households	(2) Reapers, per 100 households	(3) Wheat, % of all crops	(4) Barley, % of all crops	(5) Land under crops, %
Distance from German townships	-0.899***	-0.453	-0.577***	-0.463*	0.100
	(-4.63)	(-1.65)	(-3.61)	(-2.22)	(0.38)
Population density	0.086	-0.062	-0.100**	-0.132**	0.005
	(1.25)	(-1.71)	(-2.38)	(-2.78)	(0.08)
Literacy	0.087	0.039	0.119**	0.033	0.095
	(1.05)	(0.90)	(2.55)	(0.53)	(1.72)
Animals per household	0.234***	0.234***	0.030	0.029	0.064
	(3.44)	(3.59)	(0.54)	(0.46)	(1.45)
Railroad	-0.041	-0.085	-0.047	-0.029	-0.010
	(-0.68)	(-1.01)	(-1.28)	(-0.79)	(-0.17)
Ruggedness	-0.038	0.003	0.113	0.144	-0.031
	(-1.05)	(0.04)	(1.57)	(1.22)	(-0.27)
River dummy	-0.015	-0.090*	0.001	0.123	0.194**
	(-0.33)	(-2.25)	(0.01)	(1.35)	(2.29)
Population composition controls	✓	✓	✓	✓	✓
County fixed effects	✓	✓	✓	✓	✓
R^2	0.669	0.486	0.792	0.385	0.481
Observations	249	250	250	250	250

Notes: Dependent variables are number of fanning mills and reapers per 100 households (columns 1 and 2 respectively), share of arable land sowed by wheat and barley (columns 3 and 4 respectively), and share of arable land sowed with any crop. Ten *volosts* with more than 99% of Germans are excluded from the sample. Population composition controls include shares of Ukrainians, Tatars, Old Believers, Jews, and Germans. All regressions are run on the *volost* level with robust standard errors clustered at the *uezd* level. Standardized beta coefficients are reported with t-statistics in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Non-Diffusion of High-Skilled Occupations (OLS regressions)

	(1) Craftsman, % of households	(2) Smithy,	(3) Carpentry,	(4) Textiles,	(5) Shoe shops,	(6) Tannery,
		per 1000 households				
Distance from German townships	-0.061	-0.236	0.183	-0.236	0.053	0.462
	(-0.43)	(-1.37)	(0.78)	(-1.37)	(1.16)	(1.62)
Population density	0.020	-0.049	-0.036	-0.049	-0.036	0.046
	(0.33)	(-0.98)	(-0.53)	(-0.98)	(-0.77)	(0.59)
Literacy	0.313***	0.071	-0.055	0.071	0.085	0.251
	(4.49)	(0.95)	(-0.98)	(0.95)	(0.87)	(1.61)
Animals per household	-0.193	0.062	-0.014	0.062	-0.022	-0.170
	(-1.82)	(0.96)	(-0.14)	(0.96)	(-0.93)	(-1.20)
Railroad	0.054	0.036	-0.064	0.036	-0.055	0.077
	(1.76)	(0.98)	(-1.56)	(0.98)	(-0.86)	(1.01)
Ruggedness	0.329***	-0.021	0.055	-0.021	-0.112	-0.010
	(3.84)	(-0.39)	(1.65)	(-0.39)	(-0.88)	(-0.12)
River dummy	0.137	0.197	-0.048	0.197	-0.040	-0.103
	(1.42)	(1.26)	(-1.08)	(1.26)	(-0.99)	(-1.02)
Population composition controls	✓	✓	✓	✓	✓	✓
County fixed effects	✓	✓	✓	✓	✓	✓
R^2	0.464	0.287	0.063	0.287	0.062	0.299
Observations	250	232	232	232	232	232

Notes: Dependent variable in column 1 is share of households in a *volost* employed in craftsmanship (*promysly*). In columns 2-6 dependent variables are number of smithies, carpentry workshops, textile factories, shoe workshops, and tanneries per 1000 households in a *volost*. Ten *volosts* with more than 99% of Germans are excluded from the sample. Population composition controls include shares of Ukrainians, Tatars, Old Believers, Jews, and Germans. All regressions are run on the *volost* level with robust standard errors clustered at the *uezd* level. Standardized beta coefficients are reported with t-statistics in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Diffusion of Agricultural Equipment and Crops (IV Regressions)

	(1) Heavy ploughs	(2) Fanning mills	(3) Reapers	(4) Wheat	(5) Barley
Distance from German townships	-1.149**	-1.065***	-0.603	-0.793**	-0.814
	(-2.45)	(-5.74)	(-1.17)	(-2.69)	(-1.67)
Standard set of controls	✓	✓	✓	✓	✓
County fixed effects	✓	✓	✓	✓	✓
Second stage R^2	0.557	0.665	0.483	0.785	0.366
Potential caloric yield (mean)	0.413***	0.413***	0.413***	0.413***	0.413***
(first stage coefficient)	(6.44)	(6.44)	(6.44)	(6.44)	(6.44)
First stage F-statistics	73.35	73.37	73.35	73.35	73.35
First stage R^2	0.871	0.871	0.871	0.871	0.871
Observations	250	249	250	250	250

Notes: Lower panel reports fist stage estimation results where the dependent variable is distance to German townships. Upper panel reports second stage coefficients for the main explanatory variable. Standard set of controls include same controls as in Tables 3-5. Ten *volosts* with more than 99% of Germans are excluded from the sample. All regressions are run on the *volost* level with robust standard errors clustered at the *uezd* level. Standardized beta coefficients are reported with t-statistics in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Placebo Regressions: Neighboring Counties without German Settlements (OLS)

	(1)	(2)	(3)	(4)	(5)
	Heavy ploughs per household				Wheat, %
Potential caloric yield (mean)	0.011	-0.021	0.182	-0.032	-0.014
	(0.12)	(-0.21)	(1.59)	(-0.29)	(-0.16)
Ruggedness		0.147	0.057	0.047	0.046
		(1.47)	(0.56)	(0.59)	(0.66)
Population density			-0.513***	-0.418***	-0.456***
			(-4.29)	(-3.91)	(-3.86)
Private serfs in 1858, %			-0.034	-0.038	-0.249***
			(-0.32)	(-0.40)	(-3.38)
Ukrainians, %				0.420***	0.485***
				(4.81)	(5.28)
Belorussians, %				0.063	0.013
				(0.69)	(0.15)
Muslims, %				-0.136	-0.046
				(-1.60)	(-1.00)
R^2	0.000	0.021	0.256	0.440	0.664
Observations	106	106	106	106	106

