Structural Change, Elite Capitalism, and the Emergence of Labor Emancipation*

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Abstract

This study argues that the decline of coercive labor institutions over the course of industrialization was partly driven by complementarity between physical capital and effective labor in manufacturing. Given the difficulty of extracting labor effort in care-intensive industrial tasks through monitoring and punishment, capital-owning elites ultimately chose to emancipate workers to induce their supply of effective labor and, thus, boost the return to physical capital. This hypothesis is empirically examined in the context of serf emancipation in nineteenth-century Prussia. Exploiting variation in proto-industrialization across Prussian counties, the analysis finds that, consistent with the proposed hypothesis, the initial abundance of elite-owned physical capital is associated with a higher pace of serf emancipation and lower redemption payments to manorial lords.

Keywords: Labor coercion, serfdom, emancipation, industrialization, capital accumulation, effective labor, nineteenth-century Prussia

JEL classification codes: J24, J47, N13, N33, O14, O15, O43

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1 Introduction

The evolution of coercive labor institutions over the course of human history has been explored by a broad range of disciplines. The emergence of labor coercion has generally been attributed to the increased demand for agricultural labor as well as the deepening of class stratification and the scope for domination within societies following the Neolithic Revolution. In contrast, labor emancipation has been ascribed to demographic shocks caused by the Black Death and sociopolitical forces in the early modern period, such as the Enlightenment movement and attempts by the elites to mitigate the threat of popular revolts.[1]

This paper highlights a mechanism of labor emancipation that is rooted in structural economic change and the evolving material incentives of elites in society. It suggests that the decline of labor coercion during the industrial stage of development was partly a by-product of complementarity between physical capital and effective labor in the production process. Agriculture was largely intensive in manual labor and landowning elites had an incentive to promote and maintain coercive institutions that limited labor mobility and boosted land rents.[2] Over the course of industrialization, accumulation of physical capital by the elites altered their viewpoint regarding the profitability of exploiting coerced labor. Specifically, as the extraction of worker effort through monitoring and punishment is especially costly in care-intensive industrial tasks (Fenoaltea, 1984), the elites found it in their self-interest to end labor expropriation and grant freedom to their workers. This, in turn, incentivized freed laborers to increase their effort, thereby boosting the capital rents of the elites.[3] This mechanism suggests that the incentives to end coercion were stronger among the elites owning more physical capital.

The proposed hypothesis is examined empirically by exploiting cross-sectional variation in *de facto* serf emancipation in nineteenth-century Prussia. Although serfdom was *de jure* abolished in 1807, the process of *de facto* emancipation was heterogeneous across regions, extending well into the second half of the nineteenth century. In each particular case, the termination of feudal labor relations was the outcome of a bargaining process in which the terms of redemption of lifetime servile duties were negotiated between the manorial lord and the serf.[4] This generated cross-regional variation in the rate of *de facto* emancipation. Our empirical analysis links this variation in the emancipation rate to regional differences in the initial abundance of relevant physical capital. Specifically, the latter is measured as the per-capita stock of water mills, a form of proto-industrial capital that not only prefigured broad-based industrialization but was also exclusively owned by the landed elites.

[1] In particular, the Age of Enlightenment triggered major institutional transformations throughout regions of Europe that were occupied by Napoleon's French Revolutionary Army, paving the way for subsequent economic development (Acemoglu et al., 2011; Buggle, 2016).

[2] It is generally agreed that, because feudal relations prevented efficient labor allocation, economic development was held back in regions characterized by coercive institutions and elite absolutism (North and Thomas, 1973; Brenner, 1976; Acemoglu et al., 2011).

[3] Labor emancipation then benefits both the workers and the elites, rather than resulting from a divisive struggle between the social classes. A similar viewpoint is shared by Lizzeri and Persico (2004) in the context of the extension of suffrage institutions during Britain's Age of Reform. The role of alternative economic forces in the emergence of labor emancipation is explored by Lagerlöf (2009). In his theory, the elites choose between imposing serfdom and freedom in order to maximize their payoffs, as determined by population density and the level of technology.

[4] In addition, state supervision provided a commitment device for both serfs and landlords to honor the redemption agreement (Ogilvie, 2014).

Exploiting county-level data on emancipation cases, originally collected by the Prussian state agency that supervised these settlements, our analysis finds a positive and significant relationship between the per-capita stock of water mills in 1819 and the share of serfs emancipated between 1821 and 1848. This relationship is robust to accounting for a wide range of potentially confounding factors, including geographic, cultural, institutional, and other county-level characteristics, which mitigates concerns about the omitted variable bias.

We account for the role of alternative mechanisms of labor emancipation in Prussia.[5] For instance, the degree of coercion may respond to changes in labor scarcity and the availability of outside options for workers (Postan, 1966; Domar, 1970; Brenner, 1976; Acemoglu and Wolitzky, 2011; Lagerlöf, 2016).[6] Elites may also strategically relinquish their political and coercive economic power to avert social unrest (Acemoglu and Robinson, 2000; Aidt and Franck, 2015). Other channels include the influence of Enlightenment ideals and the French Revolution, particularly the institutional reforms that occurred throughout regions of Europe occupied by Napoleon (Acemoglu et al., 2011). Our analysis incorporates these alternative mechanisms via controls for labor abundance, urbanization, the presence of urban artisans and traders, the prevalence of social uprisings, the acquisition of noble estates by enlightened bourgeois commoners, and an indicator for Napoleonic occupation. Although the decline of serfdom in Prussia is indeed partly explained by these alternative forces, our channel continues to account for a significant portion of the variation in serf emancipation. Specifically, it explains roughly the same fraction of variation in emancipation rate as the outside-options channel but substantially more than the other mechanisms.

We provide additional evidence in support of the main hypothesis. First, we find that the prevalence of water mills in 1819 is negatively associated with a measure of the average redemption cost per emancipation settlement as of 1848. This is consistent with the notion that landlords with higher stakes in industrial capital were willing to accept lower redemption payments from their serfs, thereby hastening the process of emancipation. This lower "price" of redemption supports the argument that higher emancipation rates reflected an increase in the "supply" of (or willingness to accept) emancipation by the landlords, rather than an increase in the "demand" (or willingness to pay) for emancipation by the serfs due to the presence of superior outside options.

Second, we document a positive association between the rate of serf emancipation during 1821–1848 and the prevalence of skilled workers in manufacturing in 1849. This contemporaneous measure of skilled employment plausibly reflects effective labor acquired through occupational training and experience, a crucial form of specific human capital in earlier stages of industrialization. Our analysis also finds positive relationships between the emancipation rate and measures of schooling in the second half of the nineteenth century. This is in line with the notion that the freedom to reap the benefits of own labor effort should eventually encourage the accumulation of general human capital in later stages of industrialization.

[5] See Ogilvie and Carus (2014) for an overview of some alternative explanations.

[6] Relatedly, Naidu and Yuchtman (2013) document labor market tightness as a driver of the selective use of coercive institutions in nineteenth-century industrial Britain, whereas Dippel, Greif and Trefler (2020) provide evidence that the fall of labor coercion in the sugar plantations of the British Caribbean was associated with a decline in the power of the planter elites to suppress the outside options of their workers. Gary et al. (2022) show that the re-introduction of serfdom in eighteenth-century Denmark led to a sharp decrease in the wages of farmhands by restricting labor mobility. Fenske (2013) explores the salience of the labor-scarcity mechanism in a global sample of societies.

This paper contributes to the broader debate on the causes of institutional reform in societies. On the one hand, the proposed mechanism advances modernization theory (e.g., Lipset, 1959), highlighting structural economic transformation, namely, industrialization and the increased demand for free workers, as a catalyst of institutional change. Specifically, we explore the role of modernization in driving the changes in *local* labor relations. On the other hand, because Prussian agrarian and emancipation reforms occurred partly in response to the threat of Napoleonic occupation, such *de facto* changes were only possible following the "critical juncture" (Acemoglu and Robinson, 2012) of a *de jure* shift in centralized *state* institutions.[7]

The mechanism of institutional transformation highlighted in this paper also speaks to previous studies linking elite support for universal public schooling to the rise in the demand for human capital over the course of industrialization (Galor and Moav, 2006; Galor, Moav and Vollrath, 2009). In contrast to that literature, this study implies that the provision of universal public education per se may be insufficient to facilitate mass investments in human capital, particularly when the skill premium is subject to expropriation under labor coercion. The termination of coercive institutions therefore represents a necessary condition for efficient investment in human capital.

Although the focus of this paper is on the causes of emancipation, it also contributes to the literature on the long-run consequences of coercive institutions. Acemoglu et al. (2011) document that institutional changes, including the abolition of serfdom, that arose from the diffusion of reforms triggered by the French Revolution into regions occupied by Napoleon are associated with divergence in long-run development across German polities. Cinnirella and Hornung (2016) provide evidence linking landownership concentration to slower emancipation and reduced school enrollment rates in the Prussian context.[8] Markevich and Zhuravskaya (2018) document that serf emancipation was related to subsequent increases in agricultural productivity in nineteenth-century Russia. Nafziger (2012) shows that the abolition of Russian serfdom affected non-farming activities undertaken by former serfs, whereas Buggle and Nafziger (2021) examine the long-run consequences of labor coercion for comparative development across post-Soviet regions.

The remainder of the paper is structured as follows. Section 2 provides a basic formalization of the proposed hypothesis. Section 3 discusses the historical and institutional background relevant for the labor emancipation and proto-industrialization experiences in Prussia. Section 4 introduces the data on serf emancipation, elite-owned physical capital, and other variables used in the analysis. Section 5 discusses the empirical findings and Section 6 concludes. Online appendices contain further details about the data and additional analyses.

2 Conceptual framework

Consider a society comprising two classes of individuals: capitalists (elites) and coerced laborers (serfs). Their respective population shares are $\lambda \in (0,1)$ and $1-\lambda$. Rather than drawing an explicit distinction between landowners and capitalists (e.g., Doepke and Zilibotti, 2008; Galor,

[7] In a related paper, Heldring, Robinson and Vollmer (2021) highlight the role played by the "critical juncture" of the dissolution of English monasteries in giving rise to a landed entrepreneurial middle class (the gentry), which led to industrialization through the commercialization of agriculture.

[8] A related literature (e.g., Sacerdote, 2005; Bertocchi and Dimico, 2014; Bobonis and Morrow, 2014) has explored the relationship between slavery and the accumulation of human capital in the Americas.

Moav and Vollrath, 2009), we portray the elites as a single homogeneous class.[9] The elites in our model may therefore be viewed as landowners who have already gained sufficiently large stakes in manufacturing from their accumulation of physical capital. As explained in Section 3.3 below, our modeling choice is consistent with the historical reality of nineteenth-century Prussia, where the landed nobility were among the most active early capitalists and established industrial production on their estates.

The economy lasts for two periods. At the beginning of the first period, the elites – who hold all the political power – decide whether laborers should be coerced or granted freedom in the second period. We assume that the elites can credibly commit to enforcing such a decision, e.g., by enacting legislation that abolishes serfdom and following established settlement procedures.[10] After learning about their status, laborers choose their optimal amount of costly effort. In this context, worker effort captures the exercise of care and the acquisition of occupational skills relevant for industrial tasks. Production occurs in the second period, in which the elites and the laborers inelastically supply physical capital and effort-driven effective labor, respectively.

Output, Y, is produced according to a standard Cobb-Douglas production function, using physical capital and effective labor, K and H, as inputs:

$$Y = AH^{1-\alpha}K^{\alpha}, \quad \alpha \in (0,1),$$

where A captures technological level, or total factor productivity. Thus, the production process is characterized by complementarity between K and H, that is, the marginal product of physical capital is increasing in the quantity of effective labor.

Under freedom of labor, all factors earn their marginal products, i.e.,

$$r = \alpha A k^{\alpha-1}, \quad w = (1-\alpha)Ak^{\alpha}, \quad k \equiv K/H,$$

where r is the rate of return to physical capital and w is the perfectly competitive wage rate in this economy.[11] Under serfdom, the elites appropriate all of the output after providing a "subsistence" level of consumption, $\tilde{c}$, to each laborer.

If the elites decide at the start of the first period that serfdom will prevail, the laborers will have no incentive to supply costly effort because they would only receive $\tilde{c}$ in the second period. Here, we assume that appropriate effort cannot be extracted from serfs through punishment and supervision. This is motivated by our setting of industrial production where such strategies to elicit effort have been argued to be ineffective and costly (Fenoaltea, 1984). Specifically, physical punishment or the threat of it generate high levels of anxiety that inhibit performance in tasks requiring care, attention, and skill. In addition, when the workforce is engaged in a diverse set

[9] In Online Appendix B, we discuss several possible extensions of our framework along with their implications for our central mechanism.

[10] According to Ogilvie and Carus (2014, p. 482), the economic history of Prussian serfdom provides "arguably the best example" of how the state solved the credible commitment problem by devising and enacting a clear set of rules for serf emancipation. Unlike our framework, however, these authors view the abolition of serfdom as a zero-sum event in which the serfs were the only winners. As such, to ensure that the reforms would not be blocked by the losing elites, adequate compensation of the landlords was effectively enforced by the accompanying legislation.

[11] For simplicity, we assume that physical capital depreciates fully, so that the gross and net returns to capital are identical.

of specialized tasks, monitoring the effort of individual workers requires a large number of skilled supervisors, making this approach to enforcement exceedingly costly. In contrast, the absence of punishment under freedom improves worker performance in care-intensive industrial tasks, and the competition between workers in a free labor market reduces the need for costly supervision.[12]

The laborers will only consider supplying effort if they are granted economic freedom to secure the perfectly competitive rate of return from that effort. Specifically, they choose their effort level, e, in order to maximize the following utility function:

$$wh(e) - v(e) = w(1+e)^{\phi} - e,$$

where w is the perfectly competitive wage rate in the second period; $h(e) = (1+e)^{\phi}$, $\phi \in (0,1)$, is each worker's effective labor, which is increasing and concave in the amount of effort, e; and $v(e) = e$ is the disutility to the worker from this effort. Since $h(0) = 1$, each worker is assumed to be endowed with a basic unit of effective labor to be supplied in the second period. Utility maximization by a worker then yields the following optimal level of effort under freedom:

$$e^* = \max\left\{(\phi w)^{\frac{1}{1-\phi}} - 1, 0\right\} = \max\left\{(\phi(1-\alpha)Ak^{\alpha})^{\frac{1}{1-\phi}} - 1, 0\right\}.$$

For simplicity, we assume that the elites depend entirely on their capital rents and thus do not participate in the labor market. It follows that, under serfdom, the total stock of effective labor is $(1-\lambda)h(0) = (1-\lambda)$, whereas under freedom, it is $(1-\lambda)h(e^*) = (1-\lambda)(1+e^*)^{\phi}$.

At the beginning of the first period, the capitalist elites make their decision regarding the status of laborers, passing appropriate legislation if they choose to abolish serfdom. The elites make this choice to maximize their second-period income. Under freedom, this income is simply rK_0, the total competitive-market return to physical capital, whereas under serfdom, it is $Y - (1-\lambda)\tilde{c}$, the total output of the economy after providing for the subsistence consumption of all laborers.

If the workers find it optimal to exert effort under freedom (i.e., when $e^* > 0$), the equilibrium level of capital per unit of effective labor, k, is given by

$$k = \frac{K}{H} = \frac{K_0}{(1-\lambda)\left(\phi(1-\alpha)Ak^{\alpha}\right)^{\frac{\phi}{1-\phi}}} \quad \Longrightarrow \quad k = k_0^{\frac{1-\phi}{1-\phi(1-\alpha)}} \cdot (\phi(1-\alpha)A)^{\frac{\phi}{\phi(1-\alpha)-1}},$$

where K_0 is the stock of capital owned by the elites and $k_0 \equiv K_0/(1-\lambda)$. Alternatively, if serfdom prevails, or if workers choose $e^* = 0$ under freedom, then $k = k_0$. Along with the above expression for the optimal level of effort, this implies that the workers will exert effort if and only if they are granted freedom and $k_0^{\alpha} > 1/(\phi(1-\alpha)A)$. In other words, freed laborers will consider it worthwhile to exert effort when the perfectly competitive wage rate is high – i.e., when the stock of complementary physical capital is large and/or the economy's technological level is more advanced.

[12] A related argument has been made by Millward (1984), who explains the adoption of serf-labor quitrent systems in Eastern Europe by arguing that "[t]he smaller was the scope for scale economies in supervising groups of serfs the more profitable was it for the noble to avoid setting predetermined performance levels and to give the serf economic incentives to raise output" (p. 425). In addition, Schlumbohm (1981) notes that the German nobility withdrew from their attempts to organize industrial production under the feudal system after early trials were overwhelmingly unsuccessful, primarily due to the fact that "industrial products demanded a higher quality of workmanship than could be enforced under feudal relations" (pp. 96–97).

In the second period, under freedom, the income of the elites is given by $rK_0 = \alpha A k^{\alpha-1} K_0$. It is strictly increasing in the stock of effective labor as the latter augments the rate of return to physical capital due to complementarity between these two factors in the production process. Under serfdom, however, since $K = K_0$ and $H = 1 - \lambda$, the second-period income of the elites is $A(1-\lambda)^{1-\alpha} K_0^{\alpha} - (1-\lambda)\tilde{c}$. The elites will choose to abolish serfdom if and only if their second-period income under freedom exceeds that under serfdom, which gives rise to the following proposition.

Proposition 1. Assume that $\phi\tilde{c} < 1$. There exists a unique value k_0^* such that the elites abolish serfdom and the freed laborers exert effort if and only if $k_0 > k_0^*$.

Proof. See Online Appendix A.

Thus, our basic model suggests that, other things equal, a large enough stock of physical capital per worker triggers labor emancipation. The accumulation of physical capital by the elites inevitably leads to the abolition of serfdom: the boost to the rate of return on physical capital from the supply of effort by freed laborers is sufficient to make this institutional change profitable, even in the absence of compensatory transfers from serfs. However, as explained in the following section, in the context of nineteenth-century Prussia, redemption payments were a typical component of the terms of emancipation and could be negotiated between individual lords and their serfs. In our model, the presence of redemption payments would clearly accelerate the emancipation process. Furthermore, as the following proposition shows, for large enough values of k_0, the minimum transfer that would make the elites favor the abolition of serfdom is inversely related to the stock of physical capital per worker. In other words, the higher is the expected benefit from the supply of complementary effort by free laborers, the lower is the compensation the elites would require to emancipate their serfs.

Proposition 2. Let $\hat{p}$ be the minimum transfer from the freed laborers to the elites, paid at the end of the second period, such that the elites opt to abolish serfdom whenever $p > \hat{p}$. Then, there exists a unique value k_0^{**} such that $\hat{p}$ is decreasing in k_0 for $k_0 \in (k_0^{**}, k_0^*)$, and the payment $\hat{p}$ is feasible for the freed laborers.

Proof. See Online Appendix A.

In sum, our model yields two key testable predictions: all else equal, a larger per-worker stock of elite-owned physical capital is expected to be associated with 1) a higher rate of labor emancipation and 2) lower redemption payments made by the emancipated serfs to the elites.

3 Historical background

3.1 Agrarian reforms, serf emancipation, and elite class structure

The Prussian agrarian (Stein-Hardenberg) reforms of the early nineteenth century provide a historical setting that is well-suited for an empirical exploration of our hypothesis. These reforms generated the variation in the pace of serf emancipation across Prussian regions over the course of the nineteenth century. They also affected the composition of rural elites, resulting in the adoption of industrial production methods on manorial estates.[13]

[13]Our hypothesis is broadly consistent with various elements of the Prussian historical narrative regarding emancipation and industrialization. For instance, Pierenkemper and Tilly (2004, p. 26) viewed the peasant

Peasant labor coercion associated with feudal political authority of the landed nobility (Junkers) was practiced throughout the Kingdom of Prussia for centuries (Ogilvie and Carus, 2014). A notable change in relevant *de jure* institutions occurred in the early nineteenth century, following the 1806 defeat of Frederick William III of Prussia by Napoleon's army and the ensuing Second Treaty of Tilsit, in which Prussia ceded about half of its territories and was forced to make substantial tribute payments to France. These events triggered the so-called "defensive modernization" of Prussia. For a short period of time, the balance of power shifted away from the landed nobility to a group of progressive bureaucrats who enacted various institutional reforms based on the principles of economic liberalism.

De jure emancipation proceeded in a sequence of legislative acts affecting different categories of enserfed population.[14] Here, we summarize only the main milestones and relegate further details to Online Appendix H. The "October Edict" of 1807 granted equality before the law and freedom from personal subjection to the entire population of Prussia from 1810 onwards. It was followed up by the "Regulation Edict" of 1811 that granted peasants holding weak (non-hereditary) land tenure the legal right to own the lands that they farmed and the ability to redeem their lifetime servile dues. This, however, required serfs to hand over between a third and two-thirds of their lands to manorial lords as compensation.

The balance of power shifted back to the conservative landowning nobility in the aftermath of the German Campaign of 1813 that effectively ended the short-lived domination of Prussia by the French. Following the Congress of Vienna in 1815, the Prussian Kingdom was established within new borders, regaining most of its territories lost during the Napoleonic wars and annexing new territories in the western regions of the former Holy Roman Empire (Rhineland and Westphalia) and in Saxony. As a result of opposition to reforms from a rehabilitated landed nobility, the Regulation Edict was amended by the Declaration of 1816 to exclude peasants residing on small parcels of land from acquiring allodial title rights and redeeming their lifetime servile dues.

The "Dissolution Ordinance" of 1821 established that peasants holding strong (hereditary) land tenure could terminate their feudal labor relations by compensating their manorial lords with 25 times the annual value of forgone services and labor dues in either money or land. As further discussed in Section 4, the main dependent variables in our empirical analysis are based on emancipation cases settled precisely under the 1821 ordinance. Hence, it is important to understand how this particular legislation influenced the extent of *de facto* peasant emancipation process in Prussia. Recent estimates have placed the number of rural households in early-nineteenth-century

emancipation process as a prerequisite for widespread industrialization, arguing that labor productivity increased over the course of the reform period. However, historical literature generally focused on either the redistribution of resources from peasants to the nobility (e.g., Schissler, 1978; Dipper, 1980; Harnisch, 1984; Pierenkemper, 1989) or the economic conditions of those peasants who remained attached to agriculture following their emancipation (e.g., Knapp, 1887; Böhme, 1902; Berthold, 1978). Complementing our hypothesis, this literature also highlights other forces behind the elite's support of emancipation reforms, including changing conditions in agricultural markets, the temporary decline in political power of the nobility in the aftermath of Prussia's defeat by Napoleon in 1806, and the use of compensation payments to overcome debts associated with noble estates.