Notes: Placebo regressions on counties (*uezd*) without German colonies neighboring the Saratov province. The dataset covers 106 counties in 10 provinces: Don ($n = 9$), Kaluga ($n = 11$), Kursk ($n = 15$), Orel ($n = 12$), Penza ($n = 10$), Ryazan ($n = 12$), Simbirsk ($n = 8$), Stavropol ($n = 5$), Tambov ($n = 12$), Tula ($n = 12$). The dependent variables are the number of heavy ploughs per household (columns 1-4), and share of arable land sowed with wheat (column 5). See Section 4 for data sources. Standardized beta coefficients are reported with t-statistics in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: Heavy Plough and Labor Productivity in Wheat Production (OLS)

	(1)	(2)	(3)	(4)	(5)
	log Wheat yield per household				
Heavy ploughs per household	0.518***	0.507***	0.482***	0.485***	0.282***
	(4.52)	(3.90)	(4.59)	(5.47)	(4.71)
Animals per household		-0.048	0.007	0.087	0.100*
		(-0.37)	(0.07)	(1.78)	(1.88)
Literacy		0.137	0.113	0.122	0.069
		(1.42)	(1.58)	(1.81)	(1.24)
Railroad		-0.053	-0.026	0.005	0.054
		(-0.78)	(-0.41)	(0.09)	(1.52)
Ruggedness				0.460***	0.137
				(5.48)	(1.44)
River dummy				-0.097	-0.066
				(-1.39)	(-0.76)
Population composition controls			✓	✓	✓
County fixed effects					✓
R^2	0.268	0.292	0.355	0.529	0.753
Observations	260	252	250	250	250

Notes: Dependent variable is log wheat yield per household. Ten *volosts* with more than 99% of Germans are excluded from the sample. Population composition controls include shares of Ukrainians, Tatars, Old Believers, Jews, and Germans. All regressions are run on the *volost* level with robust standard errors clustered at the *uezd* level. Standardized beta coefficients are reported with t-statistics in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

10 Figures

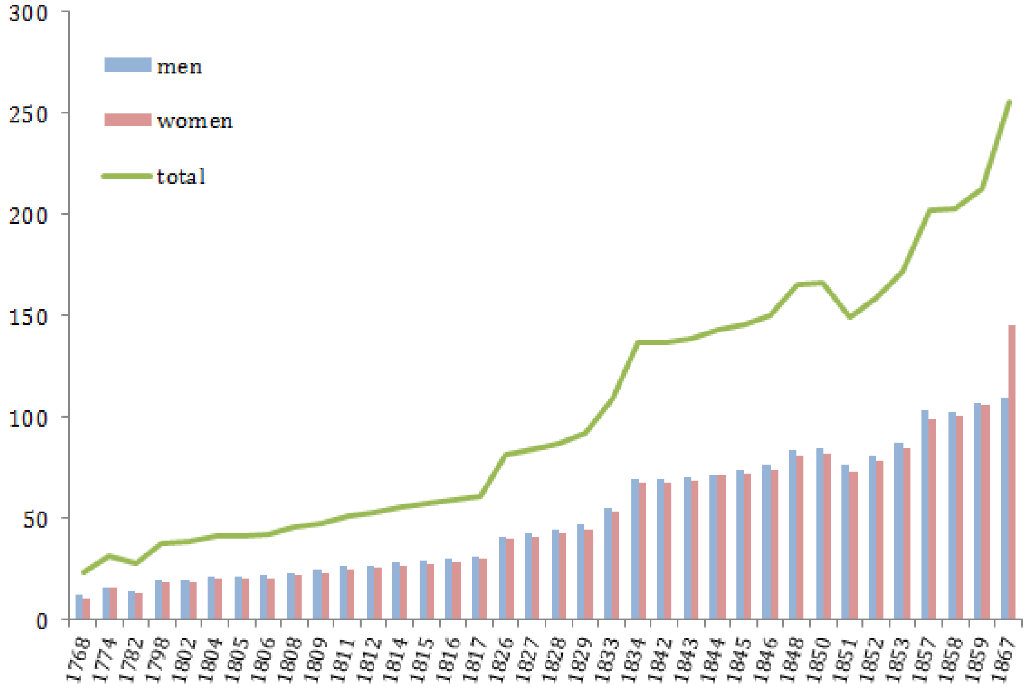

Figure 3: Population of German colonies on Volga (thousands). Source: Kabuzan (2003)

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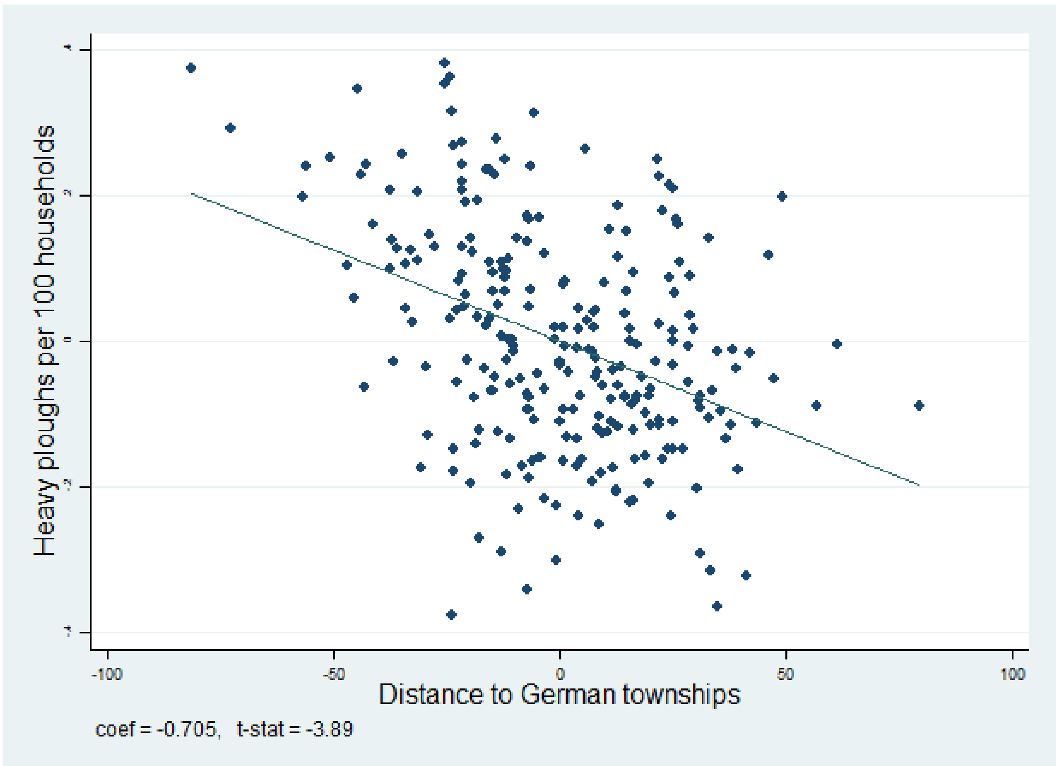