[14] Anecdotal evidence suggests that these reforms were at least partly motivated by the attainment of higher economy-wide productivity. For instance, as Reddy (1987, p. 84) notes, "Hardenberg had promised in 1811 that "the state would thus acquire a new, estimable class of motivated property owners" and that "through the desire to enter this class, the cultivation of the soil would profit from more hands, and through their greater effort, because freely given, more work as well.""

Prussia at approximately one million: ca. 710,000 peasant households and 283,000 lodgers (Eddie, 2013, p. 83). Of these rural households, roughly 11–13 percent held only weak rights to land tenure and were thus emancipated under the terms of the 1811 regulation and its 1816 amendment. The vast majority of households, however, held strong rights to land tenure, and their emancipation was therefore largely governed by the terms of the 1821 ordinance.

Finally, the "Commutation Law" of 1850, adopted by the new parliament in the aftermath of the German Revolution of 1848–1849, allowed the remaining servile duties, particularly those associated with peasants residing on small land parcels, to be liquidated via redemption payments to the nobility. As discussed further below, despite *de jure* emancipation, the compensation payments imposed on peasants and the power of landed nobility over the terms of settlements effectively made *de facto* emancipation a protracted and heterogeneous process that extended into the final decades of the nineteenth century (Eddie, 2013).

The agrarian reforms of the early nineteenth century also changed the composition of the landed elites towards an ever increasing representation of the bourgeoisie. A significant aspect of the October Edict of 1807 was the termination of nobility's monopoly over manorial landownership, which permitted the trade of noble estates. Following Prussia's defeat by Napoleon in 1806, the market for noble estates was opened to commoners as part of an effort to recapitalize the economy that was overburdened by reparations to France. Consequently, the capital market witnessed an increase in the trade of manorial estates and, according to Schiller (2003, p. 477), the replacement of less productive noble estate owners. Once the market became accessible to commoners, the early buyers of knight estates were primarily merchants and industrialists from Berlin, but also mill owners and master masons (Schiller, 2003, p. 259). By the mid-nineteenth century, a significant share of manorial estates were owned by the bourgeoisie, which produced a "socially mixed elite of landed businessmen" (Bowman, 2011, p. 33).

3.2 Redemption of servile dues and peasant mobility

The landed nobility exercised substantial control over the pace of *de facto* emancipation by adjusting the terms associated with the redemption of lifetime servile dues of serfs. This suggests, in particular, that progressive and capital-owning elites may have been willing to accelerate emancipation by settling for terms that were more favorable to their peasants.[15]

The redemption process associated with each emancipation case was overseen by the General Commission, staffed with public officials having legal training and knowledge of agricultural markets. At the highest level of administration, the Commission comprised a total of 6 agencies, each holding jurisdiction over several districts. At the lowest administrative level, county mediation agencies were staffed with 2-6 local officials that were elected by county assemblies and worked closely with county supervisors. Importantly, because county assemblies were predominantly composed of noble landowners, officials at the mediation agencies were typically strongly aligned with entrenched members of the local nobility.

[15] Historical accounts of the time suggest the prevalence of such incentives among the elites. Schissler (1978, p. 126) discusses how noble estate owners in Pomerania renounced some of the land they were entitled to as compensation for forgone servile dues. The estate owner, Ernst von Büllow-Cummerow, for example, welcomed the abolition of serfdom, based on the idea that free labor would serve to increase land and worker productivity.

The settlement between a manorial lord and his serf peasants was triggered by the so-called "provocation of the redemption" and was to be filed with the General Commission.[16] Either party could invoke the process. If no agreement was reached, the terms were settled in a formal hearing where the exact amount of compensation was arbitrated by an expert. Contemporary observers from the period acknowledge that forgone labor services were extremely difficult to value, so "norms" for the valuation of compensation payments to the nobility had to be set by the central authority (Eddie, 2013, p. 211). Consequently, redemption values were based on either "normal prices" or expert judgment.

As noted by Berdahl (1988), following the passage of the Dissolution Ordinance, "tempering of the moderate reforms had begun in the interest of the landowning nobility" (p. 269). The nobility protested against the bureaucratic intrusion into what they deemed to be a "happy patriarchal relationship" on their lands and appealed to the Crown to leave the settlements for the lords to work out with their peasants (Berdahl, 1988, p. 281). In response to these appeals, the General Commission in Königsberg was "ordered to reduce its staff and to plan intentionally for a slower pace of work" (Berdahl, 1988, p. 269). The growing influence of the nobility on the Crown and the fact that county commissioners were aligned with the nobility meant that the settlement of emancipation cases became subject to the will of landowners.[17]

Importantly, the design of emancipation reforms and existing institutional restrictions ensured limited mobility of peasants even after their *de facto* emancipation. As Skocpol (1979, p. 109) explains, "when serfdom was abolished, the landlords influenced the process in ways that ensured as far as possible the maintenance of their accustomed economic hegemony in new forms. Prussian peasants were forced to cede to the large, Junker-owned estates one-third to two-thirds of the holdings they had worked for themselves under serfdom, in order to gain property title to the lands that remained. This meant that the vast majority were left with inadequate land to support themselves, thus ensuring that they would continue to work on the Junker estates, henceforth, as wage laborers." Emancipated workers were unable to easily migrate in search of new employment opportunities as permanent relocation to another municipality (an administrative subdivision of a county) in Prussia was severely restricted until 1842. It required obtaining an official permit and paying a substantial admission fee to the host municipality (typically equal to 5–10 times the annual value of an average household's use of public goods). Although municipalities were not allowed to reject most potential immigrants after 1842, admission fees remained in place and represented a serious barrier to labor mobility. As a result of these institutional constraints, it was very hard for poor peasants from rural areas to find employment in industrial centers (Ziekow, 1997, p. 155).

These limitations on labor mobility are a crucial aspect of our empirical setting. They imply that the elites realized their ability to largely retain freed peasants as workers on their estates, complementing their growing stock of physical capital. Thus, the threat of labor scarcity arising from emancipated peasants exploiting better outside options was likely not a primary concern. Even

[16] Hagen (2002, pp. 627–639) provides some detailed micro-historical examples of the redemption process at the noble lordship of Stavenow in the central Prussian province of Brandenburg.

[17] They were also able to challenge the legal status of the peasants or their eligibility under the regulations with respect to their tenancy rights. The baseline year for the determination of peasant land tenancy was 1752, and written records from that time were sparse.

if such opportunities existed theoretically, they were not easily accessible, which also meant that peasants were unable to exploit them to expedite the redemption of their lifetime servile dues.[18]

3.3 Industrialization of the estate economy

According to the stereotypical view, Prussian landowning nobility were a highly conservative reactionary group, strongly attached to a traditional lifestyle and focusing almost exclusively on agricultural economic activities. Although historical literature on the period leading up to and following the agrarian reforms acknowledges an increasingly capitalist organization of the estate economy, the Junkers are usually not described as progressive (Rosenberg, 1978; Bowman, 2011; Schiller, 2003; Wehler, 2006).

However, according to Eddie (2008, p. 177), "a mostly overlooked feature of the nineteenth-century economy of eastern Germany is the significant role that industrial production on agricultural estates played in that economy." Based on information from industrial censuses in the latter half of the nineteenth century, the author affirms the existence of a dense network of rural industrial establishments on large manorial estates (averaging about one establishment for every 2.5 square kilometers). He concludes that "the stereotypical picture of Junkerland as being a vast expanse of extensively cultivated estates with almost no industry is clearly wrong" (Eddie, 2008, p. 180). Thus, although the Junkers had not held any immediate stakes in the proto-industrial economy of pre-reform Prussia due to their exclusion from bourgeois occupations (e.g., Carsten, 1988, p. 51), production activities in Junkerland underwent considerable structural change once relevant institutional constraints were removed.

The industrialization of the Prussian estate economy also reflects the entry of the bourgeoisie into the class of landowning elites in the period following the agrarian reforms. The case of Johann Gottlob Nathusius (1760–1835) provides a prominent illustration of this phenomenon. Nathusius became the richest man in Magdeburg as the first tobacco-factory owner in Prussia in 1787. In 1810/11, he purchased three manorial estates to grow his own tobacco and eventually developed these estates into the first industrial conglomerate in Prussia including a porcelain factory, a machine factory (involved in the production of hydraulic presses and steam engines), a sugar refinery, and several distilleries, brick works, and grain mills (Görlitz, 1981, p. 220). The Nathusius conglomerate eventually gave rise to several spin-off enterprises run by former employees and strongly influenced the intensity of local industrialization.

The case of Nathusius also illustrates the changing incentives of the elites with regard to using coerced labor. In discussing the status of peasants on the manorial estates that he purchased, his daughter and biographer writes: "at first the peasants served him, but he soon insisted on a *cheap* [emphasis added] redemption for them" (von Nathusius, 1915, p. 239). Moreover, "[h]e vigorously advocated for better instruction in the schools, especially for the practical sciences, and also in rural schools, which represented the best means of uplifting industry" (p. 237). Thus, landlords not only perceived freed workers to be more productive but actually reaped these benefits by facilitating the emancipation of their serfs, employing them as free workers, and ultimately encouraging their acquisition of skills.

[18] Section 5.4 provides evidence of labor market segmentation, consistent with existing institutional restrictions.

Similar evidence comes from Biernacki (1995, p. 305) quoting Adam Heuss, who worked for a smith in Nürnberg and published his observations in 1845. Heuss noted how it was considered advantageous to have "tradable wares manufactured in factories with machines" and cited the relevant case of the "Mecklenburger estate lords [*Gutsherren*] who released their subject peasants and turned them into day laborers."

In sum, evidence points to the emergence of significant stakes in industrial production among the rural landowning elites, comprising both nobility and bourgeoisie. According to our hypothesis and consistent with historical anecdotes, this process contributed to the formation of emancipation-oriented incentives within that class.

3.4 The use of serf labor in manufacturing

In our conceptual framework, capital-owning elites choose to emancipate their serfs because they rationally expect free workers to exert more effort. An important part of our argument is that extraction of such effort through monitoring and punishment is ineffective in care-intensive industrial tasks compared to agriculture. Although measurements of the relative effectiveness of labor coercion in manufacturing and farming in Prussia are not available, historical literature generally suggests that serf labor was rarely used in manufacturing (Kwaśny, 1992, p. 135) providing *prima facie* evidence on its lower productivity in this setting.

In cases where industrial enterprises were established on noble estates, skilled workers were often recruited from outside the estate, while local serfs sometimes provided auxiliary labor (Krüger, 1958, pp. 58–63). In feudal mining and metal production, serfs could be involved in tasks such as carting wood and making charcoal (Krüger, 1958, p. 61). In textile production, serfs engaged in spinning and weaving but usually did so at a piece wage (Krüger, 1958, p. 60–61).

Case studies on mining and iron production on noble estates confirm that serfs were primarily used as auxiliary workers. For example, in the case of ironworks in Wocklum on the Landsberg estate in Westphalia, serfs are mentioned only in the context of transporting wood and iron ore (Hinz, 1977, p. 37 and p. 208). In contrast, the valuable wrought iron was delivered to customers by professional carters who were paid based on volume. Charcoal burning, a care-intensive task, was performed by experienced burners who received high wages (Hinz, 1977, p. 189). Even highly standardized tasks such as roasting, washing, and pounding of iron ore were executed by paid day laborers despite the apparent availability of serfs (Hinz, 1977, p. 168). Similarly, when describing the workforce in the ironworks on the Rödinghausen estate in Westphalia, Schlecking (2010, p. 113) mentions serfs only as carters employed due to the spatial dispersion of mining, smelting, and forging. All other workers received wages.

Studies of the textile industry, particularly the well-known Silesian linen manufacturing, mention that spinners and weavers were recruited from the serf population on a large scale (Brentano, 1893; Grünhagen, 1894). However, these serfs worked for a piece wage in the so-called putting-out system of cottage-industry-based fabric production. Thus, free-labor-type incentives were present in this textile industry along with a form of coercion since employees had to pay the landowner a weaving fee or a cash rent for commuting their labor services in agriculture (Kisch, 1959). Often they were also coerced into purchasing yarn exclusively from the estate. Overall, some historians

viewed the use of serf labor as partly responsible for the decline of Silesian linen industry because of its low productivity and the lack of incentives to adopt novel production techniques.[19]

4 Data

Our empirical analysis links the initial abundance of elite-owned physical capital to the subsequent rate of serf emancipation and the average size of associated redemption payments. This section discusses the most relevant aspects of our data set, relegating additional details to Online Appendix I. Table I.1 provides descriptive statistics for the main variables.

4.1 Serf emancipation and redemption costs

We employ administrative data on *de facto* serf emancipation and redemption costs. These data come from sources published by the Prussian Statistical Office and were first presented in Meitzen (1868) to document the progress of the emancipation process by the mid-nineteenth century.

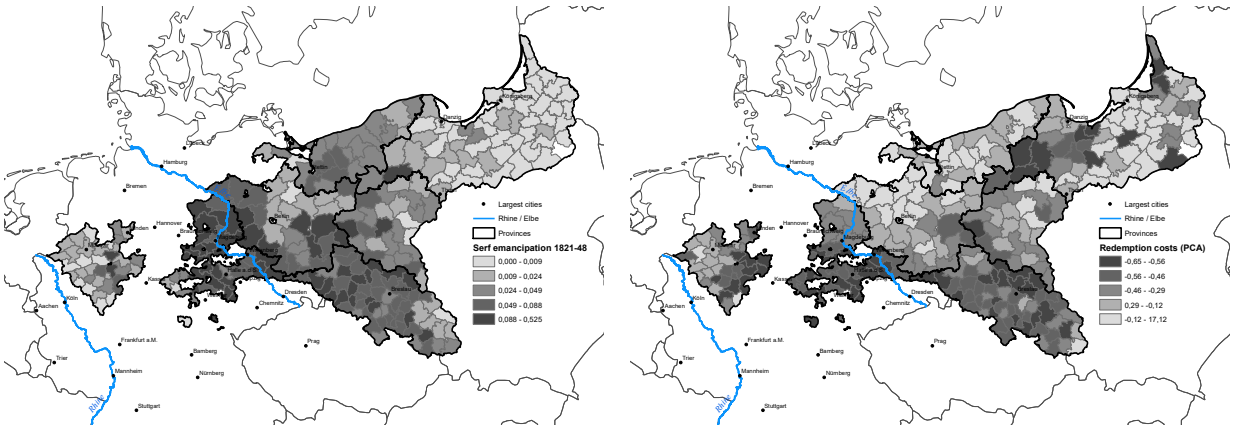
The main dependent variables in our analyses are based on the cumulative stock of emancipation cases settled in each county as of 1848. We attempt to explain the observed cross-county variation in the labor emancipation rate and redemption costs in Prussian regions east of the river Rhine.[20] The original data tables indicate specific legislation under which each emancipation case was settled. Our measures are based on the number of former service and duty payers who redeemed their lifetime servile dues under the Dissolution Ordinance of 1821 (*Dienst- und Agabenpflichtige, welche abgelöst haben*). In these cases, upon settlement, former serfs were no longer required to provide labor services to their manorial lords.

Next to the number of settled cases, Meitzen (1868) reports the number of redeemed days of service as well as the cost of redemption in cash, in kind, and in land.[21] We use this information to generate three variables. First, the number of cases settled as of 1848 is used to calculate the serf emancipation rate, our main outcome variable. Second, the information on compensation payments made to the landlords across settled cases is used to construct another outcome variable reflecting the willingness of the elites to facilitate emancipation. Because compensation was individually negotiated to be paid in various ways, including money, rye, and land, we extract the first principal component of four different categories of reported redemption payments and focus on this single measure. Third, we use the number of redeemed days of service per settled case as a proxy for the

[19] For example, Brentano (1893, p. 328) notes: "It is characteristic: the free weavers make the high-quality fabric, while the serfs make the mass product."

[20] Our county-level data set consistently links information from different censuses over time. The original sources exclude regions west of the river Rhine where, due to Napoleonic occupation, agricultural and emancipation reforms developed in a radically different fashion than in the rest of Prussia. This also applies to the district of Stralsund where such reforms had been introduced by the Swedish Crown in 1806. Furthermore, no information is available for city counties presumably because serfdom was not at all prevalent in these purely urban areas.

[21] Harnisch (1974) discusses the data on Prussian emancipation and finds inconsistencies in the information for 1838 versus 1848. Although concerns regarding the number of settled cases are not raised, Harnisch questions the reliability of the data on redemption costs reported for 1848. He argues that these statistics, published shortly after the German Revolution of 1848, may systematically underreport the actual redemption payments. In fact, it is plausible that redemption payments were only applicable to emancipation cases settled under the 1821 ordinance, creating inconsistencies identified by Harnisch.



(a) Serf emancipation rate as of 1848 (b) Redemption costs

FIGURE 1: Spatial distribution of the main outcome variables

Notes. Panel (a) depicts the serf emancipation rate, i.e., the total number of emancipation cases settled as of 1848, expressed as a fraction of the rural population in 1816 (net of the population in small peasant landholdings). Panel (b) depicts redemption costs, i.e., the first principal component of four different types of compensation payments (where each payment type reflects its average amount across all emancipation cases settled as of 1848) made by peasants to their landlords for the redemption of servile duties.

average intensity of coercion prior to emancipation, which is included as a control variable in some specifications.

One shortcoming of our data is that regionally disaggregated information on the initial population of serfs (as of the early nineteenth century) is not available. To measure the rate of serf emancipation, we normalize the number of settled cases by the rural population of the county as of 1816, net of the population in small peasant landholdings (that were only eligible for emancipation after the Commutation Law of 1850).[22]

Figure 1 shows a considerable variation in both of our main outcome variables. The rate of serf emancipation, mapped in panel (a), ranges from 0% to 52% and has the mean of 6%. The emancipation process was more advanced in counties belonging to the central and southeastern provinces of Saxony, Brandenburg, and Silesia, whereas lower emancipation rates are found in the eastern regions of Prussia and the western province of Westphalia. Panel (b) shows that redemption costs were relatively low in Saxony, Silesia, parts of Westphalia, and western parts of the province of Prussia, whereas they were particularly high in Brandenburg, Pomerania, and the eastern parts of the province of Prussia.

[22] In using this measure, we assume that the entire rural population of a county, including peasant family members, farm hands, and day laborers, were bonded serfs engaged in the provision of servile labor duties. To account for cross-county differences in the size of peasant households, we include average family size in 1849 as a covariate in our empirical model. To address other potential sources of systematic measurement error in our dependent variable, we additionally control for the prevalence of free peasants and the legal status of serfs across counties. Our main findings are also robust to the use of several alternative denominators when normalizing the number of settled emancipation cases. These include, for example, total population, the number of peasant landholdings, and the number of servants in agriculture, all measured in 1816.

4.2 Relevant proto-industrial physical capital

Our empirical analysis employs the number of water mills (per 1,000 inhabitants) in 1819 as a proxy measure of the initial abundance of physical capital. Water mills account for nearly 40% of all proto-industrial establishments in the average county in our sample for that year. Moreover, unlike other available measures of proto-industrial physical capital discussed in Online Appendix C, water mills have two crucial features that make them particularly relevant for examining our hypothesis.

First, the ownership of water mills was almost exclusively restricted to the nobility, thus ensuring that the rents associated with milling were available for reinvestment and subsequent capital accumulation by the elites. Prior to the agrarian reforms of the early nineteenth century, the construction and operation of a grain mill was a noble prerogative. According to the "suit of mill," all local peasants had the legal obligation to grind their grain in the mill on their landlord's estate. Furthermore, the lords had the right to levy a tax on the milled grain (multure). Seigniorial rights associated with grain milling generated considerable profits for the landed nobility, some of which were used to finance investments in new mills (e.g., Bloch, 1967; Hills, 1996; Lucas, 2006; van der Beek, 2010).[23]

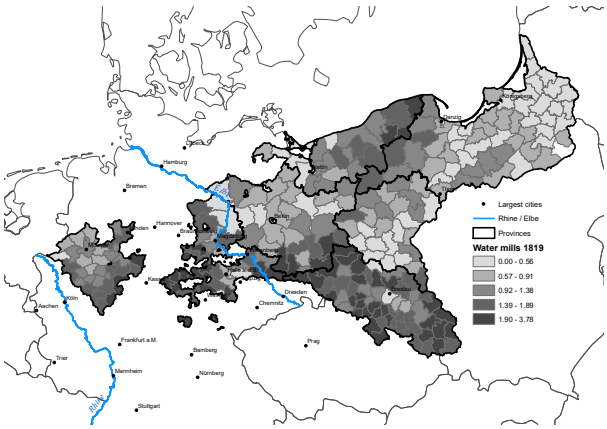
Second, the use of water mills foreshadowed the subsequent adoption of steam engines that fueled broad-based industrialization. Historians of the Industrial Revolution have argued that early investments in water mills – the proto-industrial installations most closely related to steam engines because of their reliance on water availability – may well have made the adoption of steam-engine technology more "appropriate" over the course of industrialization.[24] Furthermore, steam engines had a direct link to water mills from an engineering standpoint. Because steam engines were initially only water-pumping engines that were unable to convert steam power into a steady rotary motion by themselves (e.g., the Savery and Newcomen variants), early industrial production sites often exploited steam power in conjunction with water wheels. The engine was used to pump water up into an elevated reservoir, which then supplied hydraulic power to an existing overshot water wheel (see, e.g., Reynolds, 1983, pp. 322–323).[25]

The map in panel (a) of Figure 2 shows the spatial distribution of water mills per capita across counties in our sample. There were on average 1.2 mills per 1,000 inhabitants in 1819, with the measure ranging from 0 to 3.8. This variation reflects, in particular, a relative capital abundance in Westphalia and the central regions of Saxony and Silesia, and scarcity in Brandenburg and the eastern provinces of Prussia.

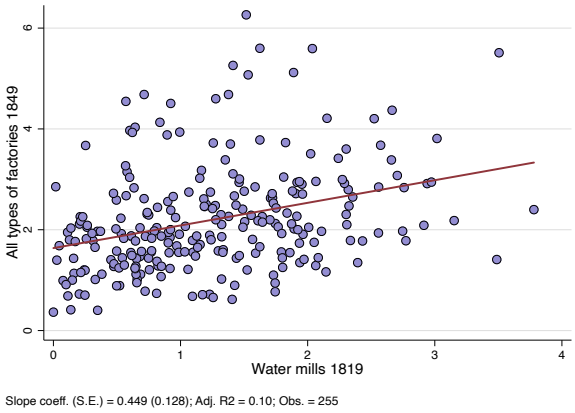
The scatter plots in Figure 2 substantiate the link between the initial presence of water mills and various measures of subsequent industrialization. Panel (b) shows a statistically significant positive association between water mills in 1819 and the extent of broad-based industrialization in

[23] Indeed, as claimed by Hills (1996, p. 26–27), "[t]he rights to a watermill were owned by the lord of a manor and, in an age when there were no stocks and shares to provide an income, the corn mill presented one of the few profitable capital investments available. [...] Once the mill was established, it became another potential capital investment and, with the 'soke' or control over the milling rights which the lord of the manor held, the mill became something worthwhile building and owning [...]."

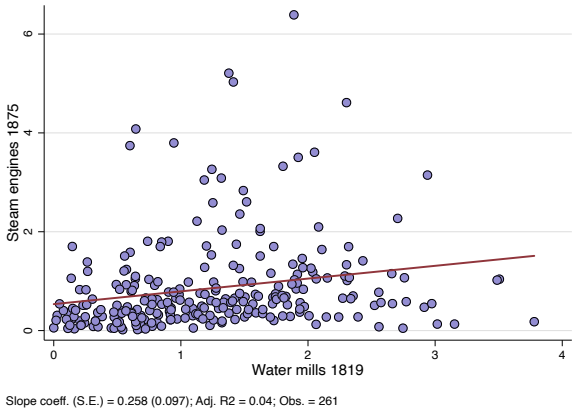
[24] For instance, Mokyr (2002, p. 256) states that "[...] the owner of machines that become obsolete will take a loss on those machines, but he can always buy into the new technology by purchasing new machines that yield higher profits through lower costs. This explains, for instance, the relatively weak resistance to the introduction of steam engines despite the huge locational rents that were being secured by the owners of water mills sites. Industrialists using water power might have been losing when their mills fell into disuse, but they could make up for those losses



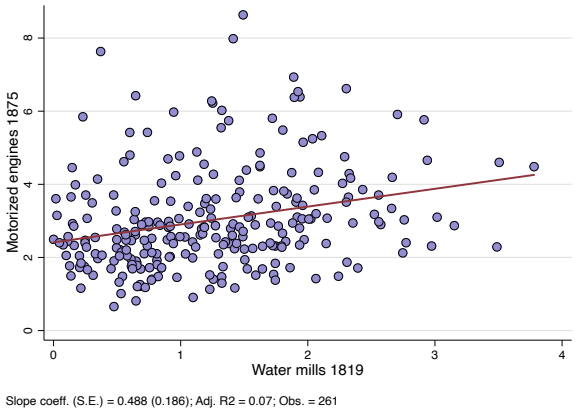
(a) Water mills in 1819



(b) Factories in 1849



(c) Steam engines in 1875



(d) Motorized engines in 1875

FIGURE 2: Water mills, industrialization, and skill-intensive technology adoption

Notes. Panel (a) maps the distribution of water mills per 1,000 inhabitants as of 1819 (county population is measured as of 1821, the census year closest to 1819). Scatter plots illustrate the significant positive relationship between the water mills measure and three measures of subsequent industrialization. These include: the number of factories across manufacturing sectors (textiles, metals, paper, chemicals, food-processing, etc.) in 1849, in panel (b); the number of steam engines across manufacturing establishments in 1875, in panel (c); the number of all types of motorized engines across manufacturing establishments in 1875, in panel (d). Each measure of industrialization is divided by the county's population (in thousands) in the relevant year.

1849, as captured by the number of factories per 1,000 inhabitants. Similarly, panels (c) and (d) depict significant positive relationships between water mills and the adoption of steam engines and motorized engines in 1875, illustrating path dependency in industrialization over several decades.

As shown in Online Appendix C, in contrast to water mills, alternative measures of proto-industrial structures and devices in the early nineteenth century are unrelated to the degree of

by buying into steam technology themselves, which is precisely what happened in Lancashire during the British Industrial Revolution."

[25]See also Nuvolari, Verspagen and von Tunzelmann (2011, p. 294 and p. 309) and references cited therein. In particular, this study documents that during the 1775–1800 time period, a larger number of Newcomen steam engines were installed in British counties that had a higher prevalence of water wheels.

subsequent industrialization and are thus not suitable for our analysis.[26] Hence, we focus on water mills as the relevant measure of proto-industrial physical capital.

4.3 Control variables

We account for a sizable set of potentially confounding factors that may have affected both initial capital abundance and the subsequent rate of serf emancipation.

The first set of control variables ("geographic controls") aims at accounting for spatial heterogeneity in geographic endowments that may directly affect agricultural productivity and access to markets and may also indirectly affect cultural and institutional characteristics through various mechanisms. Specifically, our geographic controls include temperature, precipitation, soil suitability for cereal crops, the share of sand in the top soil, and distance to navigable rivers. We also include an indicator for counties east of the river Elbe, where both industrialization and serf emancipation are known to have been delayed due to the vested interests of the nobility in the continuation of large-scale agriculture (see, e.g., Harnisch, 1986; Melton, 2000; Acemoglu et al., 2011; Cinnirella and Hornung, 2016).

Our second set of control variables ("proximate controls") comprises more proximate potential confounders. To account for differences in the initial level of economic development (or industrialization), labor abundance, and workers' access to outside options in urban markets, we include population density and urbanization rate in 1816 as controls.[27] Peasant household demographics are captured by average family size in 1849, the earliest year for which data are available. Because emancipation settlements typically involved entire peasant households, larger family sizes could have been associated with delayed emancipation, reflecting higher required redemption payments. Furthermore, since our measure of emancipation normalizes the number of settled cases by the rural population of a county, it is by construction expected to be negatively associated with the average size of peasant families.

Pre-existing levels of investments in general human capital are accounted for by controlling for the school enrollment rate in 1816. Agglomeration effects arising from the early location of water mills are captured by the population shares of urban traders and artisans in 1819. Cultural and institutional differences in the propensity to emancipate and/or industrialize are captured by the population share of Protestants in 1816, the population share of non-Germanic ethnic groups in 1861 (the earliest available data), an indicator for the predominant law of peasant land inheritance (i.e., primogeniture versus partible), and the share of large noble landholdings (i.e., knight estates) that were generally associated with strong feudal institutions.

Our final set of covariates ("additional controls") includes measures capturing other alternative mechanisms of emancipation and potential confounders. In particular, we control for the number of social uprisings during 1816–47 to account for the incentives of the elites to grant emancipation under a credible threat of mass revolts.[28] We also control for the share of noble

[26] Table C.1 further documents that, as expected, these alternative measures are *not* positively associated with subsequent emancipation.

[27] The salience of alternative emancipation mechanisms proxied by these variables is further explored in Online Appendix F.

[28] Our measure of social uprisings includes not only peasant rebellions but also uprisings involving commoners. In fact, peasant uprisings in Prussia were virtually nonexistent in the period following the introduction of the agrarian

estates owned by commoners as of 1856 to address the possibility that proto-industrialized estates requiring recapitalization were selectively purchased from the indebted nobility by "enlightened" members of the bourgeoisie. To further account for the influence of Enlightenment ideals, we include an indicator for counties exposed to Napoleonic occupation.

To capture heterogeneity in access to external (urban) markets or outside options for the enserfed population, we include indicators of (i) the presence of at least one main road as of 1848, (ii) the presence of a railway line in 1848, and (iii) the presence of coal mining. Relatedly, we control for the share of the population born outside the county in 1871 (based on the earliest available data), employing this *ex post* realization to partly address the *ex ante* possibility that upon emancipation, workers could have emigrated to pursue external employment opportunities. In order to account for differences in historical exposure to the Commercial Revolution of the early modern period, we include an indicator for the presence of a university or a commercially vibrant urban center (as reflected by its status as an Imperial City or a member of the Hanseatic League) in 1517.[29]

To account for heterogeneity in elite incentives to prolong their use of serf labor and in the ability of peasants to redeem their servile duties, we control for a measure of the prevailing intensity of coercion. Specifically, we extract the first principal component of the average amounts of two different types of labor services (i.e., with and without a team of draft animals, both measured in days) that peasants needed to redeem as part of their settlements with the landlords.

Finally, we employ two proxy measures to capture cross-county variation in the availability of free peasants (i.e., workers that could have been employed in industry while serf labor was used in agriculture) before the *de jure* abolition of serfdom. The first proxy is the share of a county's estates that operated under the so-called Kulm law, which conferred long-term legal protection to local peasants from landownership exclusion and enserfment.[30] The second proxy is the share of a county's land in royal domains (i.e., land owned initially by the Prussian Crown and later by the state), in which peasants were granted personal freedom as early as 1799 and were subsequently able to commutate dues and labor services into cash rents.[31]

reforms and until the German Revolution of 1848–49. Specifically, peasant rebellions occurred almost exclusively in the province of Silesia between 1809 and 1811 due to a misunderstanding of the October Edict by the region's enserfed Polish-speaking population, which had misinterpreted the legislation as abolishing not just the personal subjection of peasants but their servile duties as well (e.g., Carsten, 1988, p. 82) It is, however, possible that the elites may have perceived non-peasant uprisings as potential triggers for more widespread revolts.

[29]The importance of late medieval universities and of early modern cities participating in Imperial or Hanseatic Diets as factors that contributed to the Commercial Revolution has been noted by several papers in the recent empirical literature on German economic history (see, e.g., Becker and Woessmann, 2009; Cantoni, 2012; Cantoni and Yuchtman, 2014; Jedwab, Johnson and Koyama, 2019).

[30]The Kulm law is a legacy of the Monastic State of the Teutonic Knights (1230–1525), with the corresponding *Köllmer* estates established mostly in the areas surrounding the towns of Kulm and Thorn. At the turn of the nineteenth century, *Köllmer* and other peasant groups that enjoyed personal freedom, such as *Schulzen*, were required to provide only minor dues in quitrents or labor services to the nobility accounted for about 4% of rural households across Prussia (Eddie, 2013, p. 83).

[31]It has been conjectured that by 1806, about one-third of all peasants residing in royal domains fully redeemed their servile duties and about one-tenth purchased their lands (Eddie, 2013, p. 185).

4.4 Other outcomes

In an extension of our main analysis, we explore the link between serf emancipation and ensuing accumulation of skills and general human capital in society. Specifically, we use three alternative outcomes. The first one aims to capture the accumulation of skills through occupational training and experience. It measures the number of workers classified as foremen and skilled manual laborers in factories and crafts, expressed as a share of the working-age male population. The other two outcomes capture the accumulation of general (educational) human capital in later stages of industrialization. They are the school enrollment rate in 1864 and the literacy rate among population aged 10 and above in 1871.

5 Empirical analysis

5.1 Model specification

We empirically explore our hypotheses in a cross-section of 261 Prussian counties by estimating the following model using ordinary least squares (OLS):

$$y_i = \alpha + \beta \cdot \text{Mills}_i + \mathbf{X}_i' \cdot \mathbf{\Lambda} + \varepsilon_i. \tag{1}$$

Here, y_i represents one of our two main outcomes of interest in county i, i.e., the share of serfs emancipated between 1821 and 1848 or the size of redemption payments per settled case for the same period. Mills_i is our measure of initial physical capital abundance, i.e., the number of water mills per 1,000 inhabitants in 1819. The vector $\mathbf{X}_i$ represents other covariates discussed in Section 4.3 and ε_i is a county-specific error term.

The coefficient of interest, β, relates our proxy for elite-owned physical capital to the outcome variables. According to our conceptual framework, the estimates of β are expected to be positive in serf emancipation rate specifications but negative for the case of redemption payments. In our empirical analysis, we incrementally add sets of control variables to our estimating equation. To account for possible interdependence of error terms across counties within larger administrative units, we cluster standard errors at the district level.[32]

Since the abundance of water mills is measured prior to serf emancipation, reverse causality is not a concern. However, although our analysis accounts for a large set of potentially confounding factors, omitted-variables bias due to relevant unobservable characteristics cannot be fully ruled out. In Online Appendices D and E, we implement two strategies to mitigate potential endogeneity concerns. The first strategy employs terrain slope as a plausibly exogenous source of variation in the prevalence of water mills in an instrumental-variables setting. This strategy yields estimates that are quantitatively similar to the OLS case reported below, when conditioning on a sizable vector of geographic and other factors.

[32] Alternatively, to allow for a more general form of spatial correlation in error terms across counties, we implement the "Conley correction" for all of our main specifications examining serf emancipation. Table G.10 in Online Appendix G shows that the resulting standard errors, based on spatial cutoffs in the range of 200 to 500 kilometers, are similar to the baseline estimates, and the statistical significance of the relationship of interest remains unaffected.

The second strategy exploits time-varying district-level data on the number of settled redemption cases during the latter half of the nineteenth century. It implements a flexible panel estimation in which the initial capital stock is allowed to have a dynamic relationship with the average annual flow of emancipated serfs across time. This setting incorporates fixed effects to account for unobserved heterogeneity in time-invariant district-level characteristics. We find that districts with a higher prevalence of water mills per capita in 1819 experienced a larger flow of emancipation cases in the mid-nineteenth century.

5.2 Explaining serf emancipation rate

Table 1 presents the results of estimating our regressions in the full sample of 261 counties (columns 1–4) and a subsample representing the 195 counties east of the river Elbe (columns 5–8). Although our full-sample analysis includes the east-of-Elbe indicator, its presence is insufficient to claim that the positive association of interest actually held under the distinct institutional conditions of that region. In what follows, we focus on the main coefficient of interest and refer the reader to Online Appendix D for a detailed discussion of other estimates. We standardize our main variables for ease of interpretation.

Column 1 reports the coefficient of interest, conditional on geographic controls. It is statistically significant at the 1% level and implies that an increase in the prevalence of water mills by one standard deviation is associated with an increase in the rate of serf emancipation by 24% of a standard deviation in our full sample.[33] According to Table D.2 in Online Appendix D, almost all geographic covariates enter this regression with their expected signs, although only temperature and precipitation are statistically significant.[34]

In column 2, we augment our analysis to account for potential proximate confounders. Our intention is to assess the extent to which these covariates can explain away the relationship of interest, conditional on our full set of geographic controls. Notably, the estimate of our main coefficient is virtually identical to that obtained in column 1. The analysis in Table D.3 of Online Appendix D shows that, when included individually, most proximate controls are significantly related to emancipation rate and enter the regression with their expected signs. However, once all covariates in this set are included simultaneously, only the urbanization rate and average family size remain statistically significant.

In column 3, we include additional controls accounting for further potential confounders and prominent alternative mechanisms of emancipation. Again, the coefficient of interest remains both highly statistically significant and largely unchanged in magnitude relative to the baseline estimate in column 1. The coefficients on additional covariates, shown in Table D.4 in Online Appendix D, indicate that greater coercion intensity and a higher preexisting prevalence of free peasants are significantly negatively related to emancipation when all controls are included simultaneously.

[33] The scatter plot in panel (a) of Figure D.3 in Online Appendix D depicts the corresponding bivariate relationship between the non-standardized counterparts of our variables of interest.

[34] In an unreported analysis, we also examined how serf emancipation is associated with the interaction between water mills and an indicator of above-median soil suitability for cereal cultivation. This was done to investigate whether water mills accelerated economic modernization and, thus, serf emancipation through an alternative mechanism capturing complementarity between water mills and agricultural productivity. Contrary to this alternative mechanism, the interaction term is associated with a *lower* rate of emancipation.

TABLE 1: Explaining serf emancipation rate

Dependent variable:	Serf emancipation rate, 1821–48							
	Full sample				East-Elbia sample			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water mills 1819	0.243***	0.239***	0.207***	0.077	0.286***	0.246***	0.169**	0.040
	(0.057)	(0.051)	(0.058)	(0.056)	(0.089)	(0.060)	(0.064)	(0.062)
Geographic controls	×	×	×	×	×	×	×	×
Proximate controls		×	×	×		×	×	×
Additional controls			×	×			×	×
Province fixed effects				×				×
Observations	261	261	261	261	195	195	195	195
Adjusted R^2	0.31	0.42	0.47	0.50	0.24	0.40	0.49	0.54
Partial R^2 of mills	0.07	0.06	0.05	0.01	0.09	0.06	0.03	0.00

Notes. Serf emancipation rate and water mills variables are both standardized to have zero means and unit standard deviations. *Geographic controls* are: temperature, precipitation, soil suitability for cereal crops, the share of sand in the top soil, distance to navigable rivers, and an indicator for counties east of the river Elbe. *Proximate controls* are: population density in 1816, urbanization in 1816, the population share of urban craftsmen, the population share of urban traders, family size in 1849, school enrollment rate in 1816, population share of non-German ethnic groups in 1861, inheritance law (primogeniture or partible), and the share of knight estates. *Additional controls* are: number of social uprising 1816-47, indicators for the presence of a main road in 1848, the presence of a railway line in 1848, and the presence of coal mining, the share of the population born outside the county in 1871, an indicator for either the presence of a university in 1517 or for status as an Imperial City or member of the Hanseatic League in 1517, the size of labor duties requiring redemption, the share of noble estates owned by commoners in 1856, the share of estates operated under the Kulm law, the share of land in royal domains, and an indicator for French occupation under Napoleon. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

Furthermore, while counties with railway access experience higher emancipation rates, having a commercial city by 1517 is associated with lower rates.

In column 4, we include province fixed effects that may account for confounding factors at the regional level that are not captured by our extensive set of controls (there are seven provinces in total). In this specification, the coefficient on water mills falls in magnitude and loses its statistical significance. This outcome may be the result of accounting for unobserved heterogeneity, particularly spatially correlated confounders. However, it may also reflect the tendency of the fixed-effects estimation to reduce useful variation in the variable of interest (Angrist and Pischke, 2009, p. 225–226). Indeed, province fixed effects alone effectively wipe out more than a fifth of variation in the water mills variable. This is particularly important since water mills are a noisy measure of the relevant elite-owned proto-industrial capital, and fixed-effects estimation tends to exacerbate attenuation bias due to measurement error (Gormley and Matsa, 2014, p. 645).[35] Note also that the administrative division into provinces was introduced in Prussia in 1815 as part of

[35]In a simulation exercise, we repeatedly split our baseline sample into arbitrary clusters of contiguous counties to generate artificial regions of sizes comparable to the actual Prussian provinces. For each of the 1,000 iterations and the corresponding artificial regions, we ran our main regression (with geographic controls) including respective fixed effects. Our exercise shows that the water mills variable loses statistical significance in an overwhelming majority of iterations after including artificial regional fixed effects. In this sense, there is nothing special about the actual Prussian provinces. Results are available from the authors upon request.

TABLE 2: Assessing the relative importance of emancipation mechanisms

		Partial R^2	Shorrocks-Shapley	
		(1)	(2)	(3)
Explanation	Proxy	Value	Value	in %
Elite capitalism	Water mills 1819	0.047	0.056	0.108
Outside options	Urbanization rate 1816	0.042	0.050	0.095
Labor abundance	Population density 1816	0.012	0.022	0.043
Threat of revolution	Number of uprisings 1816-47	0.001	0.003	0.006
Enlightenment ideals	Commoner estates (share)	0.003	0.002	0.004
External institutions	Napoleonic occupation (dummy)	0.003	0.002	0.003
	All other variables	0.334	0.389	0.742
R^2		0.524	0.524	

Notes. This table presents the decomposition of the overall R^2 of the emancipation rate regression with the full set of control variables, presented in column 3 of Table 1, into partial R^2 statistics (column 1) and Shapley values (column 2). Relative contributions are shown in column 3.

the Stein-Hardenberg reforms to facilitate the self-governance of regions and did not determine the institutional aspects of serfdom until its abolition.[36]

The regressions in columns 5–8 examine our hypothesis in counties located to the east of the river Elbe. Reassuringly, our estimates from these specifications document empirical patterns that are qualitatively similar to those observed in columns 1–4.

Tables G.1–G.6 in Online Appendix G present the results of further robustness checks. Our results for either estimation sample are robust to controlling for longitude, river density, subterranean coal deposits, local state capacity (the population share of civil servants), measures of population diversity (religious and linguistic fractionalization), and the sex ratio.

Table 2 presents an assessment of the relative importance of alternative emancipation mechanisms, as reflected by the contributions of respective proxy variables to the explained variation in serf emancipation rate across counties. Specifically, based on our full specification in column 3 of Table 1, we report the partial R^2 and the Shapley values for each of six alternative channels, along with their percentage contributions to the overall explanatory power of the regression. In performing this exercise, we follow Shorrocks (2013) and Henderson et al. (2018). The results suggest that our mechanism ("elite capitalism") accounts for about 11% of the explained variation in emancipation rate. This is similar to the explanatory power associated with the presence of outside options but substantially more than the explanatory power of mechanisms pertaining to labor abundance, the threat of popular revolts, the Enlightenment and modernization, and externally imposed Napoleonic institutions. While our main channel appears to be particularly important for emancipation in the context of nineteenth-century Prussia, naturally, a similar ranking of alternative mechanisms need not hold in other settings.

[36]Table G.7 in Online Appendix G shows that our main finding is robust to the one-at-a-time exclusion of each of the seven Prussian provinces from our estimation sample. Thus, the key empirical pattern is not driven by the differences between any one province and the remainder of the sample. This is further supported by findings reported in Tables G.8 and G.9, where we either exclude or use dummies to control for counties belonging to the historical territory of Prussia at various points in time. These findings suggest that our results are not driven by east-west institutional differences that led to substantially lower emancipation rates in regions of historical Prussia.