Figure 4: Adoption of heavy (iron) ploughs. Source: Table 3, column 5

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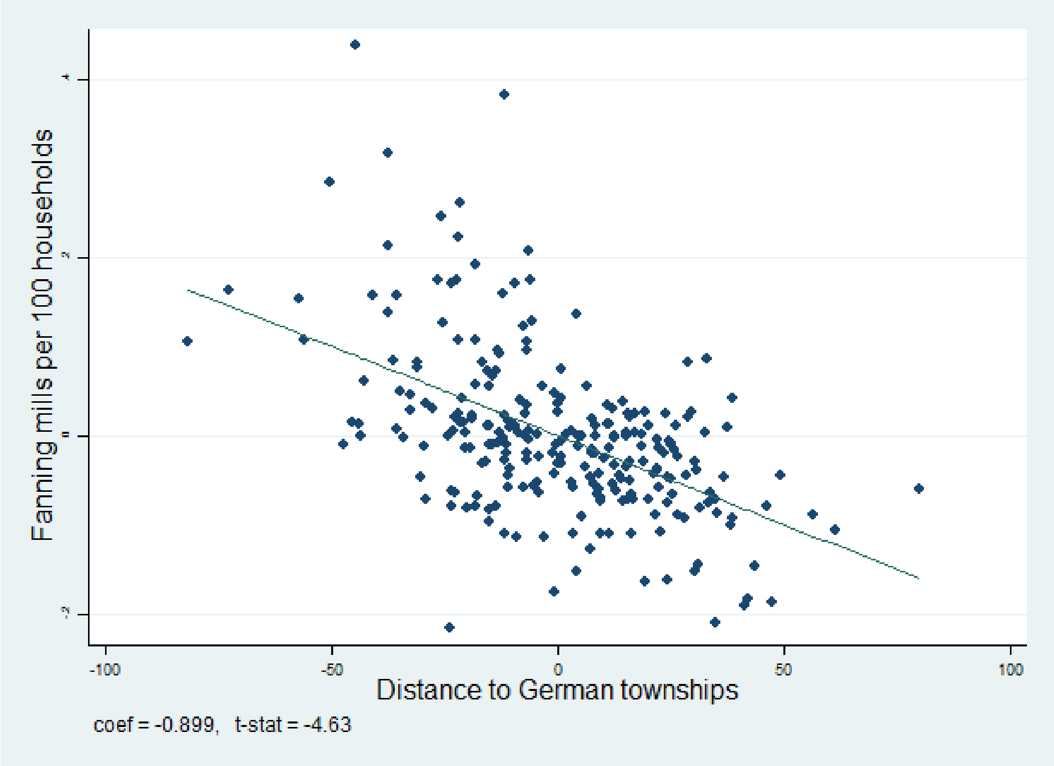

Figure 5: Adoption of fanning mills. Source: Table 4, column 1
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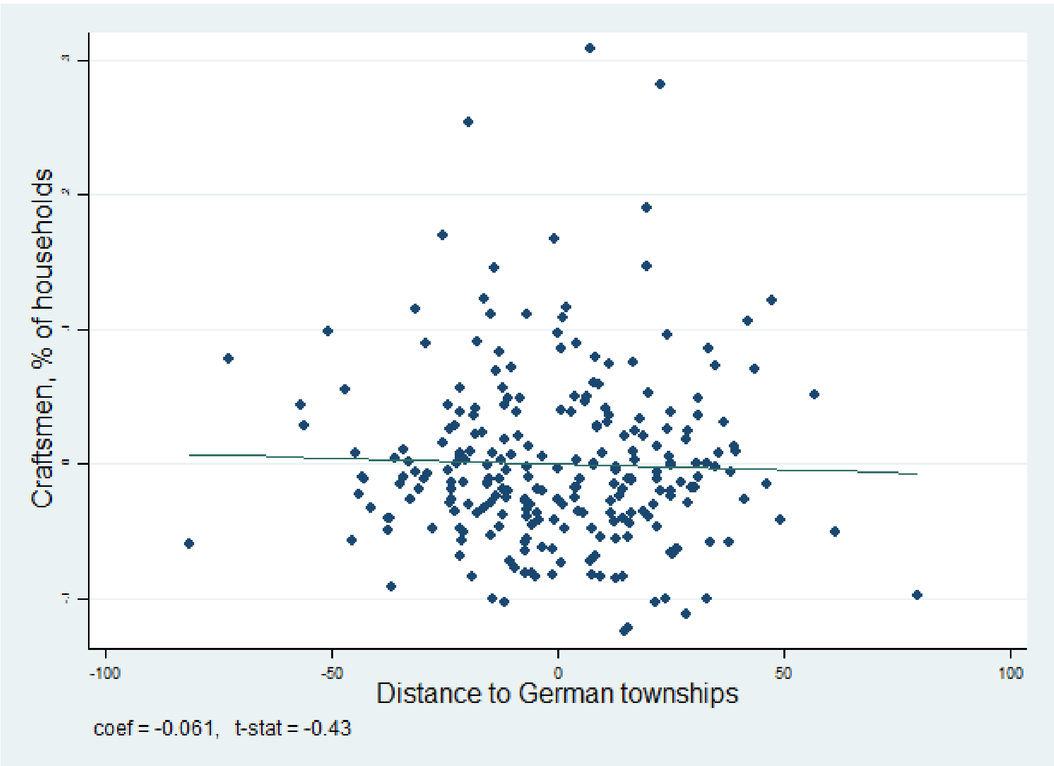