TABLE 3: Explaining redemption costs

Dependent variable:	Redemption costs							
	Full sample				East-Elbia sample			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water mills 1819	−0.162***	−0.121***	−0.142***	−0.101**	−0.200***	−0.110***	−0.133***	−0.096**
	(0.036)	(0.034)	(0.036)	(0.042)	(0.044)	(0.028)	(0.032)	(0.036)
Geographic controls	×	×	×	×	×	×	×	×
Proximate controls		×	×	×		×	×	×
Additional controls			×	×			×	×
Province fixed effects				×				×
Observations	261	261	261	261	195	195	195	195
Adjusted R^2	0.37	0.49	0.52	0.56	0.39	0.51	0.55	0.57
Partial R^2 of mills	0.08	0.05	0.06	0.02	0.11	0.03	0.04	0.02

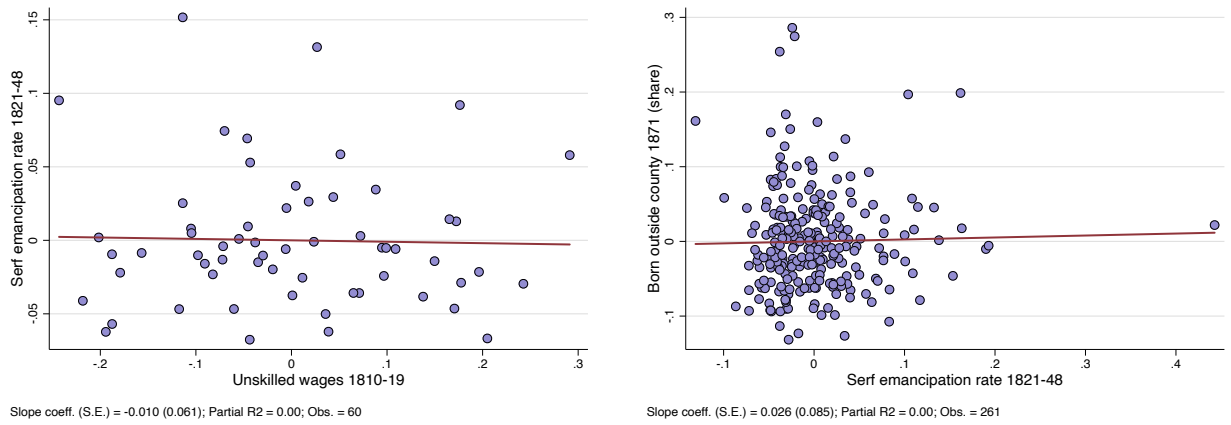
Notes. Redemption costs are measured as the first principal component of four different types of compensation payments made by peasants to their landlords for the redemption of servile duties (where each payment type reflects its average amount across all emancipation cases settled as of 1848). Redemption costs and water mills variables are both standardized to have zero means and unit standard deviations. See notes to Table 1 for the lists of geographic, proximate, and additional controls. Each specification also includes a servile duties variable representing the first principal component of two different types of labor services (where each type reflects its average amount in service days across all emancipation cases settled as of 1848) redeemed by peasants. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

5.3 Explaining redemption costs

Our findings regarding the serf emancipation rate could be driven both by supply and demand forces. On the one hand, the observed pattern could result from an increase in the supply of (or willingness to accept) emancipation by the elites aiming to elicit higher labor effort complementary to their physical capital. On the other hand, it could also be explained by an increase in the demand (or willingness to pay) for emancipation by the serfs, arising from better outside options for workers in industrializing regions. The revealed "price" of emancipation – namely, the size of compensation payments made by the serfs to the elites for the redemption of servile dues – permits an assessment of the relative strengths of these two forces. In particular, lower (higher) average redemption costs would suggest the dominance of the former (latter) mechanism.

Table 3 shows the results of regressions linking water mills to the costs of redemption, based on the average compensation payments made to the landlords across emancipation cases settled between 1821 and 1848. Using a structure similar to our preceding analysis of the serf emancipation rate, the table consecutively adds sets of controls variables in each column for our full and East-Elbia samples. Since our measure of redemption costs reflects the total compensation payment to the landlord, rather than the negotiated price *per unit* of servile dues redeemed, the outcome variable is expected to be mechanically positively correlated with the amount of servile dues in the redemption agreement. Thus, we control for the average intensity of coercion across settled emancipation cases in all specifications.

The full-sample results presented in columns 1–4 reveal that the "price" of emancipation was significantly lower in regions with a larger prevalence of water mills, suggesting an instrumental role played by the material incentives of the elites in facilitating emancipation. Conditional on all controls (column 3), an increase in the prevalence of water mills by one standard deviation is



(a) Unskilled wages and subsequent serf emancipation (b) Serf emancipation and labor migration

FIGURE 3: Serf emancipation, unskilled wages, and labor migration

Notes. Unskilled wages are measured as the average daily wage rate of male "seasonal fill" workers (day laborers) in the forestry sector during 1810–19. Both diagrams are residual scatter plots (after accounting for geographic controls). The sample of counties in panel (a) is constrained by the availability of data on wages.

associated with a decrease in redemption costs by 14% of a standard deviation. The magnitude of the coefficient decreases in the specification with province fixed effects (column 4), but it remains negative and statistically significant. Our estimates are largely similar for the subsample of counties located east of the river Elbe (columns 5–8).

5.4 Evidence on labor market segmentation

As discussed in Section 3.2, existing institutional restrictions on migration and the ability of landlords to effectively set the size of compensation payments meant that peasants had limited mobility. Thus, freed serfs faced severe restrictions in pursuing potentially better outside options elsewhere in the country and often continued working for their former lords upon emancipation. Given the importance of this factor for our conceptual argument, in this section, we present evidence consistent with a high degree of labor market segmentation across Prussian counties.

Panel (a) of Figure 3 shows the relationship between unskilled wages in 1810-1819 and the serf emancipation rate, conditional on geographic controls. The former is measured as the average daily wage rate of male "seasonal fill" workers (day laborers) in the forestry sector. First, this scatter plot shows a high cross-county variation in the unskilled wage rate, consistent with non-convergence of prices across weakly integrated factor markets (Becker and Hornung, 2023). It further shows that this variation in the wage rate is uncorrelated with serf emancipation rate during 1821–1848. One possible interpretation of this finding is that the potential for labor mobility across county boundaries did not influence the elites' decision to either delay or accelerate the emancipation process. Moreover, serfs were not necessarily able to exploit higher day-laborer wages in order to expedite the redemption of their lifetime servile dues.[37]

[37] As further explored in Online Appendix F, this null relationship may also be masking heterogeneous effects associated with different mechanisms linking market wages to labor emancipation *within* counties.

Panel (b) of Figure 3 shows that the intensity of county-level migration inflows over the relevant time period, proxied by the share of population of any age in 1871 that was born outside the county, is largely unrelated to the pace of the emancipation process, conditional on geographic factors. This further highlights the apparent absence of any clear relationship between serf emancipation and subsequent labor movements across counties.

5.5 Indirect consequences of emancipation

According to our hypothesis, emancipation is supported by capitalist elites to foster the expansion of effective labor through worker effort, capturing the exercise of care and the acquisition of occupation-specific skills relevant for industrial tasks. Extending this argument, the absence of wage expropriation following emancipation should eventually contribute to educational investments, too, once the demand for general human capital becomes salient. This suggests a positive link between the initial stock of relevant physical capital and the intensity of skill acquisition after the emancipation process has been unfolding for some time. Moreover, this link should be partially mediated by the intensity of serf emancipation itself. In particular, to the extent that the initial capital stock is correlated with broad-based industrialization in the long run, the residual link between water mills and post-emancipation human-capital outcomes would reflect the higher demand for skills in later stages of industrialization.

Table 4 presents the results from regressions linking the prevalence of water mills in 1819 and the rate of serf emancipation between 1821 and 1848 to three outcomes reflecting the accumulation of human capital a few decades following the onset of emancipation. The first outcome is the share of skilled manufacturing workers in the working-age male population in 1849 (columns 1–3). An increase in this measure plausibly captures an expansion of specific human capital through occupational training and experience in earlier stages of industrialization. On the other hand, the latter two outcomes – the school enrollment rate in 1864 (columns 4–6) and the literacy rate among the population aged 10 and above in 1871 (columns 7–9) – reflect the accumulation of general human capital in later stages of industrialization. Along with geographic and demographic covariates, the set of control variables in this analysis includes the school enrollment rate in 1816, which accounts for the potentially confounding influence of initial investments in general human capital.[38] In addition to affecting initial physical capital abundance and subsequent labor emancipation, early human capital accumulation could be positively associated with the intensity of post-emancipation skill acquisition through other mechanisms of structural persistence (e.g., schooling infrastructure).

The results in columns 1, 4, and 7 indicate that, as expected, the share of serfs emancipated between 1821 and 1848 is positively and significantly associated with subsequent human capital accumulation. Furthermore, estimates in columns 2, 5, and 8 suggest that the initial stock of relevant physical capital also has a positive and significant relationship with each indicator of skill acquisition. Finally, columns 3, 6, and 9 show that, in a "horse race" specification including both serf emancipation rate and initial capital abundance, both variables show significant positive associations with each outcome measure. However, possibly due to the role of emancipation

[38] We also control for urbanization rate, which may have increased the incentives to accumulate human capital following emancipation, because former serfs could elicit an appropriate skill premium in more competitive urban labor markets (see, e.g., Naidu, Posner and Weyl, 2018).

TABLE 4: Explaining post-emancipation human capital accumulation

Dependent variable:	Skilled employment rate 1849			Enrollment rate 1864			Literacy rate 1871		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Serf emancipation 1821–48	1.798***		1.077*	2.209***		1.772**	1.145***		0.965**
	(0.623)		(0.587)	(0.743)		(0.728)	(0.365)		(0.355)
Water mills 1819		2.891***	2.608***		2.047***	1.579***		0.906***	0.652**
		(0.751)	(0.782)		(0.496)	(0.516)		(0.255)	(0.263)
Enrollment rate 1816	0.073*	0.041	0.034	0.252***	0.241***	0.228***	0.218***	0.215***	0.208***
	(0.036)	(0.035)	(0.034)	(0.059)	(0.057)	(0.056)	(0.027)	(0.028)	(0.027)
Control variables	×	×	×	×	×	×	×	×	×
Observations	261	261	261	261	261	261	261	261	261
Adjusted R^2	0.60	0.63	0.64	0.64	0.63	0.65	0.88	0.88	0.88
Partial R^2 of emancipation	0.05		0.02	0.08		0.05	0.05		0.04
Partial R^2 of mills		0.14	0.11		0.07	0.04		0.04	0.02

Notes. All dependent variables are expressed in percent. Serf emancipation rate and water mills variables are defined as earlier. Both of these explanatory variables are standardized to have zero means and unit standard deviations. Control variables include the full set of geographic covariates from Table 1, population density in 1816, urbanization rate in 1816, the share of Protestants in 1816, and the share of other ethnic groups in 1861. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

in facilitating subsequent investments in human capital, the coefficients on water mills become somewhat attenuated in comparison to their corresponding estimates from columns 2, 5, and 8.

6 Concluding remarks

This paper argues that capital accumulation over the course of industrialization contributed to the decline of coercive labor institutions. The key insight of the highlighted mechanism is that labor emancipation is ultimately profitable for capital-owning elites since it provides the incentives for the freed workers to exert effort, exercise care, and acquire occupational skills essential in industrial tasks. The unleashed supply of effective labor boosts the capital rents of the elites due to complementarity of inputs in the production process, which more than compensates for the costs of relinquishing labor coercion. The main testable predictions of the theory are supported by our empirical analysis of serf emancipation in nineteenth-century Prussia. In regions characterized by a higher initial stock of relevant physical capital, emancipation occurred faster and the elites were more willing to accept lower redemption payments from their serfs.

Quantitatively, our channel accounts for a significant share of the variation in emancipation rate across Prussian counties when compared to other potentially relevant mechanisms, including the presence of outside options, labor abundance, the threat of social unrest, Enlightenment ideals, and the imposition of Napoleonic institutions. Of course, this does not necessarily imply the predominance of our mechanism in other contexts of emancipation, especially in preindustrial times when capital accumulation was all but absent. For example, the evolution of serfdom institutions in Europe in the aftermath of the Black Death suggests that labor abundance and the availability of outside options for agricultural workers were of central importance during this period (Domar, 1970; Brenner, 1976; Jedwab, Johnson and Koyama, 2022).

As suggested in earlier research, the idea that elites may gain from employing free rather than forced labor, particularly in care-intensive tasks, helps explain historical patterns of coercion and emancipation in non-industrial settings. For instance, the higher degree of care-intensity of olive and vine arboriculture in the Mediterranean during classical antiquity, in comparison to work on the cotton, corn, and sugar plantations of the Antebellum U.S. South, can partly explain the viability of slavery in the latter case and its disappearance in the former (Fenoaltea, 1984). Similarly, the higher prevalence of slave manumissions in skilled activities and urban sectors, as well as in classical antiquity relative to the Antebellum U.S. South, may reflect the elites' understanding that worker effort in care-intensive tasks is elicited more effectively using rewards (including release from slavery) rather than punishment (Findlay, 1975; Fenoaltea, 1984). Our contribution shows that these same forces, pertaining to elite incentives, can generate large-scale emancipation when structural economic change raises labor demand in activities that require care and the acquisition of occupational skills.

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Online Appendices

Appendix A Proofs

Proof of Proposition 1. Define $\kappa \equiv k_0^{\alpha}$ and $\gamma \equiv \phi(1-\alpha) < 1$. Then, as shown in the main text, the freed laborers exert positive effort if and only if $\kappa > \hat{\kappa} \equiv 1/(\gamma A)$.

If $\kappa \leqslant \hat{\kappa}$ and serfdom is abolished, the second-period income of the elites is $rK_0 = \alpha A k_0^{\alpha-1} K_0 = \alpha A (1-\lambda)^{1-\alpha} K_0^{\alpha}$, whereas under serfdom, it is $Y - (1-\lambda)\tilde{c} = A(1-\lambda)^{1-\alpha} K_0^{\alpha} - (1-\lambda)\tilde{c}$. Based on a direct comparison of these income levels, if $\kappa < \bar{\kappa} \equiv \tilde{c}/((1-\alpha)A)$, the elites would be better off emancipating their serfs, even if the freed laborers supply zero effort upon emancipation. This happens because, in this case, the productive capacity is too low and/or the subsistence consumption costs are too high. Thus, in order to realistically model the emancipation process, we only consider the case of $\kappa \geqslant \bar{\kappa}$, in which serfdom is profitable for the elites for low enough values of κ above $\bar{\kappa}$. Note also that $\bar{\kappa} < \hat{\kappa}$ under the maintained assumption that $\phi\tilde{c} < 1$. Thus, serfdom is maintained for $\kappa \in (\bar{\kappa}, \hat{\kappa}]$.

If $\kappa > \hat{\kappa}$ and serfdom is abolished, the freed laborers will supply a positive level of effort and, as indicated in the main text,

$$k = k_0^{\frac{1-\phi}{1-\phi(1-\alpha)}} \cdot (\phi(1-\alpha)A)^{\frac{\phi}{\phi(1-\alpha)-1}}.$$

In this case, comparing the second-period incomes of the elites between the serfdom and freedom scenarios yields the following condition for the abolition of serfdom:

$$rK_0 = \alpha A k_0^{\frac{(1-\phi)(\alpha-1)}{1-\phi(1-\alpha)}} \cdot (\phi(1-\alpha)A)^{\frac{\phi(\alpha-1)}{\phi(1-\alpha)-1}} \cdot K_0 > A(1-\lambda)^{1-\alpha} K_0^{\alpha} - (1-\lambda)\tilde{c},$$

which, upon rearrangement, yields

$$G(\kappa) \equiv \alpha A \kappa^{\frac{1}{1-\gamma}} \cdot (\gamma A)^{\frac{\gamma}{1-\gamma}} - A\kappa + \tilde{c} > 0.$$

Observe that $G(\kappa)$ is a continuous and strictly convex function with a unique global minimum point and that $G(\hat{\kappa}) < 0$. Thus, applying the intermediate value theorem, there exists a unique value $\kappa^* > \hat{\kappa}$ such that $G(\kappa) > 0$ if and only if $\kappa > \kappa^*$. It follows immediately that there exists a unique value $k_0^* = (\kappa^*)^{1/\alpha}$ such that labor emancipation occurs if and only if $k_0 > k_0^*$. ■

Proof of Proposition 2. Consider the relevant case of $\kappa \in (\hat{\kappa}, \kappa^*)$, in which the freed laborers supply a positive level of effort, but this per se is insufficient to make the elites better off under freedom. In this case, the minimal transfer, $\hat{p}$, necessary to induce the elites to grant freedom is simply the compensating differential between the elites' second-period incomes under serfdom versus freedom. Thus, the minimal transfer payment to the elites is $\hat{p}(\kappa) = -G(\kappa)$. Direct calculation yields

$$\frac{\partial \hat{p}(\kappa)}{\partial \kappa} = A - \frac{\alpha A}{1-\gamma} \cdot (\gamma A \kappa)^{\frac{1}{1-\gamma}} < 0 \quad \Longleftrightarrow \quad \kappa > \kappa^{**} \equiv \frac{1}{\gamma A} \cdot \left(\frac{1-\gamma}{\alpha}\right)^{\frac{1-\gamma}{\gamma}} \in (\hat{\kappa}, \kappa^*).$$

The transfer payment is feasible for the freed laborers if their wage rate upon emancipation exceeds $\hat{p}$. In fact, a stronger statement of feasibility can be made for the relevant case of $\kappa > \kappa^{**}$, in which the competitive-market wage rate of the laborers covers not only the minimal transfer payment, $\hat{p}$, but also the subsistence consumption level, $\tilde{c}$. For this to be the case, the following condition must hold:

$$w(1+e^*)^{\phi} = \phi^{\frac{\phi}{1-\phi}}((1-\alpha)Ak^{\alpha})^{\frac{1}{1-\phi}} > \hat{p} + \tilde{c}.$$

Upon substitution of $\hat{p}$ and k, followed by rearrangement, the condition above yields $\kappa > \hat{\kappa}$, which is always true in the considered case. ■

Appendix B Extensions of the conceptual framework

Our basic model from Section 2 may be extended in several dimensions without qualitatively altering the key insight. First, although we presented our main argument in a two-period setting for simplicity, our model can be integrated into an overlapping-generations framework à la Galor and Moav (2004, 2006) or Galor, Moav and Vollrath (2009), incorporating endogenous capital accumulation. In such a dynamic setting, capital accumulation may occur through either the bequest or the standard saving motive, and the choice between maintaining and abolishing serfdom will be made by each generation of the elites. Prior to labor emancipation, the growth process will be driven purely by the accumulation of physical capital by the elites, but following emancipation, the former serfs will also contribute to this process, initially by increasing their effort-driven effective labor and eventually by accumulating physical capital as well. By modeling physical capital accumulation, this setting illustrates that labor emancipation occurs as a by-product of the development process. Relatedly, technological progress, as reflected by a rise in the level of productivity, A, will produce a similar effect as capital accumulation in this setting, raising the elites' demand for effective labor and incentivizing labor emancipation.

Second, relaxing the assumption that the elites do not participate in the labor market will have the following implications. Rather than freeing their coerced workers, the elites will initially increase effective labor in the economy by supplying their own effort to the workplace when the return from doing so becomes sufficiently high – i.e., when there is a large enough stock of physical capital. Although this process will delay serf emancipation, diminishing returns to worker effort will ensure that, sooner or later, the supply of effort by the elite minority alone will cease to support a high rate of return to their physical capital. Thus, akin to our basic model, the increase in elites' demand for effective labor will eventually make it incentive-compatible for them to abolish serfdom.[B.1]

Third, although our basic model assumes that the supply of effort by freed laborers does not involve any fixed cost in terms of output (as would be the case if they initially required better nourishment or worker training), relaxing this assumption and even introducing credit market imperfections (e.g., Galor and Zeira, 1993; Galor and Moav, 2004, 2006; Galor, Moav and Vollrath,

[B.1] In such an extension of the model, where the elites are allowed to engage in labor supply, the elites' decision to maintain or abolish serfdom will be conditioned by a secondary effect of emancipation on their second-period incomes. Namely, the increase in economy-wide effective labor from emancipation will tend to depress the wage income of the elites, thereby delaying their support of emancipation reforms. Because this general-equilibrium effect unnecessarily obscures our main mechanism, we model the elites as a pure rentier class.

2009) will merely serve to delay the abolition of serfdom. In particular, under binding constraints on the ability of the former serfs to obtain credit, the elites will need to tax themselves to finance the fixed cost associated with the supply of effort by freed laborers. Thus, the profitability of granting freedom from the viewpoint of the elites will be conditioned by the amount of this fixed tax burden. Nevertheless, once the elites' demand for effective labor becomes sufficiently high due to a large enough stock of physical capital, they will find it incentive-compatible to financially support emancipation, as the profitability of granting freedom net of the fixed tax burden inevitably rises above the profitability of maintaining the status quo with serfdom.

Fourth, our basic model abstracts from the potential conflict of interest between landowners and capitalists in the decision to maintain or abolish serfdom, choosing instead to treat the elites as a single class of landowning capitalists.[B.2] The implications of relaxing this assumption, however, can be inferred from the findings of Galor, Moav and Vollrath (2009), who examine the role of landownership inequality in delaying the emergence of human-capital promoting institutions, such as public schooling. A central feature of their argument is that human capital is less complementary to land than it is to physical capital. Thus, for as long as their stakes in industrial production are small, the landed nobility has little incentive to financially support the advent of universal education: it would not only require the nobility to tax themselves but would also divert workers away from the agricultural sector, thereby raising wages and lowering the return to land. Hence, to the extent that landowners are politically influential, their incentives initially impede the introduction of public schooling. Similarly, if our basic model is extended to incorporate an agricultural sector, where worker effort is more easily extracted by coercion, the landowning elites will initially attempt to block the abolition of serfdom. Nevertheless, once their stakes in industrial production become sufficiently large and their economic interests are aligned with those of the capitalist elites, emancipation will inevitably follow.

Finally, consider the possibility that there exists an external urban industrial sector that offers a higher wage to workers relative to what free laborers could earn in the rural industrial sector. Our main mechanism will remain operative in the presence of such an outside option for emancipated serfs, so long as their reallocation to the urban sector upon gaining freedom is unlikely. This could be the case if there are significant impediments to labor mobility across space, due to geographically or institutionally imposed mobility costs, and if there is heterogeneity across workers in their willingness or ability to absorb such costs. Common knowledge regarding the presence of such impediments, combined with access to private information on their serfs, would be sufficient for the elites to expect that a significant portion of their emancipated peasants would continue to remain employed in the rural industrial sector as freed workers.

Overall, our fundamental insight regarding the influence of capital accumulation by the elites in society on their decision to support labor emancipation remains qualitatively unchallenged by these additional considerations.

[B.2] In our empirical analysis, where we account for the potential role of "conservative" landowners by including a measure of landownership concentration (share of knight estates) in our estimating equations.

Appendix C Alternative measures of proto-industrial capital

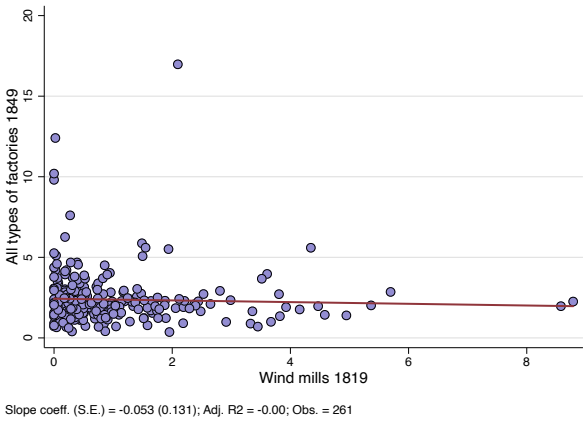
As explained in the main text, we focus on water mills as our main measure of relevant physical capital because it satisfies two crucial requirements: 1) exclusive ownership by the landed nobility, 2) direct link to the eventual adoption of industrialization due to path dependence from technological complementarities and agglomeration effects. In this appendix section, we show that other alternative measures of proto-industrial capital fail to meet at least one of these two requirements.