Figure 6: Non-diffusion of craftsmanship. Source: Table 5, column 1.
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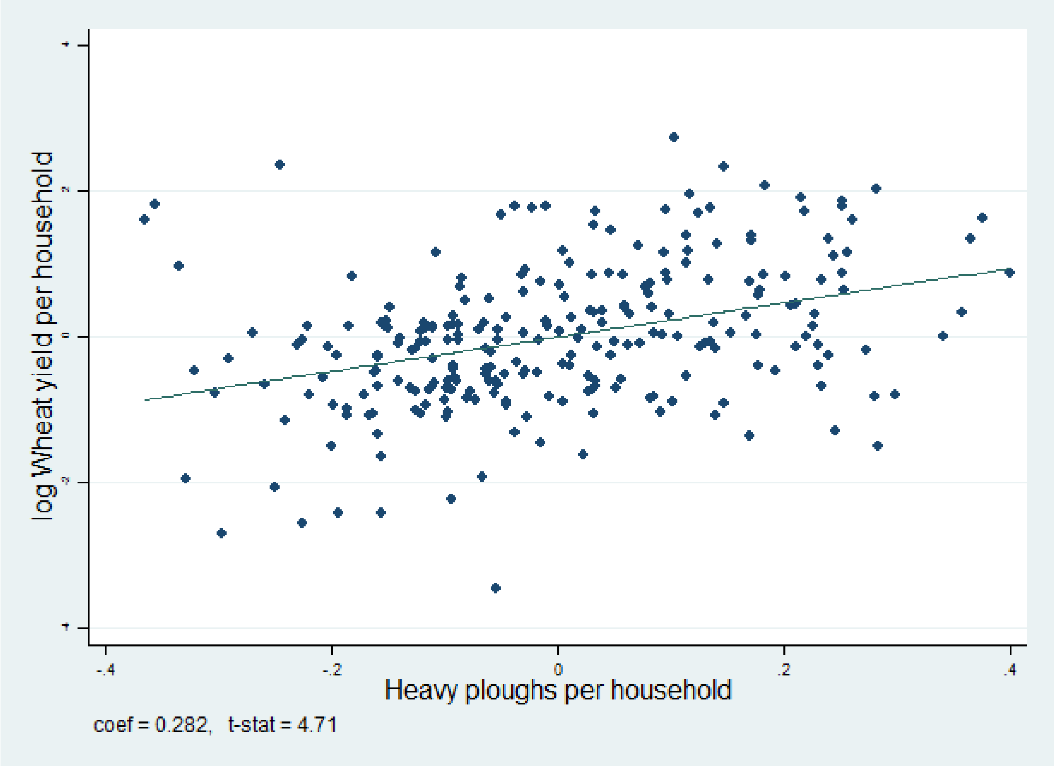

Figure 7: Heavy plough and wheat yield per household. Source: Table 8, column 5
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11 Appendix

11.1 Sources for Main Dataset

Variable	Description	Source
Heavy ploughs, per 100 households	The number of heavy (iron) ploughs per 100 households in 1914	the Saratov Provincial Zemstvo (1914)
Fanning mills, per 100 households	The number of fanning mills per 100 households in 1913	
Reapers, per 100 households	The number of reapers per 100 households in 1913	
Smithy	The number of forges per 1000 households in 1883	Central Statistical Committee (1883)
Carpentry	The number of carpentry workshops per 1000 households in 1883	
Textiles	The number of textile factories per 1000 households in 1883	
Shoe shops	The number of shoe workshops per 1000 households in 1883	
Tannery	The number of tanneries per 1000 households in 1883	
Wheat, % of all crops	The percentage of wheat of total crops in 1917	the Saratov Provincial Statistics Bureau (1919)
Barley, % of all crops	The percentage of wheat of total crops in 1917	
Land under crops, %	The percentage of sown land of total arable land in 1917	
Craftsmen, %	The percentage of households engaged in craftsmanship in 1917	
Wheat yield per household	Wheat yield in *poods* in 1914 per household in 1913	Voznesensky (1915)
Distance from German townships	Distance from the township centroid to the centroid of German colonies (excluding Sarepta), in km	Own calculations, using the map of Saratov province digitized from Tezyanov (1904)
Population density	Number of peasant residents per township area in 1913	the Saratov Provincial Zemstvo (1914)
Animals per household	The number of livestock in 1913	
Fairs, days per year	The location and cumulative duration of fairs in a township in days per year, by 1913	
Literacy rate	The share of population who completed any type of education in any language in late 1880s (data on each county were collected in a separate year)	the Saratov Provincial Zemstvo (1888)
Ukrainians, %	The share of Ukrainians in 1913	the Saratov Provincial Zemstvo (1914)
Muslims, %	The share of Muslims in 1897	1897 Imperial Census. Russian State Historical Archive in Saint Petersburg. F. 1290. Op. 11. D. 2041-2075.
Old Believers, %	The share of Old Believers in 1897	