Although the ownership of any grain mill was a noble prerogative, only water-powered mills foreshadowed subsequent industrialization, particularly through the adoption of steam engines. Consistent with this special role of water mills, panels (a)–(d) of Figure C.1 show that the prevalence of wind- and horse-powered mills (per 1,000 inhabitants) in 1819 bears no systematic association with either broad-based industrialization in 1849 or steam engines in 1875. On the other hand, panels (e) and (f) of Figure C.1 indicate that the prevalence of "other" (i.e., non-grain-processing) mills (per 1,000 inhabitants) in 1819 is significantly and positively associated with both of these industrialization metrics. Unfortunately, these "other" types of mills are only classified according to their milling purpose (e.g., sawing of lumber, extraction of vegetable oils, pulping of wood for paper-making) but not by their power source (i.e., water, wind, or animals). Thus, although we contend that the observed patterns reflect the role of *water-powered* mills, this overall measure is likely contaminated by the data on less relevant "dead end" milling technologies.

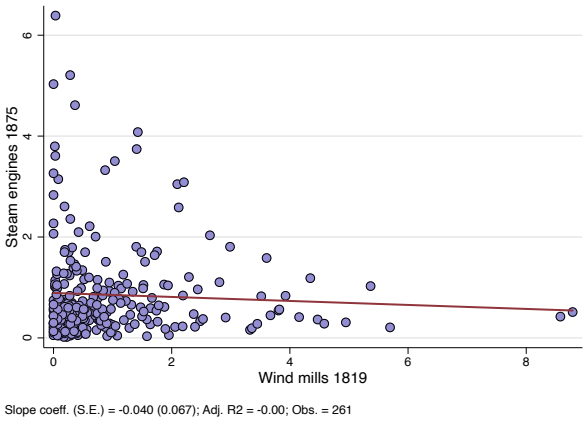
The remaining available measures of proto-industrial physical capital in the early nineteenth century capture the prevalence of structures and devices that were overwhelmingly owned by the bourgeoisie rather than the landed nobility, reflecting the legacy of institutional restrictions that prevented the nobility from engaging in bourgeois occupations at least until 1807. Therefore, these measures – namely, the number of brick- and glass-producing factories and the number of hand-driven looms in 1819 (both measured per 1,000 inhabitants) – fail to meet the first requirement of exclusive ownership by the nobility. Moreover, as shown in panels (a)–(d) of Figure C.2, these variables do not have statistically significant relationships with the two measures of subsequent industrialization.

Given that none of the alternative measures of initial proto-industrial capital fulfill the desired criteria in the context of our conceptual framework, we do not expect them to be positive and significantly related to serf emancipation rate. Table C.1 shows the relevant estimation results in the full (panel A) and East-Elbian (panel B) samples of counties. Column 1 reports our baseline estimates for the case of water mills, conditional on the full set of controls. In contrast, columns 2 and 3 show that the prevalence of wind- or horse-powered mills is unrelated to the serf emancipation rate. Column 4 provides the estimate for other types of mills, some of which are likely water-powered. While the coefficient is positive and significant in the full-sample analysis, this is not the case for East Elbia. Column 5 presents estimation results for an aggregate measure of all types of mills (regardless of milling purpose and power source). It is significantly and positively associated with the serf emancipation rate in both regression samples, likely reflecting the water-mill component of the overall metric.

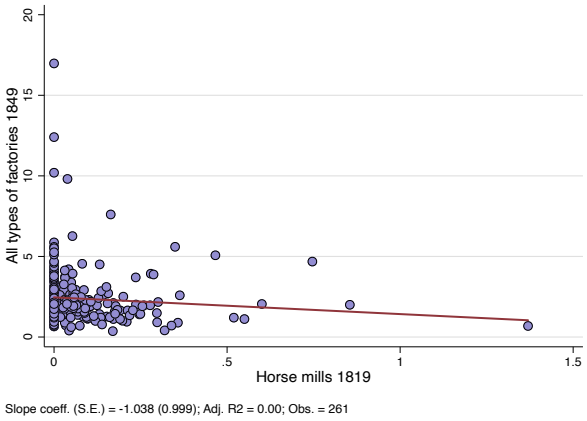
Column 6 shows that the prevalence of brick and glass factories is unrelated to the serf emancipation rate. This "null" relationship is consistent with the notion that, as of 1819, these factories were still overwhelmingly owned by the bourgeoisie rather than the landed nobility.



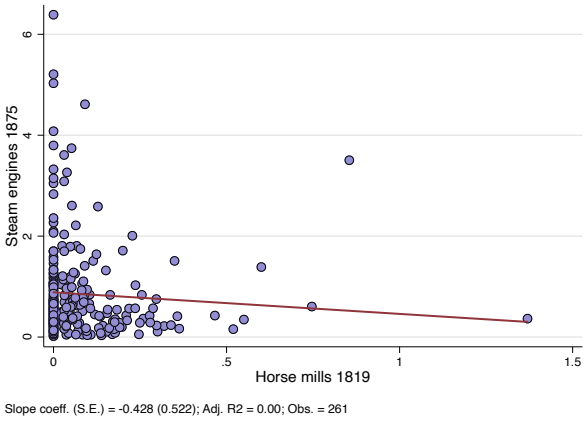
(a) Wind mills in 1819 and factories in 1849



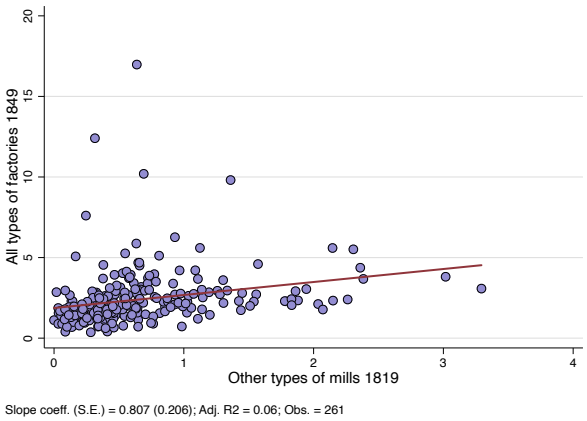
(b) Wind mills in 1819 and steam engines in 1875



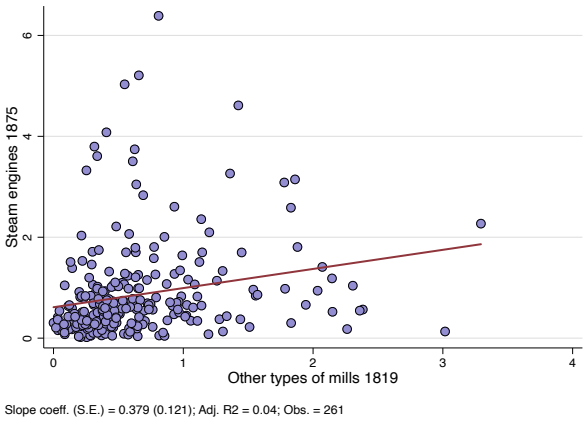
(c) Horse mills in 1819 and factories in 1849



(d) Horse mills in 1819 and steam engines in 1875

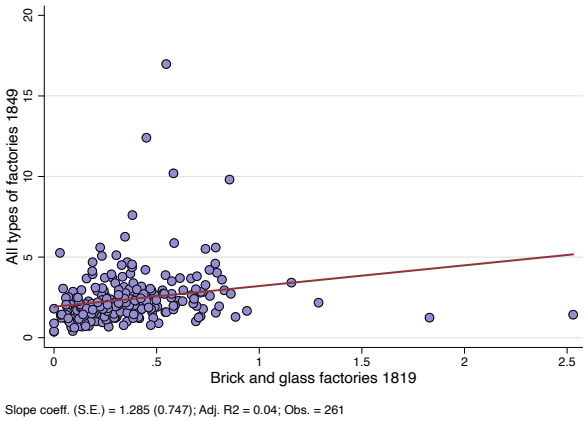


(e) Other mills in 1819 and factories in 1849



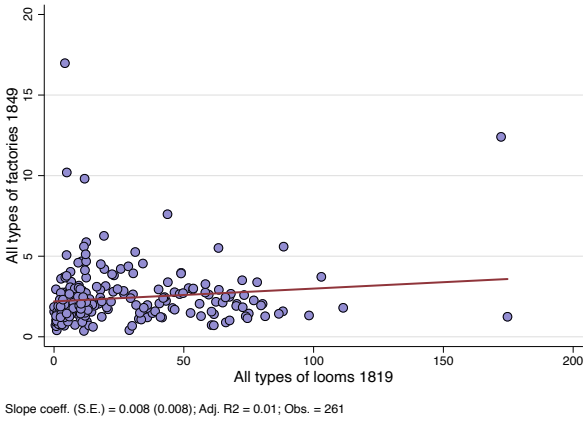
(f) Other mills in 1819 and steam engines in 1875

FIGURE C.1: Different types of mills and subsequent industrialization

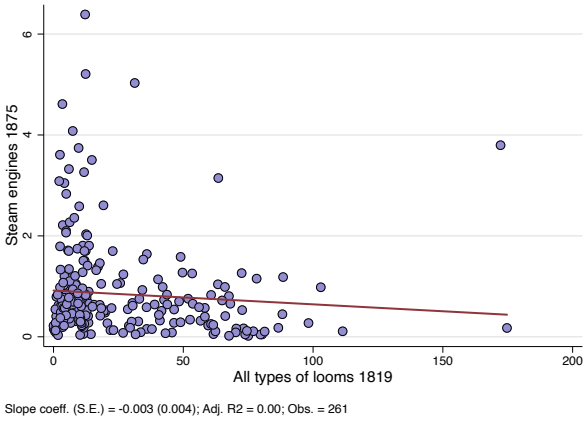


(a) Factories in 1819 and factories in 1849

(b) Factories in 1819 and steam engines in 1875



(c) Looms in 1819 and factories in 1849



(d) Looms in 1819 and steam engines in 1875

FIGURE C.2: Brick and glass factories, looms, and subsequent industrialization

Column 7 shows that the prevalence of weaving devices is significantly but *negatively* associated with the ensuing pace of serf emancipation. This pattern is consistent with the prevalence of the so-called putting-out or domestic system of cottage-industry-based fabric production. Under this system, commoner merchant employers would "put out" raw materials and weaving devices to rural households that worked primarily from their homes and returned the finished product for wage payments. The households, in turn, would have to exploit flexibility in the allocation of their labor between farm and household chores, on the one hand, and domestic putting-out work, on the other, especially during the winter season, when there was little farming work to be done. The observed association between weaving devices and delayed emancipation could be partly explained to the extent that merchants rationally tapped more heavily into those seasonal markets for putting-out labor in which potential labor supply was particularly thick. These were the regions of Prussia characterized by large-scale serf-intensive farming during the growing and harvesting seasons, where serfdom is expected to have persisted longer.

TABLE C.1: Alternative measures of proto-industrial physical capital and serf emancipation rate

Dependent variable:	Serf emancipation rate, 1821–48						
Proto-industry measure:	Water mills	Wind mills	Horse mills	Other types of mills	All types of mills	Brick and glass factories	All types of looms
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Panel A: Full sample						
Proto-industry 1819 (k)	0.207***	0.049	0.012	0.266**	0.203**	−0.007	−0.238***
	(0.058)	(0.040)	(0.060)	(0.102)	(0.072)	(0.065)	(0.079)
Observations	261	261	261	261	261	261	261
Adjusted R^2	0.47	0.44	0.44	0.49	0.47	0.44	0.48
Partial R^2 of k	0.05	0.00	0.00	0.09	0.06	0.00	0.08
ρ of k with water mills	1.00	−0.26	−0.25	0.54	0.45	0.15	−0.12
	Panel B: East-Elbia sample						
Proto-industry 1819 (k)	0.169**	0.088	−0.011	0.064	0.152*	0.037	−0.159**
	(0.064)	(0.073)	(0.065)	(0.068)	(0.074)	(0.060)	(0.071)
Observations	195	195	195	195	195	195	195
Adjusted R^2	0.49	0.48	0.47	0.48	0.49	0.47	0.49
Partial R^2 of k	0.03	0.01	0.00	0.01	0.03	0.00	0.03
ρ of k with water mills	1.00	−0.20	−0.30	0.54	0.45	0.16	−0.10

Notes. In each regression, the dependent and main explanatory variables are standardized to have zero means and unit standard deviations across counties in the relevant estimation sample. All regressions include the full set of control variables considered by the analysis in Table D.4. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

Appendix D Extended version of the cross-sectional analysis

D.1 An instrumental variables approach

As mentioned in the main text, our baseline analysis cannot fully rule out the omitted-variables bias due to relevant unobservable characteristics. Thus, we attempt to mitigate this issue by exploiting an exogenous (and, arguably, conditionally excludable) source of variation in water mills.

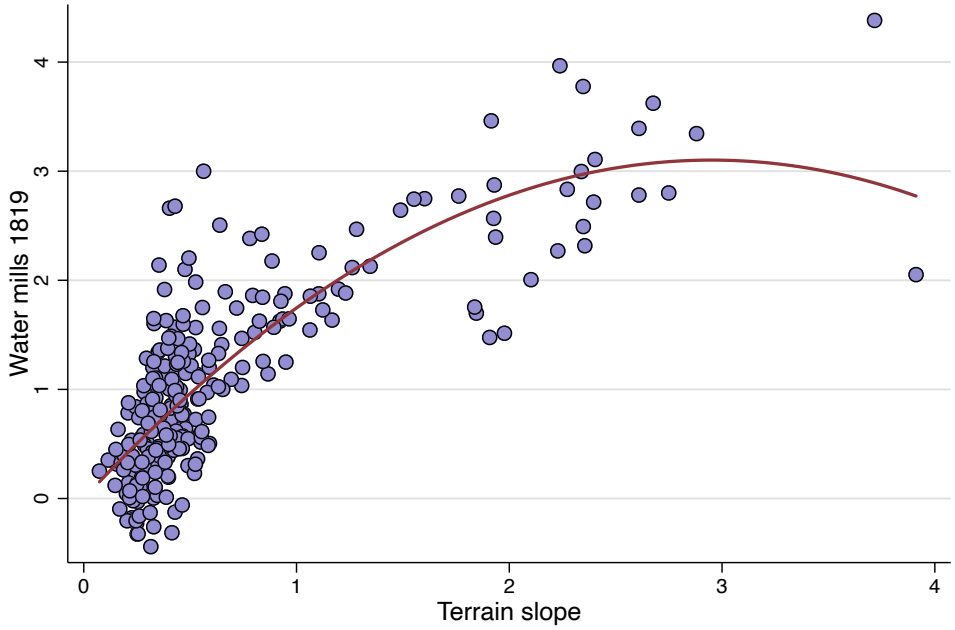
The historical suitability of a region for the effective operation of water mills was largely determined by geographic features. Since terrain undulation affects the natural speed of running water (and, thus, the hydraulic energy harnessable by water mills), the average slope of the terrain in a region had a non-monotonic influence on the region's suitability for operating water mills. At one end of the spectrum, terrains that are too flat did not permit the natural movement of water to generate a sufficient amount of kinetic energy. At the other end, in terrains that are too steep, such energy could not be feasibly harnessed, given the constraints imposed by the engineering technology in the early nineteenth century. In particular, terrain gradient is expected to have a hump-shaped relationship with the operability of water mills, reflecting a trade-off that captures the influence of terrain slope on the viability of constructing mill dams. Historically, the setup of a water mill involved the placement of a dam on a natural waterway to create an artificial mill pond, from where water was conveyed in a controlled fashion along a constructed channel to a water wheel.[D.1]

We measure the average slope of a county's terrain using geospatial elevation data at a 30-arc-second resolution by first computing the maximum elevation gradient (in angular degrees) between each grid cell and its eight contiguous neighbors and then calculating the average of this gradient measure across all the grid cells of the county. The scatter plot in Figure D.1 depicts the significant non-monotonic influence of terrain slope on the prevalence of water mills in our sample. We exploit this pattern in the first stage of a two-stage least squares (2SLS) estimation framework.[D.2] The map in Figure D.2 shows the spatial distribution of predicted water mills, based on the hump-shaped impact of terrain slope on mill operability. The first-stage results in Table D.1 show highly significant coefficients associated with the linear and quadratic terms for terrain slope, which remain rather stable when conditioning on different sets of covariates.

To alleviate concerns regarding the excludability of the terrain slope instrument, our analysis accounts for various alternative mechanisms through which it could influence the persistence of coercive labor institutions. Since average terrain slope could be correlated with local climatological and ecological features that affect the agricultural productivity of land, our analysis controls for temperature, precipitation, and different measures of soil quality. In addition, because terrain undulation may be associated with higher transportation costs and thus weaker integration of

[D.1] Although a steeper natural gradient conferred the benefit of a stronger baseline water current, it also increased the marginal cost of setting up a functional mill site, given the technological limitations of the nineteenth century. Based on a similar argument, Duflo and Pande (2007, p. 606) assert that "engineering considerations suggest that river gradient should have a non-monotonic effect on the likelihood of dam construction," and they document precisely such an effect of river gradient on the prevalence of irrigation dams across districts in modern-day India.

[D.2] Notably, the inflection point of the hump-shaped relationship depicted in Figure D.1 occurs in the neighborhood of a terrain slope value of 2.5 angular degrees, which corresponds to a rise-over-run slope ratio of $\tan(2.5) \approx 4\%$. This is, in fact, quite similar to the 3% rise-over-run "cutoff" value for the river gradient in Duflo and Pande (2007, p. 619, Table 2) – i.e., the value below (above) which river gradient is found to have a positive (negative) effect on the likelihood of dam construction across districts in modern-day India. This "external validity" result supports our identification strategy.



Linear coeff. (S.E.) = 2.103 (0.259); Quadratic coeff. (S.E.) = -0.356 (0.094); Partial R2 = 0.40; Obs. = 261

FIGURE D.1: Terrain slope and water mills in 1819

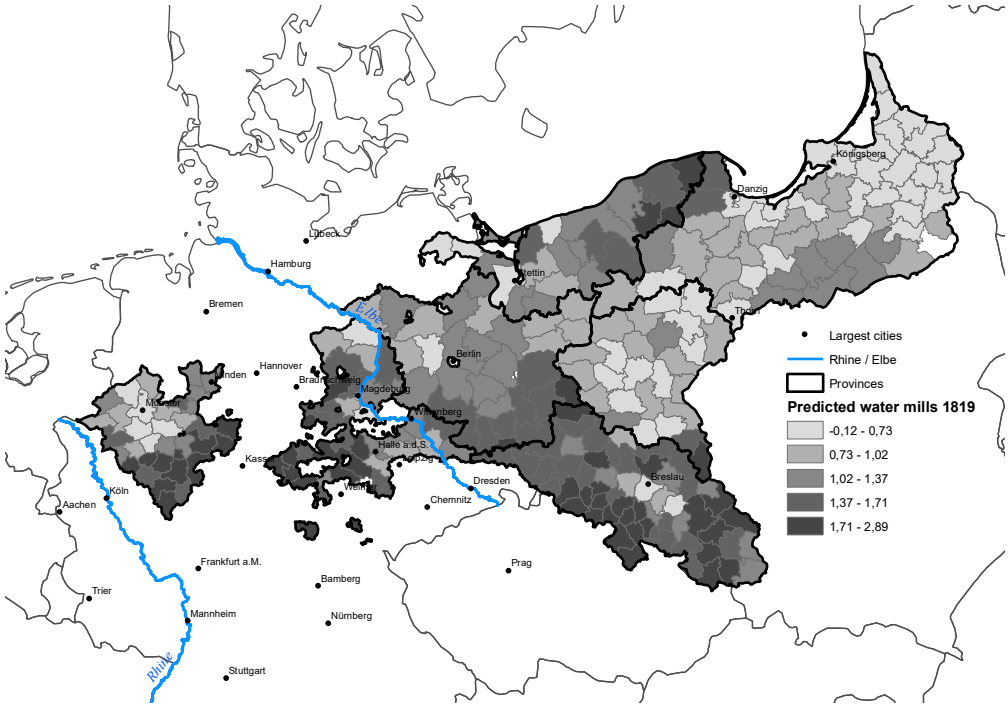


FIGURE D.2: Predicted water mills (based on terrain slope)

Notes. The map depicts water mills (per 1,000 inhabitants) in a county in 1819 predicted by terrain conditions, conditional on geographic and proximate controls. The prediction is based on the coefficients associated with terrain slope and its square from the regression presented in column 2 of Table D.1 in Online Appendix G.

TABLE D.1: First-stage regressions

Dependent variable:	Water mills 1819					
	Full sample			East-Elbia sample		
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
Terrain slope	2.741***	2.532***	2.516***	2.825***	2.602***	2.526***
	(0.337)	(0.320)	(0.344)	(0.306)	(0.363)	(0.285)
Terrain slope^2	−0.465***	−0.404***	−0.386***	−0.466***	−0.403***	−0.353***
	(0.123)	(0.112)	(0.110)	(0.126)	(0.115)	(0.098)
Geographic controls	×	×	×	×	×	×
Proximate controls		×	×		×	×
Additional controls			×			×
Observations	261	261	261	195	195	195
Adjusted R^2	0.52	0.60	0.61	0.52	0.61	0.63

Notes. The dependent variable is standardized to have a mean of zero and a standard deviation of one across counties in each regression sample. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

markets, we account for the distance to waterways, the presence of roads and railways, and more proximate measures of labor abundance and economic development, such as population density and urbanization rate.[D.3]

In the remainder of this appendix, we present a detailed discussion of our cross-sectional analysis and supplement it with 2SLS estimates.

D.2 Geographic controls

Table D.2 shows the detailed results from estimating our baseline set of regressions, with geographic controls added one at a time. Column 1 reports the coefficient estimate for the bivariate relationship of interest, and the scatter plot in panel (a) of Figure D.3 depicts the corresponding relationship between unstandardized variables of interest.