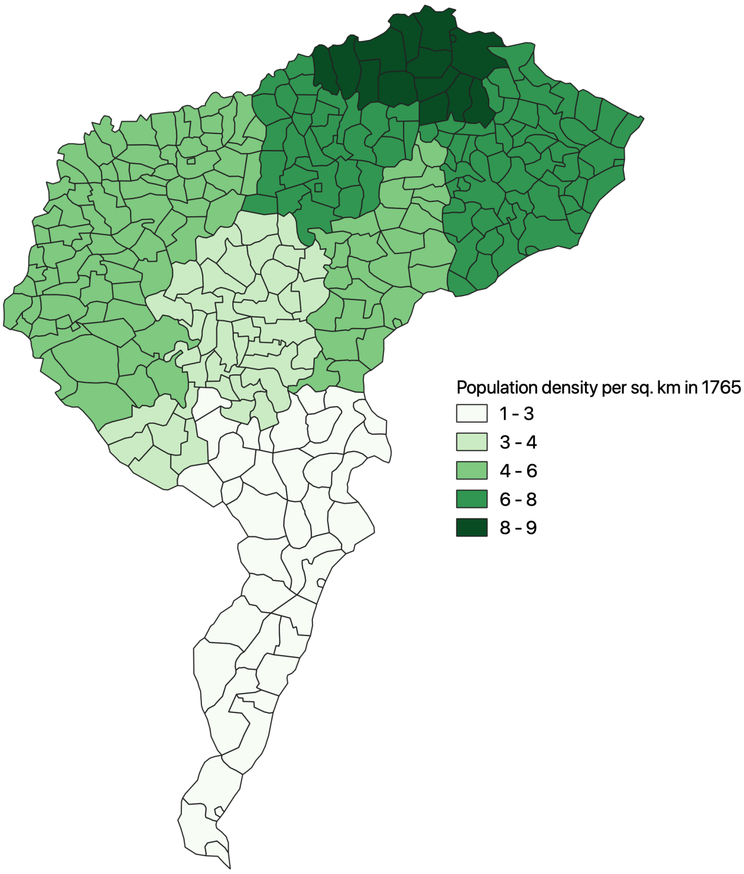
Jews, %	The share of Jews in 1897	
Germans, %	The share of Germans measured as a sum of Protestants and Catholics in a township in 1897	
Potential caloric yield	Potential agricultural output (measured in calories)	Galor and Ozak (2016)
Ruggedness	Average terrain ruggedness	Shaver et al. (2019)
Temperature	Mean and standard deviation of the year temperature	Fick and Hijmans (2017)
Precipitation	Mean and standard deviation of the annual precipitation	

11.2 Sources for Placebo Dataset

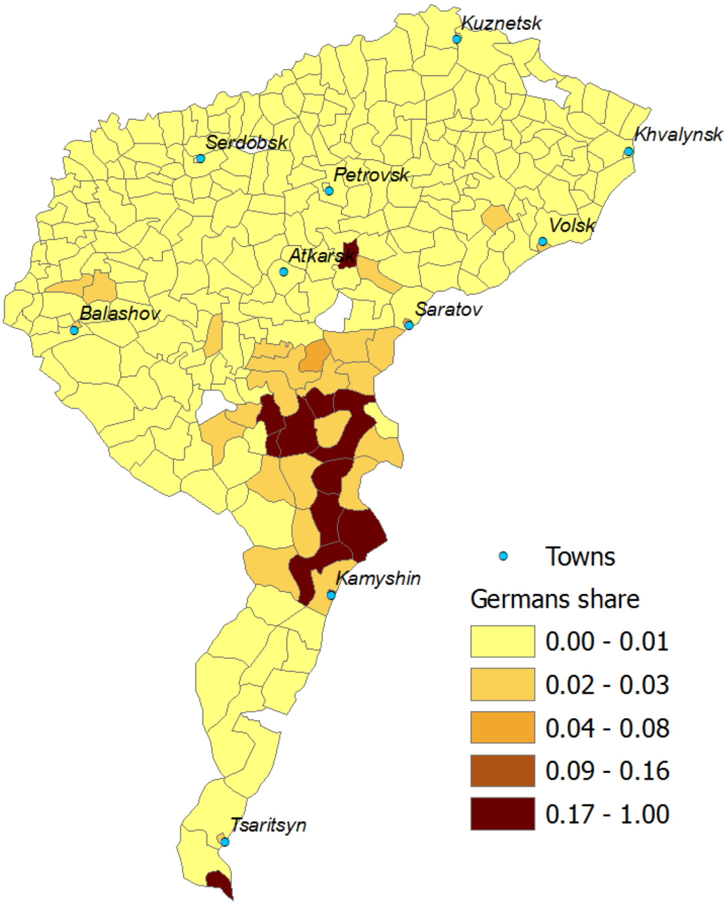
This county-level dataset covers 8 provinces located approximately on the same latitude as Saratov province: Kaluga (10), Kursk (15), Orel (12), Penza (10), Ryazan (12), Simbirsk (8), Tambov (12), Tula (12).

Variable	Description	Source
Heavy ploughs, per household	The number of heavy ploughs per household in 1917	the Central Statistics Office (1923)
Population density	The number of peasant residents per township area in 1917	
Potential caloric yield	Potential agricultural output (measured in calories)	Galor and Ozak (2016)
Ruggedness	Average terrain ruggedness	Shaver et al. (2019)
Private serfs in 1858, %	The share of private serfs in 1858	Buggle and Nafziger (2017)
Ukrainians, %	The share of Ukrainians in 1897	
Belorussians, %	The share of Belorussians in 1897	Trojnickij (1904)
Tatars, %	The share of Tatars in 1897	

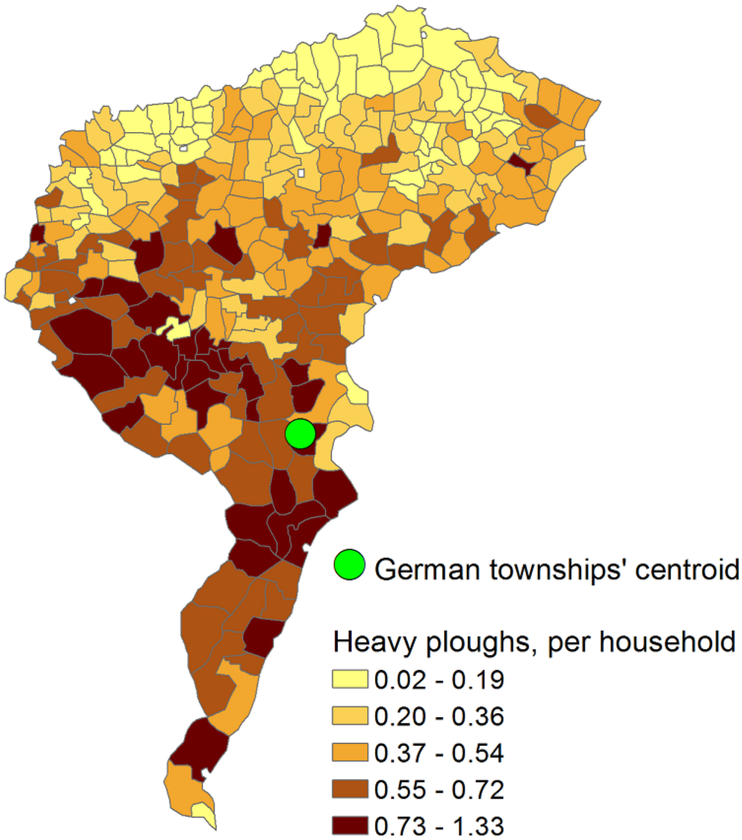
12 On-line Appendix



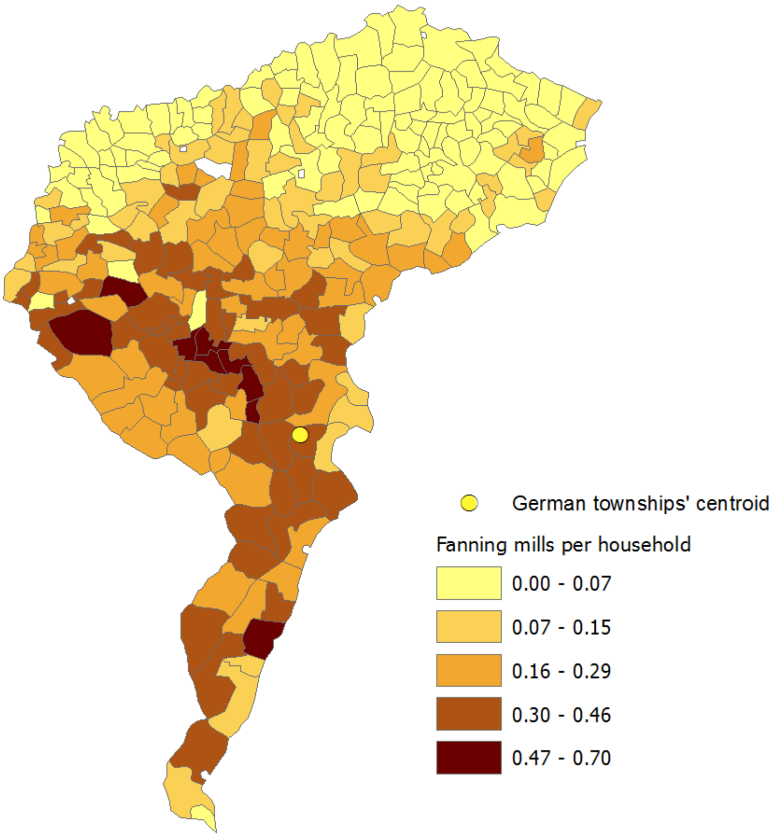
Map 1: Population density in 1765. Source: Kabuzan (1990)



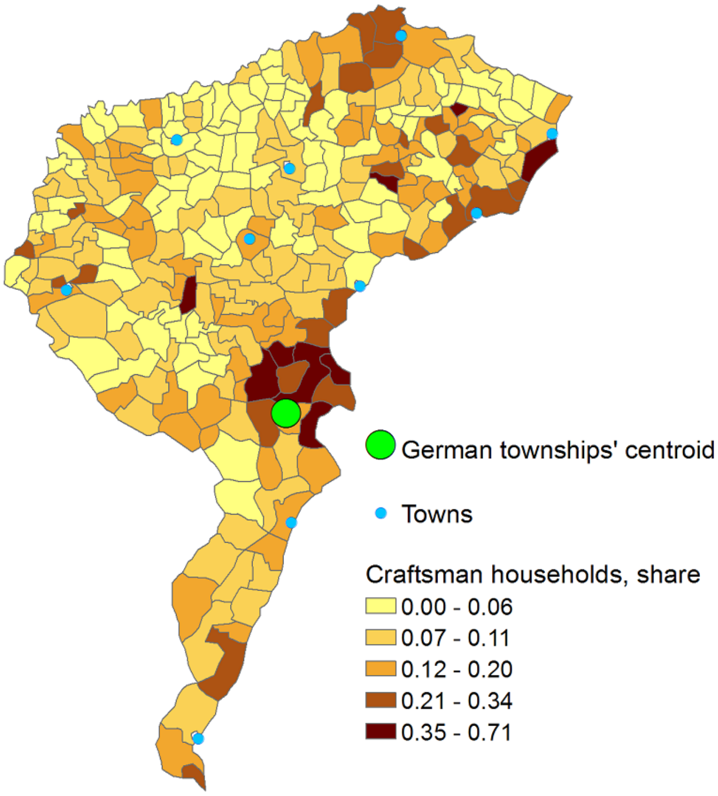
Map 2: Share of German population. Source: 1897 Imperial Census.



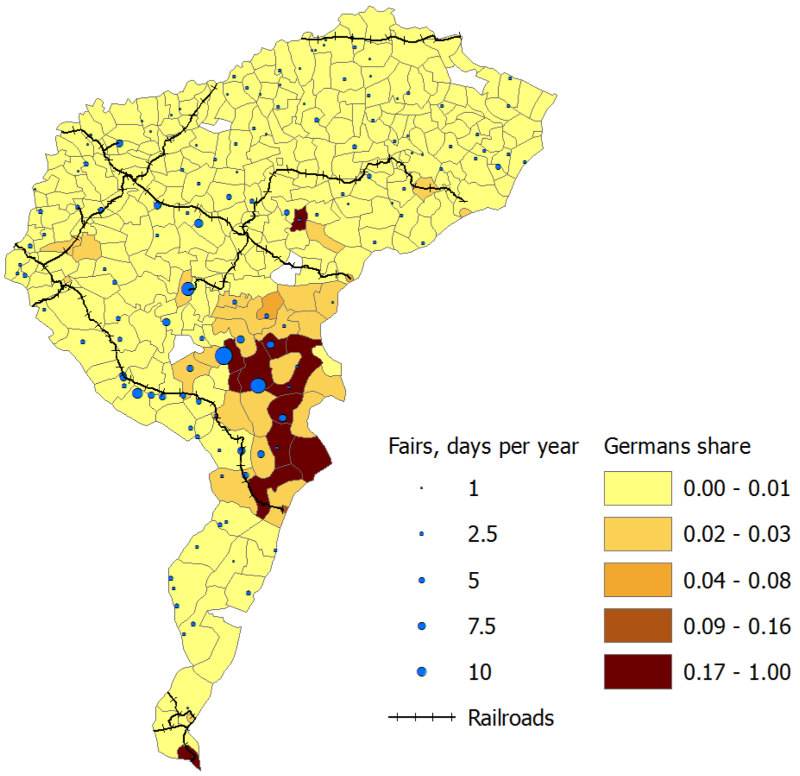
Map 3: Adoption of Heavy Ploughs. Source: the Saratov Provincial Zemstvo (1914)