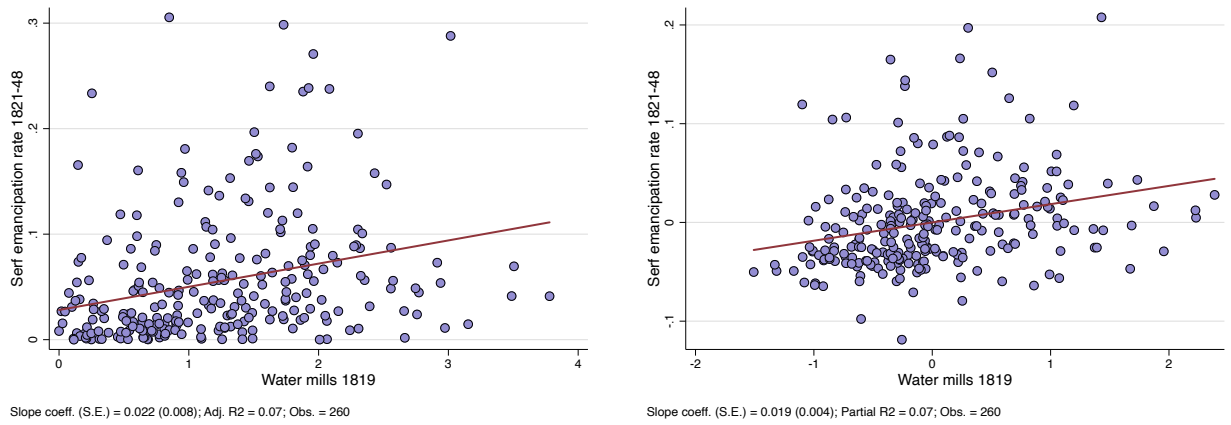
In columns 2–7, we add the following geographic covariates: average temperature, average precipitation, distance to navigable rivers, two different measures of soil suitability for agriculture, and an "East Elbia" fixed effect. The results indicate that conditional on the prevalence of water mills in 1819, the geographic factors that individually matter the most are temperature, precipitation, and soil suitability for cereal crops, all measured using contemporary high-resolution geospatial data. The significance of the latter two variables potentially reflects the stronger vested interests of the landowning elites in maintaining coercive labor institutions in those locations where, because of the higher agricultural productivity of land (arising from more precipitation and/or better soil quality), the elites could benefit more from the continued use of serf labor in

[D.3] Note that both population density and urbanization rate are observed in a census that preceded the time horizon over which serf emancipation is measured.

TABLE D.2: Controlling for geography

Dependent variable:	Serf emancipation rate, 1821–48										
	Full sample									East-Elbia sample	
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS	(8) OLS	(9) 2SLS	(10) OLS	(11) 2SLS
Water mills 1819	0.301***	0.304***	0.337***	0.292**	0.291***	0.299***	0.267***	0.243***	0.341***	0.286***	0.571***
	(0.102)	(0.092)	(0.100)	(0.102)	(0.096)	(0.102)	(0.086)	(0.057)	(0.100)	(0.089)	(0.170)
Average temperature		0.287**						0.155*	0.150	0.442***	0.352***
		(0.107)						(0.087)	(0.092)	(0.090)	(0.128)
Average precipitation			−0.251***					−0.381***	−0.383***	−0.189	−0.275
			(0.062)					(0.082)	(0.085)	(0.150)	(0.189)
Distance to navigable river				0.117				0.575	0.451	0.386	0.050
				(0.431)				(0.420)	(0.381)	(0.522)	(0.361)
Soil suitability (cereals)					−0.342**			−0.079	−0.073	−0.045	0.002
					(0.124)			(0.065)	(0.068)	(0.107)	(0.112)
Sandy soil (share)						−0.288		−0.368	−0.386	−0.281	−0.483
						(0.380)		(0.255)	(0.249)	(0.407)	(0.457)
East Elbe (dummy)							−0.434	−0.775**	−0.737**		
							(0.430)	(0.315)	(0.324)		
Observations	261	261	261	261	261	261	261	261	261	195	195
Adjusted R^2	0.09	0.14	0.16	0.08	0.15	0.09	0.12	0.31		0.24	
Partial R^2 of mills		0.10	0.12	0.08	0.09	0.09	0.07	0.07		0.09	
Shea partial R^2 of slope									0.46		0.45
Kleibergen-Paap F statistic									67.60		83.67

Notes. Serf emancipation rate and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. Estimates in columns 9 and 11 are based on the approach introduced in section D.1. The corresponding first-stage regressions are reported in columns 1 and 4 of Table D.1 in Online Appendix G. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.



(a) Bivariate relationship

(b) Conditional on geography

FIGURE D.3: Water mills in 1819 and subsequent serf emancipation rate

Notes. Panel (a) depicts the bivariate relationship between unstandardized variables, whereas panel (b) depicts the residual relationship after accounting for geographic control. For visual clarity, both plots omit a non-influential outlier from the sample of counties.

large-scale agricultural production.[D.4] On the other hand, the positive and significant coefficient estimate for average temperature likely captures the apparent latitudinal gradient in the intensity of emancipation across Prussian counties, particularly in East Elbia, as is evident from the map in Figure 1a. In all specifications corresponding to columns 2–7, our coefficient of interest remains both highly statistically significant and quantitatively rather stable, indicating that a unit standard deviation increase in the prevalence of water mills in 1819 is associated with an average increase of between 27% and 34% of a standard deviation in the intensity of *de facto* serf emancipation rate.

Controlling simultaneously for all geographic covariates, the specification in column 8 yields an estimate for our coefficient of interest that remains highly statistically significant and is only marginally smaller than the estimates from earlier columns. The corresponding conditional relationship between the unstandardized counterparts of our variables of interest is depicted by the scatter plot in panel (b) of Figure D.3. Almost all geographic controls enter the regression with their expected signs, although only temperature and precipitation are statistically significant, as is the negative fixed effect associated with counties located in East Elbia. Column 9 reports the 2SLS estimates for the specification of column 8, exploiting the non-monotonic influence of terrain slope on the prevalence of water mills in 1819 in the first-stage regression. The estimated 2SLS coefficient of interest suggests a more pronounced relationship between the prevalence of water mills in 1819 and the subsequent intensity of *de facto* serf emancipation. The high first-stage F statistic shows the strength of our instrument. A sizable partial R^2 relative to the overall R^2 reflects the considerable explanatory power of the residual cross-county variation in terrain slope for the residual variation in the prevalence of water mills in 1819.

[D.4] Our finding that soil suitability for agriculture is associated with greater persistence in coercive labor institutions is in line with those reported by Bobonis and Morrow (2014) and Dippel, Greif and Trefler (2020). Our alternative measure of soil suitability for agriculture, which reflects the share of sand in the top soil, is not statistically significant.

Finally, in columns 10 and 11 of Table D.2, we estimate the specifications examined in the preceding two columns, focusing exclusively on the subsample of counties located in East Elbia. Reassuringly, the estimates of interest are qualitatively similar to and, if anything, quantitatively even stronger than those observed in the full sample of counties.

D.3 Proximate controls

We next augment the model with geographic variables by adding our proximate controls, first one at a time and then simultaneously. To highlight the key result from this exercise, we find that the positive association between the initial abundance of water mills and subsequent intensity of serf emancipation remains strong and statistically significant across specifications, as is evident from the top row of Table D.3.

In columns 1 and 2, we present the estimates from regressions that include, respectively, population density and the urbanization rate in 1816 as additional covariates. Although both variables enter their respective regressions with positive coefficients, the one associated with initial population density is statistically insignificant. Moreover, as shown in column 10, in the specification including the full set of proximate controls, urbanization rate retains a significant positive relationship with the subsequent decline in coercive labor institutions, whereas the coefficient estimate on population density changes its sign and remains statistically insignificant. Thus, while our evidence regarding the influence of labor abundance (as captured by population density) on emancipation is mixed, the findings suggest that the threat of labor scarcity in agriculture due to better options for workers in urban markets (as captured by the urbanization rate) may well have played an important role in the decline of coercive labor institutions in nineteenth-century Prussia.

We next account for agglomeration effects by controlling for the presence of urban artisans and traders in 1819 in column 3. These measures aim to capture another dimension of outside options arising from the fact that early water mills could have attracted complementary economic activities in crafts and trade that may explain higher rates of emancipation. However, the point estimates on the shares of artisans and traders turn out to be negative and statistically insignificant, without substantial impact on the coefficient of interest.

Specification in column 4 accounts for average family size, which, as explained in the main text, is expected to be negatively correlated with serf emancipation rate.[D.5] This is confirmed by the estimates in columns 4 and 10. In column 5, we directly account for stronger vested interests of the landed nobility in maintaining coercive labor institutions by including a proxy measure of landownership concentration among the elites; namely, the share of all landholdings in a county that were designated as knight estates (*Rittergüter*).[D.6] These large manorial estates were associated with stronger feudal institutions, relying heavily on the intensive appropriation of serf labor for large-scale agriculture (Cinnirella and Hornung, 2016), especially in counties east of the river Elbe.

[D.5] The earliest year for which this variable is available is 1849. Thus, the estimated coefficients associated with family size may be marred by reverse causality. Indeed, Cinnirella and Hornung (2017) provide evidence of changes in patterns of education and fertility that may have occurred in response to the Prussian emancipation process over the course of the nineteenth century.

[D.6] Although our measure of the share of knight estates is based on data for 1856, as discussed by Cinnirella and Hornung (2016), historical evidence suggests that this share remained largely unchanged throughout the period under consideration.

TABLE D.3: Controlling for proximate economic, demographic, cultural, and institutional characteristics

Dependent variable:	Serf emancipation rate, 1821–48												
	Full sample											East-Elbia sample	
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS	(8) OLS	(9) OLS	(10) OLS	(11) 2SLS	(12) OLS	(13) 2SLS
Water mills 1819	0.235***	0.271***	0.242***	0.174***	0.245***	0.259***	0.243***	0.258***	0.206***	0.239***	0.227***	0.246***	0.323***
	(0.053)	(0.060)	(0.058)	(0.052)	(0.057)	(0.051)	(0.057)	(0.055)	(0.054)	(0.051)	(0.068)	(0.060)	(0.083)
Population density 1816	0.741									−1.379	−1.335	1.216	0.950
	(1.817)									(1.325)	(1.237)	(2.442)	(2.163)
Urbanization rate 1816		1.405*								1.542*	1.530**	1.257	1.368
		(0.749)								(0.758)	(0.732)	(1.003)	(0.924)
Urban artisans 1819 (share)			−0.465							0.312	0.352	−1.104	−1.455
			(2.413)							(2.808)	(2.650)	(2.977)	(2.739)
Urban traders 1819 (share)			−3.995							−5.785	−5.890	−1.791	−1.753
			(5.278)							(3.976)	(3.946)	(7.158)	(6.106)
Family size 1849				−1.014***						−0.915***	−0.922***	−0.979**	−0.957***
				(0.230)						(0.277)	(0.259)	(0.398)	(0.370)
Knight estates (share)					−0.145**					−0.064	−0.063*	−0.073	−0.081*
					(0.059)					(0.038)	(0.035)	(0.055)	(0.049)
Protestants 1816 (share)						0.477**				0.203	0.194	0.170	0.283
						(0.182)				(0.221)	(0.218)	(0.429)	(0.395)
Other ethnic group 1861 (share)							−0.548***			0.098	0.097	−0.080	−0.051
							(0.130)			(0.185)	(0.173)	(0.260)	(0.255)
Partible inheritance law (dummy)								−0.201		−0.234	−0.224	−0.260	−0.286
								(0.357)		(0.312)	(0.292)	(0.226)	(0.194)
Enrollment rate 1816									0.858***	0.230	0.248	0.215	0.069
									(0.186)	(0.276)	(0.271)	(0.650)	(0.592)
Geographic controls	×	×	×	×	×	×	×	×	×	×	×	×	×
Observations	261	261	261	261	261	261	261	261	261	261	261	195	195
Adjusted R^2	0.31	0.33	0.30	0.39	0.33	0.34	0.33	0.31	0.33	0.42		0.40	
Partial R^2 of mills	0.06	0.09	0.07	0.04	0.07	0.08	0.07	0.08	0.05	0.06		0.06	
Shea partial R^2 of slope											0.42		0.37
Kleibergen-Paap F statistic											57.11		43.04

Notes. The serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. Estimates in columns 11 and 13 are based on the approach introduced in section D.1. The corresponding first-stage regressions are reported in columns 2 and 5 of Table D.1 in Online Appendix G. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

In line with priors, the relevant coefficient estimate is negative and statistically significant, although its magnitude is substantially diminished when the full set of covariates is included in column 10.

In columns 6 and 7, we control for differences in religious and ethnic compositions of county populations – as captured by the share of Protestants in 1816 and the share of individuals of non-Germanic (mostly Slavic) ancestry in 1861. These factors could have affected the pace of emancipation, the onset of industrialization, or even the propensity to attract migrant groups from various ethnic backgrounds. Column 6 indicates that the prevalence of Protestantism in 1816 is positively and significantly related to the subsequent serf emancipation rate. Furthermore, the share of non-Germanic population enters the regression in column 7 with a significant negative coefficient, possibly reflecting the fact that the prevalence of individuals with Polish ancestry was higher in counties belonging to the province of Posen, where coercive labor institutions were historically more persistent. However, both coefficients become statistically insignificant in the full regression model of column 10.

In column 8, we include an indicator for the predominant law of succession of peasant landholdings; namely, partible inheritance (*Realteilung*), characterized by the equal division of land across heirs, versus primogeniture (*Anerbenrecht*) or impartible inheritance. On the one hand, the historical association between primogeniture and the prevalence of large-scale agriculture potentially implies a delayed emancipation process in regions that overwhelmingly practiced this form of land inheritance.[D.7] On the other hand, because partible inheritance could have diminished the ability of the peasantry to compensate the landlords for the redemption of servile dues, and since it may have mechanically resulted in the increased prevalence of smaller peasant landholdings (that were excluded from the emancipation process until the passage of the Commutation Law of 1850), one expects lower rates of emancipation in regions that practiced divided succession. As reported in columns 8 and 10, although the coefficient estimate for the indicator of predominant partible land inheritance is negative, it is statistically insignificant.

In column 9, we account for the initial intensity of investments in human capital, as captured by the school enrollment rate in 1816, which could have conditioned the propensity of the capital-owning elites to subsequently emancipate the peasantry while also affecting the pace of industrialization. Although the coefficient in column 9 is positive and statistically significant, the estimated relationship becomes weaker and loses significance when conditioned on the full set of covariates in column 10.

Columns 10 and 11 report OLS and 2SLS estimates of the model with the full set of proximate controls. Notably, the OLS estimate of interest is virtually identical to that in column 8 of Table D.2, when only geographic covariates were taken into account. In addition, the OLS and 2SLS coefficient estimates are now very similar, suggesting that conditional on the credibility of our 2SLS framework, any residual omitted variable bias potentially afflicting the OLS estimate of interest is negligible. In columns 12 and 13, we replicate the analysis from the preceding two columns for the subsample of counties in East Elbia. This yields an OLS estimate that is almost identical to that found in the full sample of counties in column 10. Furthermore, although the

[D.7] In particular, historians have connected larger peasant landholdings under impartible inheritance not only with demographic outcomes like lower fertility and marriage rates, smaller family size, and higher emigration from rural areas but also with structural economic outcomes like the persistence of large-scale agriculture and the late emergence of concentrated industrial activities (see, e.g., Habakkuk, 1955; Rudolph, 1995; Grant, 2005).

relevant 2SLS point estimate is somewhat larger than its OLS counterpart, this gap is substantially smaller than the one observed earlier in Table D.2, when our analysis included only geographic covariates.

D.4 Additional controls

The analysis presented in Table D.4 accounts for further potential confounders, conditional on all the covariates considered thus far. As highlighted by the top row of Table D.4, our coefficient of interest remains both highly statistically significant and largely stable in magnitude across specifications for our full sample of counties, relative to the baseline from column 10 of Table D.3.

The specification in column 1 accounts for the prevailing intensity of labor coercion, based on the average amount of servile labor dues redeemed by former serfs (through compensation payments to their manorial lords). Although statistically insignificant in column 1, the point estimate becomes significant in the fully specified model of column 9 and always carries the expected negative sign. This potentially reflects both a diminished ability of the peasantry to make the necessary compensation payments and stronger economic incentives of the landlords to prolong the employment of serf labor when the intensity of coercion is already high.

In column 2, we introduce dummy variables indicating the presence of a main road and a railway line in 1848. In addition to the initial urbanization rate, these covariates plausibly capture the extent to which a county's rural locales were integrated with external goods and factor markets. Market integration could have affected not only the process of labor emancipation, by facilitating access to better outside options for the peasantry and, thereby, increasing their bargaining power against the elites, but also the pace of broad-based industrialization, through the standard Smithian mechanism of economic development.[D.8] The results in column 2 suggest that access to railways in particular may have played an important role in accelerating the decline of serfdom in Prussia. This finding continue to hold qualitatively in the fully specified model of column 9.

The literature on Prussian industrialization during the latter half of the nineteenth century has emphasized access to coal deposits as an important determinant of not only the pace of industrialization but also the spatial distribution of industrial activities due to agglomeration effects (e.g., Pierenkemper, 1978; Kiesewetter, 2004; Gutberlet, 2014). Although coal mining in Prussia did not take off until circa 1850 and remained under state control until 1865, its emergence may nevertheless have created new labor-market opportunities for the peasantry, thus contributing to the likelihood of their *de facto* emancipation by increasing the perceived threat of labor scarcity in agriculture, at least towards the end of the time period over which our outcome variable is measured. In addition, the presence of coal deposits could be correlated with features of the local terrain (like elevation) that may have influenced the spatial distribution of water mills even in the early nineteenth century, posing a potential threat to the exclusion restriction in our 2SLS framework. As shown in columns 3 and 9, the indicator of historical presence of a coalfield enters our regressions with an expected positive coefficient, but is statistically insignificant.[D.9]

[D.8] Indeed, Hornung (2015) provides evidence that causally links railway access to urban population growth in nineteenth-century Prussia.

[D.9] Table G.3 in Online Appendix G shows the results from a robustness check in which, rather than controlling for the presence of a *mined* coalfield, we control for an area-share measure of *subterranean* coal deposits from the Carboniferous geological period.

TABLE D.4: Controlling for additional confounders

Dependent variable:	Serf emancipation rate, 1821–48											
	Full sample										East-Elbia sample	
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS	(8) OLS	(9) OLS	(10) 2SLS	(11) OLS	(12) 2SLS
Water mills 1819	0.234***	0.239***	0.228***	0.239***	0.246***	0.210***	0.240***	0.239***	0.207***	0.235***	0.169**	0.173*
	(0.053)	(0.050)	(0.053)	(0.050)	(0.053)	(0.057)	(0.051)	(0.052)	(0.058)	(0.083)	(0.064)	(0.101)
Servile duties (PCA)	−0.037								−0.064**	−0.061**	−0.107**	−0.106***
	(0.029)								(0.028)	(0.027)	(0.040)	(0.036)
Road 1848 (dummy)		−0.129							−0.127	−0.131	−0.148	−0.148
		(0.102)							(0.115)	(0.109)	(0.115)	(0.101)
Railway 1848 (dummy)		0.257***							0.209**	0.210***	0.383**	0.383***
		(0.083)							(0.077)	(0.072)	(0.144)	(0.127)
Coalfield (dummy)			0.401						0.271	0.268	1.124***	1.121***
			(0.260)						(0.255)	(0.235)	(0.162)	(0.140)
Number of uprisings 1816–47				0.024					0.036	0.036	−0.095	−0.095
				(0.077)					(0.072)	(0.066)	(0.092)	(0.082)
Napoleonic occupation (dummy)					0.164				0.154	0.161	0.539**	0.540***
					(0.251)				(0.187)	(0.183)	(0.227)	(0.206)
Commoner estates (share)					0.177				0.231	0.220	−0.103	−0.102
					(0.268)				(0.308)	(0.270)	(0.372)	(0.338)
Crown and state domains (share)						−2.049***			−2.308***	−2.270***	−2.000**	−1.994***
						(0.552)			(0.721)	(0.622)	(0.803)	(0.741)
Kulm estates (share)						−0.197			0.003	0.083	−0.095	−0.090
						(0.335)			(0.378)	(0.315)	(0.344)	(0.362)
Commercial city (dummy)							−0.606**		−0.598***	−0.600***	−0.336	−0.335
							(0.216)		(0.205)	(0.190)	(0.234)	(0.208)
Born outside county 1871 (share)								0.240	−0.346	−0.351	−0.697	−0.705
								(0.884)	(0.939)	(0.859)	(1.093)	(0.946)
Geographic controls	×	×	×	×	×	×	×	×	×	×	×	×
Other proximate controls	×	×	×	×	×	×	×	×	×	×	×	×
Observations	261	261	261	261	261	261	261	261	261	261	195	195
Adjusted R^2	0.42	0.42	0.42	0.42	0.42	0.44	0.44	0.42	0.47		0.49	
Partial R^2 of mills	0.06	0.06	0.06	0.06	0.07	0.05	0.07	0.06	0.05		0.03	
Shea partial R^2 of slope										0.38		0.34
Kleibergen-Paap F statistic										41.66		70.67

Notes. The serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. Estimates in columns 10 and 12 are based on the approach introduced in section D.1. The corresponding first-stage regressions are reported in columns 3 and 6 of Table D.1 in Online Appendix G. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

In column 4, we control for the number of social uprisings that occurred in a county during the 1816–1847 time period, aiming to capture differences across counties in the strategic incentives of the elites to relinquish their coercive economic power when faced with a credible threat of social unrest and mass appropriation of elite assets. Such incentives could have been stronger when the elites had more to lose from mass appropriation (i.e., in those counties where their ownership of capital and land was higher) or perhaps weaker, given that wealthier elites could devote more resources to the suppression of popular revolts. The results in columns 4 and 9 indicate that the relevant coefficient estimate is positive but not statistically significant. Furthermore, this control does not have any substantial impact on our primary coefficient of interest.[D.10]

In column 5, we account for the potential impact of a "culture of enlightenment". We include a dummy variable for the counties occupied by Napoleon. Furthermore, the termination of the nobility's monopoly rights over manorial landownership by the October Edict of 1807 may have resulted in the purchase of noble estates by bourgeois commoners with both emancipation oriented "enlightenment" ideals and stronger preferences for those estates where rural industrialization was already underway. Insofar as the noble lords of these estates happened to face a higher risk of delinquency in the aftermath of the Napoleonic wars, they may have been compelled to accelerate the emancipation of their serfs, using the redemption payments to pay down their debts, prior to liquidating their estates by selling them off to commoners. To account for these alternative mechanisms, the specification in column 5 also controls for the share of noble estates in a county that came to be owned by commoners as of 1856. Columns 5 and 9 indicate that these control variables enter the regressions with an expected positive sign, but are statistically insignificant.