Map 4: Adoption of Fanning Mills. Source: the Saratov Provincial Zemstvo (1914)



Map 5: Non-Adoption of Craftsmanship. Source: the Saratov Provincial Statistics Bureau (1919)



Map 6: Location and duration of fairs. Source: the Saratov Provincial Zemstvo (1914)

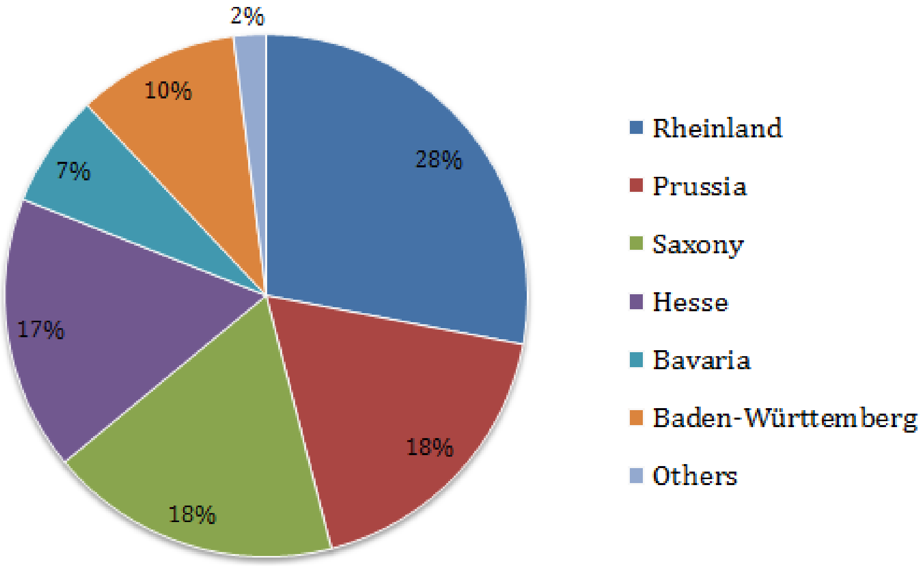


Figure 8: Source regions of German out-migration. Source: Hempel (1865)
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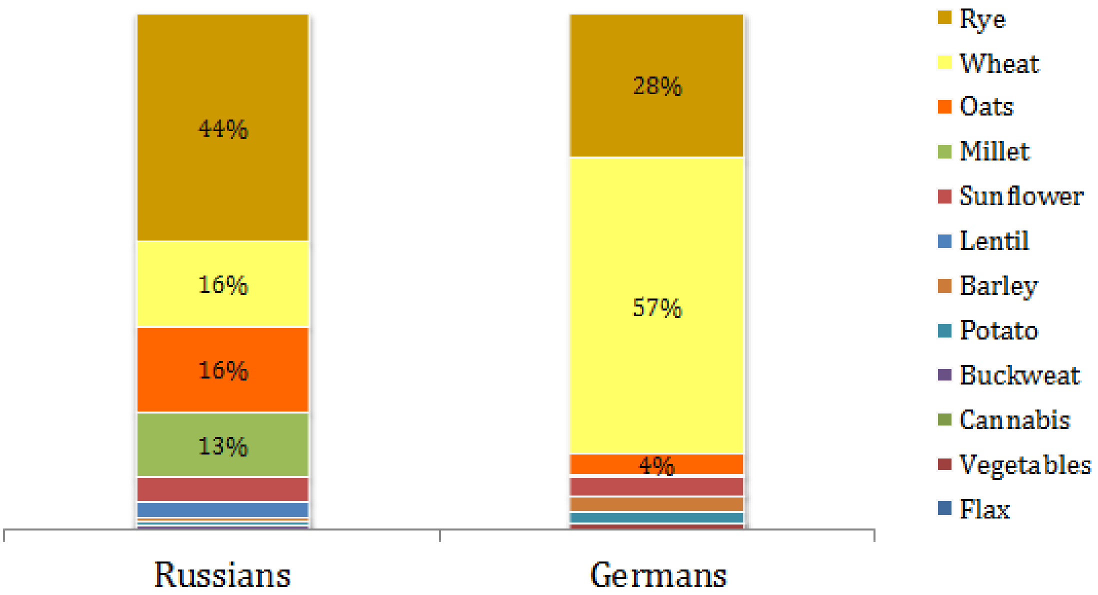

Figure 9: Crop diversity among Russians and Germans (% of cultivated area). Source: the Saratov Provincial Statistics Bureau (1919)
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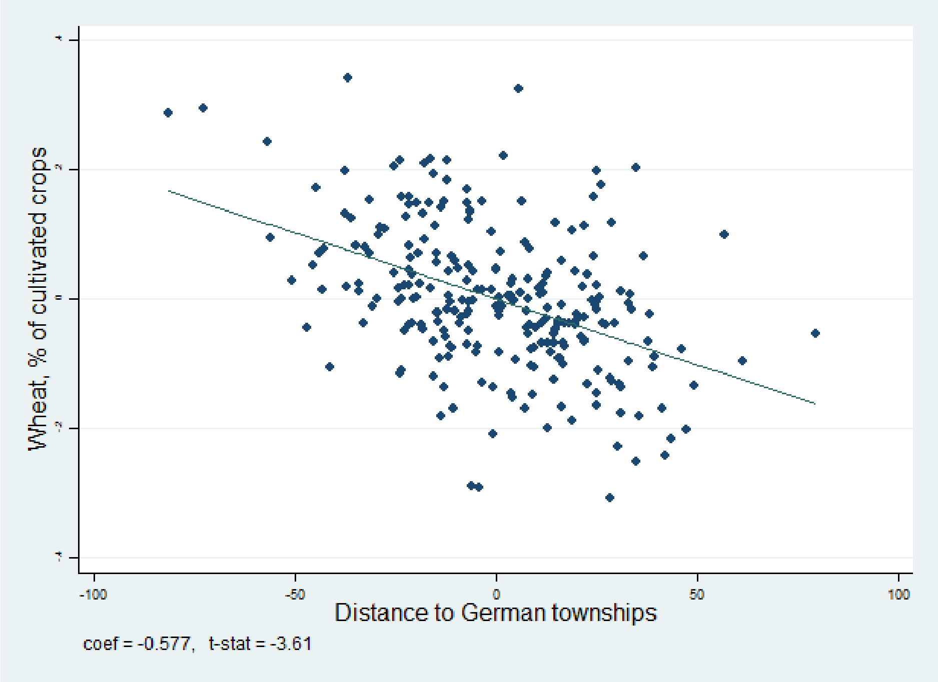