In column 6, we account for the initial availability of free peasants, which could have diluted the economic incentive to emancipate the enserfed population. In addition, because counties with a larger initial share of free peasants had smaller enserfed populations to begin with, they are mechanically expected to have converged less rapidly to a state of full emancipation. We employ two historically relevant proxies for the initial availability of free peasants at the county level: the share of landholdings owned by the Prussian Crown and/or the state and the share of manorial estates that operated under the so-called Kulm law. The results shown in column 6 indicate that, as expected, both measures are negatively related to the share of serfs emancipated as of 1848, although only the coefficient associated with the share of Crown and state domains is statistically significant. The same empirical pattern continues to hold in the fully specified model of column 9.

In column 7, we include an indicator that captures the historical exposure of a county to the Commercial Revolution of the early modern period. As is evident from columns 7 and 9, the resulting estimate is negative and statistically significant. These findings are consistent with the possibility that the landowning nobility in historically more commercial counties were particularly unfavorable towards emancipation because they had become more entrenched over time in large-scale serf-intensive agricultural production. Such an outcome in counties exposed to the Commercial Revolution may have resulted from either (i) the presence of established networks of merchant guilds that provided the landlords with greater access to long-distance trade in staples; or (ii) the strategic influence of more powerful craft guilds with vested interests in blocking the

[D.10] This robustness result is insensitive to using alternative measures of social unrest at the county level, including either the total number of days of protests or a dummy variable indicating if there was ever a protest in a county during the 1816–1847 time period.

widespread adoption of industrial production methods, which undermined the ability of landlords to diversify their production activities (see, e.g., Desmet, Greif and Parente, 2020).

Column 8 shows that the intensity of county-level migration inflows, proxied by the share of a county's population in 1871 that was born outside the county, is unrelated to the pace of the emancipation process, as discussed in Section 5.4 of the main text. Finally, columns 9–12 present estimation results for the models with full sets of controls. In the full sample of counties, the OLS and 2SLS estimates of interest remain similar to one another and to their respective counterparts in columns 9 and 10 of Table D.3. The relevant OLS and 2SLS estimates for the East Elbian subsample are more noticeably attenuated in comparison to their counterparts from columns 11 and 12 of Table D.3, but they remain statistically and economically significant, and the gap between OLS and 2SLS estimates is smaller than before.

Appendix E Flexible panel analysis

In this Appendix, we complement our cross-sectional analysis at the county level by providing additional evidence based on both cross-sectional and temporal variations in the second half of the nineteenth century at the higher administrative level of districts (*Regierungsbezirke*). We resort to using district-level data as panel data at the county level do not exist. Our data source provides annual information on the number of cases settled and the associated redemption costs during the 1850–1898 time horizon. We employ these data to conduct a flexible panel analysis of the temporal *flows* of emancipation cases and redemption costs. Specifically, we exploit annual information on emancipation cases settled in each of the 19 districts during the 1850–98 time horizon to estimate the following model (and less stringent variants thereof) using OLS:

$$y_{i,t} = \alpha_i + \gamma_t + \sum_{\tau=1850}^{1890} \beta_\tau \cdot \text{Mills}_{i,1819} \cdot \gamma_\tau + \sum_{\tau=1850}^{1895} \mathbf{X}'_{i,\tau} \cdot \mathbf{\Lambda}_\tau \cdot \gamma_\tau + \eta_{i,t}. \tag{2}$$

For specifications examining emancipation, $y_{i,t}$ is the natural log of the average annual number of emancipation cases settled in district i during a 5-year period (i.e., 1850–54, 1855–59, ... , 1895–98) indexed by the period's initial year t. For specifications examining redemption costs, $y_{i,t}$ is the natural log of the first principal component of four types of compensation payments per settled case in district i during the 5-year period starting in year t. α_i and γ_t are, respectively, time-invariant district and sample-wide period fixed effects. The inclusion of district fixed effects in this analysis allows us to account for not only the potentially confounding effects of time-invariant geographic, cultural, and institutional characteristics at the district level but also any measurement issues associated with the absence of information on the initial population of serfs. $\text{Mills}_{i,1819}$ is the number of water mills (per 1,000 inhabitants) in district i in 1819. $\mathbf{X}_{i,\tau}$ is a vector of time-varying covariates, including the population size of district i in the initial year of period τ, the number of social uprisings that occurred in district i during period $\tau - 5$, and the degree of coercion intensity, measured as the natural log of the first principal component of two types of redeemed servile duties per settled case in district i during period τ. Finally, $\eta_{i,t}$ is a district-period-specific error term.[E.1]

Although our proxy measure of the initial abundance of relevant physical capital is itself time-invariant at the district level, by interacting the measure with period dummies, our specifications allows us to estimate – via the β_τ coefficients – how the cross-sectional relationship between the prevalence of water mills in 1819 and the subsequent flow of serf emancipation and redemption costs evolved in the latter half of the nineteenth century. Notably, we are able to account for both unobserved heterogeneity in time-invariant characteristics across districts and period-specific Prussia-wide shocks to the emancipation process. In addition, the interaction of the time-varying covariates with period dummies permits us to control for the possibility that the potentially confounding influences of these covariates could themselves be changing over time. As in our cross-sectional analysis, all panel specifications examining redemption costs control for the time-varying confounding influence of coercion intensity.

[E.1] Because our sample horizon ends in 1898, the measurement of time-varying covariates for the last period is based on annual data for four rather than five years. The set of time-varying covariates included in our model is constrained by data availability at the relevant time frequency.

TABLE E.1: Flexible panel analysis

Dependent variable:	Emancipation cases			Redemption costs		
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
Water mills 1819 × 1850	0.674**	0.833*	0.761***	−0.260***	−0.225***	−0.244***
	(0.288)	(0.424)	(0.257)	(0.083)	(0.075)	(0.071)
Water mills 1819 × 1855	0.694***	0.852**	0.764***	−0.214**	−0.186**	−0.201***
	(0.173)	(0.319)	(0.251)	(0.081)	(0.072)	(0.065)
Water mills 1819 × 1860	0.420***	0.579*	0.581**	−0.101	−0.075	−0.122
	(0.124)	(0.284)	(0.249)	(0.090)	(0.086)	(0.076)
Water mills 1819 × 1865	0.822**	0.980*	0.886**	−0.064	0.019	−0.006
	(0.361)	(0.484)	(0.399)	(0.064)	(0.074)	(0.090)
Water mills 1819 × 1870	0.896***	1.054***	1.067***	−0.102	−0.040	−0.066
	(0.214)	(0.310)	(0.251)	(0.147)	(0.145)	(0.155)
Water mills 1819 × 1875	0.294*	0.453*	0.575**	−0.160***	−0.115*	−0.141**
	(0.163)	(0.241)	(0.252)	(0.042)	(0.061)	(0.062)
Water mills 1819 × 1880	−0.199	−0.040	−0.027	−0.059	−0.020	−0.042
	(0.198)	(0.254)	(0.216)	(0.039)	(0.047)	(0.042)
Water mills 1819 × 1885	−0.351**	−0.192	−0.170	−0.009	0.041	0.032
	(0.163)	(0.202)	(0.225)	(0.028)	(0.033)	(0.024)
Water mills 1819 × 1890	−0.523**	−0.365***	−0.335**	−0.030	−0.009	−0.033
	(0.204)	(0.110)	(0.132)	(0.024)	(0.033)	(0.031)
Period FE	×	×	×	×	×	×
Initial population × Period			×			×
Lagged uprisings × Period			×			×
Servile duties × Period			×	×	×	×
District FE		×	×		×	×
Observations	190	190	190	190	190	190
R^2	0.53	0.60	0.75	0.42	0.48	0.54
Joint sig. p-value for mills	0.000	0.000	0.000	0.003	0.010	0.041
Joint sig. p-value for population			0.000			0.005
Joint sig. p-value for uprisings			0.000			0.000
Joint sig. p-value for duties			0.019	0.000	0.000	0.002

Notes. The dependent variable is either the log of the average annual number of emancipation cases settled in a district over a given 5-year period (columns 1–3) or the log of the first principal component of four types of compensation payments per settled case in a district over a given 5-year period (columns 4–6). The water mills variable is standardized to have a zero mean and unit standard deviation across districts. The last period is treated as the omitted category. The reported p-value for a given explanatory variable is from the F-test for joint significance of the coefficients associated with its interaction terms that capture its time-varying cross-district relationship with the dependent variable being examined. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table E.1 reveals the results from estimating different variants of our panel model for serf emancipation (columns 1–3) and redemption costs (columns 4–6). In column 1, we present the results from our simplest specification that controls for only period fixed effects. Column 2 presents the estimated β_τ coefficients from a model that accounts for both district and period fixed effects but does not include further controls. The coefficients of interest are to be interpreted with respect to the omitted (reference) category, captured by the interaction between the prevalence of water mills in 1819 and the period dummy for 1895–98.

Consistent with our earlier findings at the county level, the results indicate that districts exhibiting a higher prevalence of water mills in 1819 also experienced a larger flow of emancipation in the mid-nineteenth century. Specifically, the estimate for the 1850–54 time period in column 2 suggests that, relative to the reference period, a one-standard-deviation increase in the prevalence of water mills in 1819 is associated with an 83.3% higher flow of new emancipation cases settled during this first 5-year period in our sample horizon. Thereafter, this significant relationship tends to become quantitatively more pronounced, achieving its peak with respect to emancipation flows in the 1870–74 time period, before weakening and turning negative towards the end of our sample horizon in the 1890s. This late *reversal* reflects the fact that districts with a larger initial prevalence of water mills subsequently experienced a more rapid convergence to a state of full emancipation, and they were therefore already associated with substantially fewer new emancipation cases before the end of our sample horizon.

In column 3, we augment our panel analysis of emancipation to account for the potentially confounding time-varying influences of population size in the initial year, the lagged number of social uprisings, and the average amount of redeemed servile duties. The results suggest that our time-varying relationship of interest from column 2 remains virtually insensitive to the inclusion of these additional controls in our model.

Turning to our corresponding panel analysis of redemption costs in columns 4–6, the results across specifications show that districts with a higher prevalence of water mills in 1819 had significantly lower redemption costs throughout the 1850s. After this decade, the estimated β_τ coefficients become insignificant for the 1860–74 time period, turning significantly negative once again for the 1875–79 time period. This trend appears to be broadly consistent with the results on emancipation flows from columns 1–3.

In sum, corroborating our cross-sectional findings at the county level, the results from our district-level flexible panel analysis suggest that a higher initial stock of relevant physical capital is associated with (i) a more rapid subsequent decline in serfdom and, thus, faster convergence to a state of full emancipation, and (ii) lower redemption payments, suggesting an instrumental role played by the material incentives of the elites in facilitating emancipation.

Appendix F Examining the Domar and Brenner mechanisms

In this appendix, we exploit the data on the average day-laborer wage rate during the 1810–1819 time period, available for a limited subsample of only 60 Prussian counties, to perform an analysis of two canonical mechanisms of labor emancipation. Specifically, we empirically assess the extent to which these mechanisms were prevalent in our setting and examine whether they can explain away the main relationship of interest between the initial prevalence of water mills and subsequent serf emancipation.

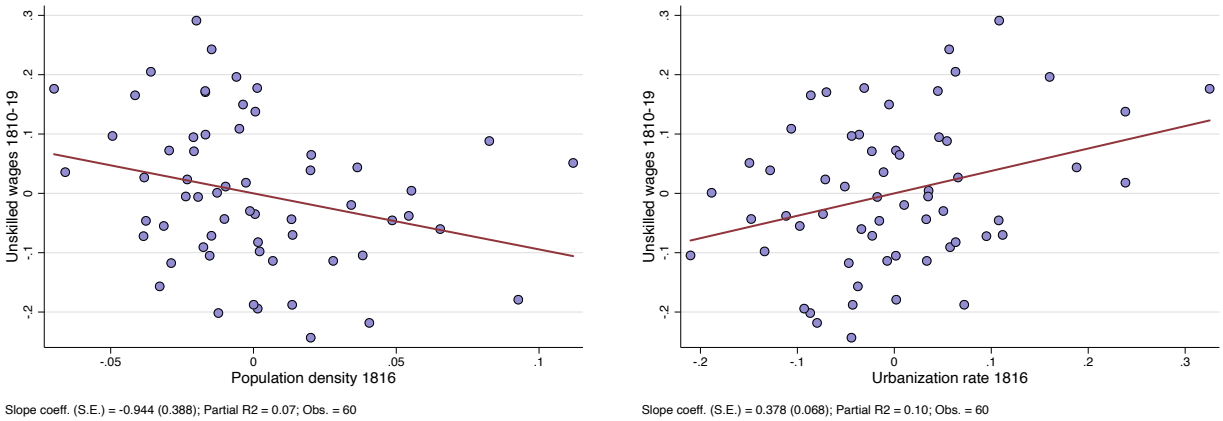
The two canonical mechanisms of labor emancipation operate by generating opposing effects on market wages. On the one hand, according to Domar (1970), holding labor demand fixed, labor abundance could have contributed to the decline of serfdom by creating downward pressure on market wages. In our setting, initial population density at the county level ought to capture the salience of this mechanism. On the other hand, according to Brenner (1976), holding labor supply fixed, higher market wages – particularly, due to increased labor demand from the urban sector – could have increased the bargaining power of serfs by improving their outside options, thereby promoting labor emancipation. As discussed in the main text, institutional restrictions on labor mobility *across* Prussian municipalities during the first half of the nineteenth century likely reduced the salience of this mechanism in our setting. However, to the extent that this mechanism was still operative due to the existence of an urban sector *within* a county, we contend that the initial urbanization rate at the county level should effectively capture its role in our analysis.

The scatter plots in Figure F.1 and the regressions in Table F.1 reveal patterns that are consistent with the presence of *both* mechanisms in our setting, which could explain the overall null relationship between wages and serf emancipation rate seen previously in panel (a) of Figure 3.

First, in line with the Domar mechanism, conditional on initial urbanization and geographic controls, higher initial population density is indeed associated with lower contemporaneous wage rates (column 1) and an accelerated pace of subsequent emancipation (column 5), with the result for emancipation being especially prominent in the East-Elbian subsample of less industrialized or urbanized counties (column 7).[F.1] Second, in line with the Brenner mechanism, controlling for initial population density and geographic confounders, initial urbanization rate is positively related to both contemporaneous wage rates (column 1) and the intensity of subsequent emancipation (column 5), although the connection with emancipation is noticeably weaker across counties in East Elbia (column 7). Thus, our measures of initial population density and urbanization appear to capture the salience of these two mechanisms in our setting.

Nevertheless, as shown earlier in Table D.3, and as verified in columns 6 and 8 of Table F.1 for the limited sample of counties with available wage data, the inclusion of initial population density and urbanization in our analysis does not explain away the relationship of interest between the initial prevalence of water mills and subsequent serf emancipation rate. Interestingly, conditional on initial population density and urbanization, the prevalence of water mills enters the contemporaneous wage

[F.1] The prominence of the Domar mechanism in the East-Elbian subsample is in line with the findings of Klein and Ogilvie (2017) for Bohemia. Corroborating the salience of Domar's mechanism in our setting, we find in other cross-county regressions (not reported) that labor scarcity, as captured by lower population density in 1819, is robustly associated with the intensity of labor coercion, as proxied by the average amount of servile dues per redemption settlement as of 1848.



(a) Population density and unskilled wages

(b) Urbanization rate and unskilled wages

FIGURE F.1: Unskilled wages, population density, and urbanization rate

Notes. Both plots depict relationships that account for geographic controls. The sample of counties is constrained by the availability of county-level data on wages in the early nineteenth century.

TABLE F.1: The "labor abundance" and "outside options" mechanisms

Dependent variable:	Unskilled wages 1810–19				Serf emancipation rate, 1821–48			
	Full sample		East-Elbia sample		Full sample		East-Elbia sample	
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS	(8) OLS
Population density 1816	−0.277**	−0.233	−0.199***	−0.193*	0.157*	0.091	0.302***	0.164**
	(0.114)	(0.144)	(0.067)	(0.091)	(0.090)	(0.090)	(0.070)	(0.063)
Urbanization rate 1816	0.257***	0.255***	0.318***	0.318***	0.212**	0.215**	0.137	0.132
	(0.069)	(0.071)	(0.098)	(0.101)	(0.088)	(0.083)	(0.098)	(0.096)
Water mills 1819		−0.104		−0.014		0.156**		0.340***
		(0.141)		(0.113)		(0.065)		(0.109)
Geographic controls	×	×	×	×	×	×	×	×
Observations	60	60	44	44	60	60	44	44
Adjusted R^2	0.21	0.20	0.25	0.23	0.33	0.33	0.31	0.39
Partial R^2 of population	0.06	0.04	0.05	0.04	0.03	0.01	0.11	0.03
Partial R^2 of urbanization	0.08	0.08	0.12	0.12	0.06	0.07	0.03	0.03
Partial R^2 of mills		0.01		0.00		0.03		0.14

Notes. All dependent and main explanatory variables are standardized to have zero means and unit standard deviations in each regression sample. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

regressions in columns 2 and 4 of Table F.1 with a negative but insignificant coefficient, possibly reflecting the broader notion that the process of industrialization was largely unskilled-labor-saving in earlier stages (Mokyr, Vickers and Ziebarth, 2015).

Appendix G Supplementary results

TABLE G.1: Accounting for longitude

Dependent variable:	Serf emancipation rate, 1821–48					
	Full sample			East-Elbia sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Water mills 1819	0.233***	0.252***	0.218***	0.212***	0.210***	0.171***
	(0.054)	(0.054)	(0.059)	(0.058)	(0.046)	(0.051)
Longitude (degrees)	−0.028	0.027	0.037	−0.181***	−0.065	0.005
	(0.034)	(0.028)	(0.031)	(0.060)	(0.050)	(0.057)
Geographic controls	×	×	×	×	×	×
Proximate controls		×	×		×	×
Additional controls			×			×
Observations	261	261	261	195	195	195
Adjusted R^2	0.31	0.42	0.47	0.31	0.40	0.49
Partial R^2 of mills	0.06	0.07	0.05	0.05	0.04	0.03

Notes. Serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. With the exception of the reported control variable(s), the different sets of covariates are identical to those employed by the analysis in Table 1. OLS estimates reported throughout. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

TABLE G.2: Accounting for river density

Dependent variable:	Serf emancipation rate, 1821–48					
	Full sample			East-Elbia sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Water mills 1819	0.245***	0.239***	0.207***	0.286***	0.246***	0.169**
	(0.055)	(0.052)	(0.058)	(0.089)	(0.061)	(0.065)
River density	0.962	−0.440	0.710	−0.010	−0.783	−0.610
	(2.078)	(2.196)	(2.381)	(1.683)	(1.396)	(2.063)
Geographic controls	×	×	×	×	×	×
Proximate controls		×	×		×	×
Additional controls			×			×
Observations	261	261	261	195	195	195
Adjusted R^2	0.31	0.42	0.46	0.24	0.39	0.49
Partial R^2 of mills	0.07	0.06	0.05	0.09	0.06	0.03
shr2						
widstat						

Notes. Serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. With the exception of the reported control variable(s), the different sets of covariates are identical to those employed by the analysis in Table 1. OLS estimates reported throughout. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

TABLE G.3: Accounting for subterranean coal deposits

Dependent variable:	Serf emancipation rate, 1821–48					
	Full sample			East-Elbia sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Water mills 1819	0.195***	0.192***	0.177***	0.280***	0.247***	0.203**
	(0.062)	(0.047)	(0.046)	(0.081)	(0.061)	(0.074)
Carboniferous area (share)	2.799	2.616	2.342	0.430	−0.129	−1.167
	(1.640)	(1.526)	(1.472)	(0.805)	(0.569)	(0.743)
Geographic controls	×	×	×	×	×	×
Proximate controls		×	×		×	×
Additional controls			×			×
Observations	261	261	261	195	195	195
Adjusted R^2	0.34	0.45	0.49	0.24	0.39	0.46
Partial R^2 of mills	0.05	0.04	0.04	0.08	0.06	0.04

Notes. Serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. With the exception of the reported control variable(s), the different sets of covariates are identical to those employed by the analysis in Table 1. OLS estimates reported throughout. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

TABLE G.4: Accounting for a proxy of local state capacity

Dependent variable:	Serf emancipation rate, 1821–48					
	Full sample			East-Elbia sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Water mills 1819	0.244***	0.232***	0.206***	0.280***	0.240***	0.166**
	(0.063)	(0.051)	(0.058)	(0.092)	(0.061)	(0.060)
Civil servants 1849 (share)	0.004	−0.068	−0.020	−0.043	−0.179**	−0.126
	(0.067)	(0.057)	(0.071)	(0.078)	(0.072)	(0.075)
Geographic controls	×	×	×	×	×	×
Proximate controls		×	×		×	×
Additional controls			×			×
Observations	261	261	261	195	195	195
Adjusted R^2	0.31	0.42	0.46	0.24	0.42	0.50
Partial R^2 of mills	0.07	0.06	0.05	0.08	0.06	0.03

Notes. Serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. With the exception of the reported control variable(s), the different sets of covariates are identical to those employed by the analysis in Table 1. OLS estimates reported throughout. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

TABLE G.5: Accounting for measures of population diversity

Dependent variable:	Serf emancipation rate, 1821–48					
	Full sample			East-Elbia sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Water mills 1819	0.239***	0.239***	0.207***	0.257***	0.233***	0.165**
	(0.057)	(0.053)	(0.060)	(0.076)	(0.056)	(0.065)
Religious diversity 1849	−0.318	−0.001	−0.105	0.687*	0.820	0.558
	(0.299)	(0.390)	(0.505)	(0.321)	(0.670)	(0.858)
Linguistic diversity 1900	−0.488*	0.027	0.006	−1.083***	−0.125	0.033
	(0.252)	(0.372)	(0.403)	(0.322)	(0.599)	(0.653)
Geographic controls	×	×	×	×	×	×
Proximate controls		×	×		×	×
Additional controls			×			×
Observations	261	261	261	195	195	195
Adjusted R^2	0.32	0.41	0.46	0.27	0.40	0.49
Partial R^2 of mills	0.07	0.06	0.05	0.07	0.05	0.03

Notes. Serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. With the exception of the reported control variable(s), the different sets of covariates are identical to those employed by the analysis in Table 1. OLS estimates reported throughout. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