Figure 10: Diffusion of wheat. Source: Table 4, column 3.

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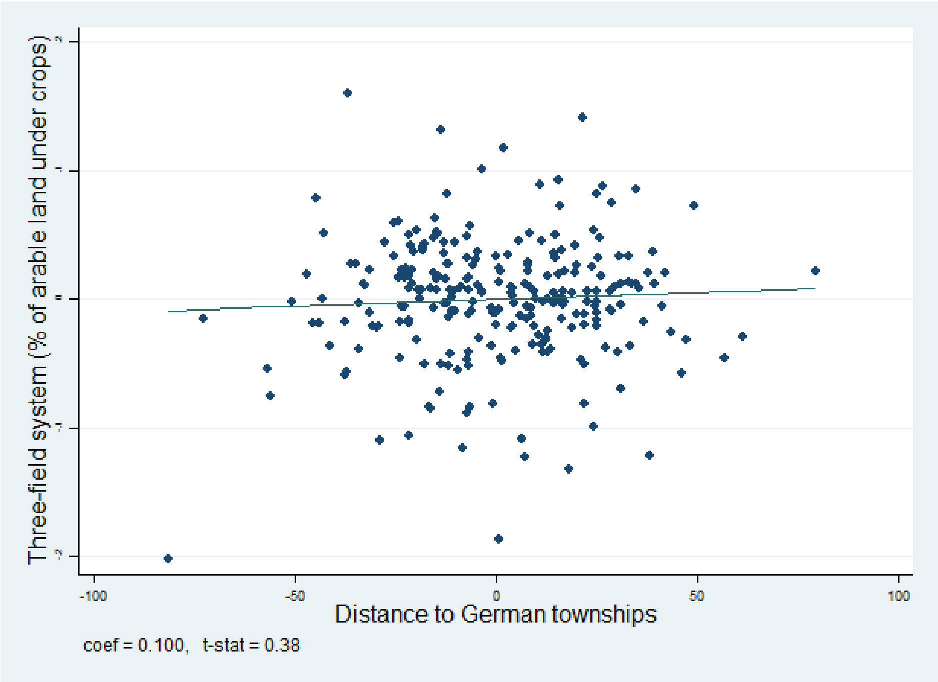

Figure 11: Non-diffusion of three-field system. Source: Table 4, column 5.

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. Source: http://wolgadeutsche.net

Photo 1: German mill near Linyovo-Ozero (former Kamyshin county)

Table 11: Summary Statistics

Variable	**Whole sample**	**German townships**	**Russian townships**
Population density, per sq. km	35.1	57.7	31.6
	(22.7)	(32.9)	(17.6)
Orthodox, %	86.9	0.0	99.8
	(23.7)	(0.0)	(0.0)
Old Believers, %	4.9	0.0	0.0
	(9.8)	(0.0)	(0.0)
Protestants, %	3.2	75.8	0.0
	(16.3)	(37.9)	(0.0)
Catholics, %	0.9	23.8	0.0
	(8.2)	(37.9)	(0.0)
Muslims, %	3.9	0.0	0.0
	(13.6)	(0.0)	(0.0)
Literacy, %	7.5	49.9	5.1
	(8.7)	(11.9)	(2.0)
Heavy ploughs, per 100 households	41.8	75.1	38.8
	(22.9)	(12.7)	(21.7)
Animals per household	9.4	16.1	9.9
	(3.3)	(3.9)	(2.8)
Craftsmen, % of households	10.8	26.9	7.2
	(9.9)	(23.3)	(5.3)
Land under crops, % of cultivated land	67.8	65.7	65.7
	(6.7)	(5.6)	(5.5)
Rye, % of all crops	38.0	28.1	44.0
	(12.3)	(7.6)	(6.9)
Wheat, % of all crops	28.2	56.9	16.7
	(22.9)	(11.6)	(17.7)
Barley, % of all crops	1.6	3.2	1.0
	(2.5)	(1.6)	(2.5)
Oats, % of all crops	11.7	3.9	16.2
	(9.3)	(2.3)	(9.2)
Fairs, days per year	1.4	6.5	0.58
	(3.0)	(8.6)	(1.17)
Number of observations	276	10	89

Note: Standard deviation in parenthesis.

Table 12: Determinants of Ethnic Settlements. Alternative Explanatory Variables (OLS Regressions)

	(1) Tatars, %	(2) Russians, %	(3) Ukrainians, %	(4) Germans, %
Temperature (mean)	-0.047	0.023	0.361***	-0.099
	(-0.52)	(0.25)	(4.19)	(-1.13)
Temperature (std)	0.084	-0.037	-0.115	-0.130
	(0.77)	(-0.33)	(-1.10)	(-1.21)
Precipitation (mean)	0.266***	0.035	-0.158*	-0.426***
	(2.92)	(0.38)	(-1.81)	(-4.79)
Precipitation (std)	0.062	-0.011	0.101	-0.052
	(0.62)	(-0.11)	(1.06)	(-0.54)
Ruggedness	0.019	-0.290***	-0.010	0.277***
	(0.23)	(-3.40)	(-0.13)	(3.34)
Township on Volga	-0.052	0.008	-0.255***	0.020
	(-0.66)	(0.10)	(-3.39)	(0.26)
R^2	0.111	0.101	0.175	0.151
Observations	271	271	272	271

Standardized beta coefficients; t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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