TABLE G.6: Accounting for the sex ratio in the working population

Dependent variable:	Serf emancipation rate, 1821–48					
	Full sample			East-Elbia sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Water mills 1819	0.226***	0.238***	0.206***	0.264***	0.246***	0.167**
	(0.057)	(0.054)	(0.063)	(0.086)	(0.060)	(0.066)
Sex ratio 1816 (working age)	−1.995**	−1.295	−1.386	−1.802	0.351	−0.575
	(0.934)	(1.106)	(1.202)	(1.380)	(1.269)	(1.245)
Geographic controls	×	×	×	×	×	×
Proximate controls		×	×		×	×
Additional controls			×			×
Observations	261	261	261	195	195	195
Adjusted R^2	0.32	0.42	0.47	0.25	0.39	0.49
Partial R^2 of mills	0.06	0.06	0.05	0.07	0.06	0.03

Notes. Serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. With the exception of the reported control variable(s), the different sets of covariates are identical to those employed by the analysis in Table 1. OLS estimates reported throughout. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

TABLE G.7: Excluding provinces as of 1848 from the estimation sample

Dependent variable:	Serf emancipation rate, 1821–48						
Excluded province:	Prussia	Posen	Silesia	Pomer.	Branden.	Saxony	Westph.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Water mills 1819	0.155**	0.208***	0.217***	0.189***	0.224***	0.173**	0.179**
	(0.064)	(0.065)	(0.057)	(0.063)	(0.063)	(0.071)	(0.070)
Geographic controls	×	×	×	×	×	×	×
Proximate controls	×	×	×	×	×	×	×
Additional controls	×	×	×	×	×	×	×
Observations	207	235	204	239	231	223	227
Adjusted R^2	0.47	0.47	0.48	0.47	0.46	0.40	0.51
Partial R^2 of mills	0.03	0.05	0.05	0.04	0.05	0.03	0.03

Notes. Serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. The different sets of covariates are identical to those employed by the analysis in Table 1. The abbreviated province names are Pomerania, Brandenburg, and Westphalia. OLS estimates reported throughout. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

TABLE G.8: Excluding eastern historical administrative regions from the estimation sample

Dependent variable:	Serf emancipation rate, 1821–48								
Excluded region:	Province of Prussia (1829–1878)			Province of East Prussia (1773–1829)			Duchy of Prussia (1618–1773)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Water mills 1819	0.231***	0.195***	0.155**	0.255***	0.214***	0.164***	0.260***	0.229***	0.180***
	(0.070)	(0.049)	(0.064)	(0.063)	(0.047)	(0.053)	(0.062)	(0.050)	(0.057)
Geographic controls	×	×	×	×	×	×	×	×	×
Proximate controls		×	×		×	×		×	×
Additional controls			×			×			×
Observations	207	207	207	227	227	227	229	229	229
Adjusted R^2	0.24	0.39	0.47	0.25	0.40	0.47	0.26	0.39	0.46
Partial R^2 of mills	0.05	0.04	0.03	0.07	0.05	0.03	0.07	0.05	0.04

Notes. Serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. The different sets of covariates are identical to those employed by the analysis in Table 1. OLS estimates reported throughout. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

TABLE G.9: Accounting for unobservables linked to eastern historical administrative regions

Dependent variable:	Serf emancipation rate, 1821–48					
Regional indicator is for:	Province of Prussia (1829–1878)		Province of East Prussia (1773–1829)		Duchy of Prussia (1618–1773)	
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Full sample					
Water mills 1819	0.218***	0.185***	0.258***	0.197***	0.264***	0.207***
	(0.065)	(0.061)	(0.064)	(0.054)	(0.063)	(0.061)
Regional indicator	−0.189	−0.214	0.138	−0.108	0.219	−0.005
	(0.180)	(0.162)	(0.156)	(0.196)	(0.137)	(0.246)
Geographic controls	×	×	×	×	×	×
Other controls		×		×		×
Observations	261	261	261	261	261	261
Adjusted R^2	0.31	0.47	0.31	0.47	0.31	0.46
Partial R^2 of mills	0.05	0.03	0.07	0.04	0.07	0.04
	Panel B: East-Elbia sample					
Water mills 1819	0.213**	0.181**	0.241***	0.155***	0.272***	0.169**
	(0.080)	(0.070)	(0.069)	(0.050)	(0.079)	(0.066)
Regional indicator	−0.505*	0.127	−0.338	−0.155	−0.122	−0.006
	(0.255)	(0.258)	(0.275)	(0.279)	(0.186)	(0.303)
Geographical controls	×	×	×	×	×	×
Other controls		×		×		×
Observations	195	195	195	195	195	195
Adjusted R^2	0.25	0.49	0.24	0.49	0.24	0.49
Partial R^2 of mills	0.04	0.03	0.05	0.02	0.06	0.03

Notes. Serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. With the exception of regional indicator, the different sets of covariates are identical to those employed by the analysis in Table 1. "Other controls" include both proximate and additional controls as defined in the main text. OLS estimates reported throughout. Standard errors, clustered at the district level, are reported in parentheses. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

TABLE G.10: Accounting for spatial dependence

Dependent variable:	Serf emancipation rate, 1821–48					
	Full sample			East-Elbia sample		
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: OLS coefficients and district-clustered standard errors					
Water mills 1819	0.243	0.239	0.207	0.286	0.246	0.169
	(0.057)***	(0.051)***	(0.058)***	(0.089)***	(0.060)***	(0.064)**
	Panel B: Standard errors corrected for spatial dependence					
Cutoff = 200km	[0.053]***	[0.061]***	[0.063]***	[0.086]***	[0.058]***	[0.055]***
Cutoff = 250km	[0.049]***	[0.060]***	[0.065]***	[0.079]***	[0.058]***	[0.055]***
Cutoff = 300km	[0.047]***	[0.059]***	[0.066]***	[0.071]***	[0.059]***	[0.057]***
Cutoff = 350km	[0.047]***	[0.057]***	[0.067]***	[0.066]***	[0.059]***	[0.057]***
Cutoff = 400km	[0.047]***	[0.054]***	[0.066]***	[0.064]***	[0.058]***	[0.056]***
Cutoff = 450km	[0.044]***	[0.050]***	[0.064]***	[0.061]***	[0.057]***	[0.054]***
Cutoff = 500km	[0.041]***	[0.046]***	[0.060]***	[0.058]***	[0.055]***	[0.051]***
Geographic controls	×	×	×	×	×	×
Proximate controls		×	×		×	×
Additional controls			×			×
Observations	261	261	261	195	195	195
R^2	0.33	0.46	0.52	0.26	0.45	0.56

Notes. The serf emancipation and water mills variables are standardized to have zero means and unit standard deviations in each regression sample. Standard errors, corrected for spatial dependence across counties, are reported in square brackets. *** denotes statistical significance at the 1% level, ** at the 5% level, and * at the 10% level. For the specifications in columns 1–3, the values of Moran's test statistic for spatial correlation among residuals (based on the inverse-distance matrix of spatial weights under spectral normalization) are 21.72, 4.53, and 1.88, respectively. The corresponding p-values are 0.000, 0.033, and 0.170, implying that the null hypothesis of the absence of spatial correlation is rejected in the first two specifications at the 5% significance level.

Appendix H Legislative variation in *de jure* serf emancipation

As of the late eighteenth century, serfdom across Prussia was practiced at varying levels of intensity, depending on the customary obligations of the peasants and the strength of their land tenure rights, and such variation was prevalent even at the village level (see, e.g., Bowman, 1980; Harnisch, 1984; Pierenkemper and Tilly, 2004; Cinnirella and Hornung, 2016). A series of regulations were enacted for the *de jure* emancipation of different categories of the enserfed population. In addition, the political origin of these reforms varied across regions of Prussia, depending on whether a region belonged to territories that were not ceded to France at the Second Treaty of Tilsit in 1807 (e.g., the provinces of Brandenburg, Pomerania, East and West Prussia, and Silesia) versus territories that were annexed or regained by Prussia following the Congress of Vienna in 1815 (e.g., the provinces of Posen, Rhineland, Saxony, Swedish Pomerania, and Westphalia). This appendix provides the details of the *de jure* serf emancipation process throughout Prussia in the first half of the nineteenth century.

In regions belonging to territories that were not ceded to France in 1807, *de jure* serf emancipation was implemented in several stages between 1799 and 1850.

- Peasants residing on royal domains gained freedom from personal subjection in 1799. Their servile dues were commutated into leases either in money or in kind until 1806. Secure property rights to landownership were transferred to these peasants in 1808, and there was no *de jure* redemption process associated with their emancipation.

- Peasants residing on noble estates and holding weak (non-hereditary) rights to land tenure gained freedom from personal subjection in 1810, under the October Edict of 1807. Secure property rights to landownership as well as redemption of lifetime servile dues could be obtained *de jure* by these peasants under terms of the Regulation Edict of 1811 and the Declaration of 1816, at the cost of between one-third and two-thirds of their existing land parcels.

- Peasants residing on noble estates and holding strong (hereditary) rights to land tenure gained freedom from personal subjection in 1810, under the October Edict of 1807. Their lifetime servile dues could be *de jure* redeemed under the terms of the Dissolution Ordinance of 1821, at 25 times the equivalent annual cost of these duties. In the province of Silesia, however, regulation for the redemption of lifetime servile dues was implemented only in 1823.

- Peasants that were engaged in only manual servile duties (*nichtspannfähige Nahrungen*) to the nobility, due to the fact that they resided on small land parcels that did not permit any agriculture of sufficient scale, gained freedom from personal subjection in 1810, under the October Edict of 1807. Their lifetime servile duties, however, could only be *de jure* redeemed under the terms of the Commutation Law of 1850, at 25 times the equivalent annual cost of these duties.

In regions belonging to territories that were annexed or regained by Prussia following the Congress of Vienna in 1815, *de jure* serf emancipation was generally triggered by external political factors,

but in many cases, the rehabilitated Prussian nobility exerted significant influence on the *de facto* emancipation process, much like they did in other regions of Prussia that never came under Napoleonic influence in the period between 1807 and 1815.

- The territory of South Prussia (i.e., the Grand Duchy of Posen, the regions of Kulm and Michelau, and the city of Thorn) was annexed by the French in 1807 (as part of the Duchy of Warsaw) and thus came under the influence of the Code Napoléon. Following its repossession by Prussia at the Congress of Vienna in 1815, the General State Laws for the Prussian States (*Allgemeines Landrecht für die Preußischen Staaten*) were reestablished in this territory in 1817. Despite temporarily coming under the influence of the Napoleonic code, the process of *de facto* peasant emancipation made little progress in this region until after its repossession by Prussia. An 1823 Edict specified that peasants in this region could *de jure* redeem their lifetime servile duties under terms similar to the Dissolution Ordinance of 1821; i.e., at 25 times the equivalent annual cost of these duties.

- Peasants in Rhineland gained freedom from personal subjection in 1794, under the Code Napoléon. According to legislation passed in 1798, their lifetime servile dues could be *de jure* redeemed at 15 times the equivalent annual cost of these duties, and redeemability was further clarified by legislation in 1804. Following Prussian annexation, the French legislation remained in place in Rhineland, which is therefore excluded from our empirical analysis.

- Peasants in the former Electorate of Saxony (i.e., the Prussian districts of Merseburg and Erfurt) did not come under the *de jure* influence of French legislation. They gained freedom from personal subjection under Prussian legislation in 1819, and their lifetime servile dues were declared to be *de jure* redeemable under the terms of the Dissolution Ordinance of 1821, at 25 times the equivalent annual cost of these duties.

- Peasants in the former Swedish Pomerania (i.e., Prussian district of Stralsund) were *de jure* emancipated under agrarian reforms enacted by the Swedish Crown in 1806. From a legislative perspective, this district continued to maintain an exceptional position after Prussian annexation, and we therefore exclude it from our empirical analysis.

- Peasants in the former Kingdom of Westphalia (i.e., the Prussian province of Westphalia and the district of Magdeburg) gained freedom from personal subjection in 1808, under the Code Napoléon. According to legislation passed in 1809, their lifetime servile dues could be *de jure* redeemed at 25 times the equivalent annual cost of these duties. The Westphalian nobility, however, successfully blocked the legislation, and redeemability was only clarified in 1825. Thus, although the French legislation remained in place in Westphalia following Prussian annexation, the significant influence of the elites on the *de facto* peasant emancipation process made the Westphalian experience akin to those of the Prussian regions that were not temporarily ceded to France.

Appendix I Variable definitions and data sources

I.1 Variables in the cross-sectional analysis

I.1.1 Variables reported in the main tables and figures

Serf emancipation 1821–48. The cumulative stock of emancipation cases settled in a county between 1821 and 1848, expressed as a fraction of the county's rural population (net of those ineligible for emancipation until after 1850) in 1816. The numerator of this variable reflects county-level data reported by Meitzen (1868, vol. 4), capturing only those settled emancipation cases in which former service and duty payers (*Dienst- und Agabenpflichtige, welche abgelöst haben*) redeemed their lifetime servile duties under the Dissolution Ordinance of 1821 (*Ablösungsordnung*).[I.1] For the denominator of this variable, the data on a county's rural population in 1816 is sourced from Mützell (1823-1825, vol. 6), but this information is then adjusted to exclude the subpopulation, reported at the county level by Meitzen (1868, vol. 4), of the peasant landowners residing on small parcels (with weak land tenure rights) that were ineligible for redeeming their lifetime servile dues under the 1821 ordinance (*nichtspannfähige bäuerliche Nahrungen*) and were only able to do so after the passage of the Commutation Law in 1850.

Redemption costs (PC). The first principal component of the average amounts (per settlement) associated with four different types of compensation payments made by peasants to redeem their lifetime labor services in the emancipation cases settled in a county as of 1848. This variable is constructed using county-level data reported by Meitzen (1868, vol. 4). The settled emancipation cases considered are those in which former service and duty payers (*Dienst- und Agabenpflichtige, welche abgelöst haben*) redeemed their lifetime servile duties under the Dissolution Ordinance of 1821 (*Ablösungsordnung*). The four types of compensation payments included in the principal component analysis are "capital" (*Kapital*), measured in Prussian Thaler; "cash annuities" (*Geldrente*), measured in Prussian Thaler; "rye annuities" (*Roggenrente*), measured in Prussian Scheffel; and "land" (*Land*), measured in Prussian Morgen. This variable captures 52% of the combined variation across counties in the four underlying measures of compensation payments.

Water mills 1819. The number of water mills (*Wassermühlen*) used for the grinding of grains into flour, grits, or pearl barley in a county in 1819, divided by the county's population (in thousands) in 1821 (the population census year closest to 1819), constructed using county-level data reported by Mützell (1823-1825, vol. 6).

Average temperature. The average temperature in degrees Celsius in a county during the 1960–1990 time horizon, constructed by temporally and spatially aggregating time series information on mean monthly temperature at a geospatial resolution of 30 arc seconds, obtained from the WorldClim (version 1) data set (http://www.worldclim.org/version1) of Hijmans et al. (2005).

[I.1] The number of settled emancipation cases is missing for five counties in the districts of Königsberg and Gumbinnen. For four of these counties, we imputed the the number of settled cases based on information pertaining to redeemed labor services and redemption costs. No such information was available for one county (Lyk), which remains missing from our sample. Furthermore, in two instances, the 1848 emancipation census reports the number of settled cases and redemption costs for two counties combined. In these cases, we decided to assign the same value for the share of emancipated serfs to each of the two counties.

Average precipitation. The average precipitation in hundreds of millimeters in a county during the 1960–1990 time horizon, constructed by temporally and spatially aggregating time series information on total monthly precipitation at a geospatial resolution of 30 arc seconds, obtained from the WorldClim (version 1) data set (http://www.worldclim.org/version1) of Hijmans et al. (2005).

Distance to navigable river. The distance in hundreds of kilometers from a county's centroid to the nearest navigable river, constructed using a map of all waterways (*Schiffahrtsstraßen*) in the *Zollverein* (German Customs Union) in 1850 (http://www.ieg-maps.uni-mainz.de/mapsp/mapw850d.htm), hosted by the "Server for Digital Historical Maps" at the Leibniz Institute of European History at the University of Mainz (IEG, 2010).

Soil suitability (cereals). The average suitability of the soil in a county for growing cereal crops, constructed by spatially aggregating information on an agro-ecological suitability index (class) for low-input-level rain-fed cereal crops at a geospatial resolution of 30 arc seconds, obtained from the Food and Agriculture Organization's (FAO) Global Agro-Ecological Zones (GAEZ) Data Portal version 3.0 (http://gaez.fao.org).

Sandy soil (share). The share of a county's land area in which the soil texture is classified as sandy (i.e., where the soil is composed of 85-100% sand, 0-15% silt, and 0-15% clay), constructed using county-level data reported by Meitzen (1868, vol. 4).[I.2] The underlying data for this variable were collected by an 1866 census, which assessed the composition of the soil in a county by gathering information on three main soil categories: the area of "clay soils" (*Lehm- und Thonböden*), the area of "sandy loam and loamy sand soils" (*sandiger Lehm und lehmiger Sand*), and the area of "sandy soils" (*Sandboden*).

East Elbe (dummy). A binary variable that assumes a value of one for counties located on or east of the river Elbe, and zero otherwise.

Population density 1816. The population of a county in 1816, divided by the county's land area (measured in Prussian Morgen), constructed using county-level data reported by Mützell (1823-1825, vol. 6).

Urbanization rate 1816. The total number of inhabitants across cities that held city rights in a county in 1816, divided by the county's population in 1816, constructed using city- and county-level data reported by Mützell (1823-1825, vol. 5–6).

Family size 1849. The population of a county in 1849, divided by the number of families in the county in 1849, constructed using county-level data reported by the Statistisches Bureau zu Berlin (1851–1855, vol. 1).

Knight estates (share). The number of knight estates (*Rittergüter*) in a county in 1856 as reported by Rauer (1857), divided by the number of all landholdings in the county in 1849 as

[I.2] To elaborate on what this measure captures, it may be noted that the ideal soil texture for agricultural productivity has a composition of roughly 40% sand, 40% silt, and 20% clay. The suitability of a particular texture of the soil for agriculture is determined by the physical properties of soil particles; sand particles are relatively round, whereas silt and clay particles are relatively slim. Although the presence of round particles in the soil permits the absorption and retention of higher amounts of air and water, this is only true up to a certain point for water retention; soils excessively rich in sand are unable to retain water due to the presence of a large amount of empty spaces between particles, thus leading to a higher likelihood of drought and crop failure.

reported by the Statistisches Bureau zu Berlin (1851–1855, vol. 5).[I.3] This variable is expressed in percent.

Protestants 1816 (share). The number of a county's inhabitants that belonged to the Reformed or Lutheran Protestant religious denomination in 1816, divided by the county's population in 1816, constructed using county-level data reported by Mützell (1823-1825, vol. 6).

Other ethnic group 1861 (share). The number of a county's inhabitants that were not of ethnic German descent (*Stammesverschiedenheit*) in 1861, divided by the county's population in 1861, constructed using county-level data reported by the Königlich Preussisches Statistisches Bureau (1861–1934, vol. 10).

Partible inheritance law (dummy). A binary variable that assumes a value of one for counties that predominantly practiced partible inheritance (*Realteilung*), and zero for counties that predominantly practiced primogeniture (*Anerbenrecht*), coded using county-level maps from circa-1900 on historical inheritance laws (Sering, 1897-1905).

Enrollment rate 1816. The total number of enrolled students across a county's public elementary schools (*Öffentliche Elementarschulen*), private elementary schools (*Privat-Elementarschulen*), public middle schools for boys or girls (*Öffentliche Bürger- und Mittelschulen für Söhne oder Töchter*), and private middle schools for boys or girls (*Private Bürger- und Mittelschulen für Söhne oder Töchter*) in 1816, divided by the county's population of children of recommended schooling age (6 to 14) in 1816, constructed using town- and county-level data reported by Mützell (1823-1825, vol. 5–6).[I.4]

Urban artisans 1819 (share). The number of inhabitants across cities with city rights in 1819 that are craftsmen (baker, butcher, tanner, etc.), divided by the county population in 1821 (the population census year closest to 1819), constructed using city- and county-level data reported by Mützell (1823-1825, vols. 5–6).

Urban traders 1819 (share). The number of inhabitants across cities with city rights in 1819 that are merchants, divided by the county population in 1821 (the population census year closest to 1819), constructed using city- and county-level data reported by Mützell (1823-1825, vols. 5–6).

Servile duties (PC). The first principal component of the average amounts (per settlement) associated with two different types of labor services redeemed in the emancipation cases settled in a county as of 1848. This variable is constructed using county-level data reported by Meitzen (1868, vol. 4). The settled emancipation cases considered are those in which former service and duty payers (*Dienst- und Agabenpflichtige, welche abgelöst haben*) redeemed their lifetime servile duties under the Dissolution Ordinance of 1821 (*Ablösungsordnung*). The two types of labor services

[I.3] Although 1856 is the earliest available census on the number of knight estates in a county, Rauer (1857) provides additional information asserting that the spatial distribution of knight estates across Prussia remained largely stable throughout the first half of the nineteenth century. For instance, only 324 out of 11,714 knight estates lost their noble prerogatives during the 1834–1856 time period.

[I.4] Of the four types of schools, public elementary schools were the only ones prevalent in both rural and urban areas in 1816. Our data source provides information on student enrollment in public elementary schools at the county level in 1816, and we supplement this with aggregated town-level information on enrollment in private and middle schools across all medium and large towns in a county.

included in the principal component analysis are "draft animal services" (*Spanndienste*) and "hand labor services" (*Handdienste*), both measured in days. This variable captures 93% of the combined variation across counties in the two underlying measures of labor services.

Road 1848 (dummy). A binary variable that assumes a value of one for counties connected to at least one main road in 1848, and zero otherwise. The coding of this variable is based on a map of all paved and unpaved main roads (*Hauptstraßen*) in the *Zollverein* (German Customs Union) in 1848 (http://www.ieg-maps.de/mapsp/maproads1848.htm), hosted by the "Server for Digital Historical Maps" at the Leibniz Institute of European History at the University of Mainz (IEG, 2010).

Railway 1848 (dummy). A binary variable that assumes a value of one for counties connected to at least one railway line in 1848, and zero otherwise. The coding of this variable is based on a map of all railway lines (*Eisenbahnen*) in the *Zollverein* (German Customs Union) in 1848 (http://www.ieg-maps.de/mapsp/mape848d.htm), hosted by the "Server for Digital Historical Maps" at the Leibniz Institute of European History at the University of Mainz (IEG, 2010).

Coalfield (dummy). A binary variable that assumes a value of one for counties that had access to a coalfield (i.e., those in which a coalfield was located within 10 kilometers of the county's centroid), and zero otherwise, coded using geospatial data on the location of coalfields from Fernihough and O'Rourke (2021).

Number of uprisings 1816–47. The number of violent protests, each involving at least 20 participants, in a county during the 1816–1847 time period, constructed using data reported by Tilly (1990) on the location and timing of such protests.

Commoner estates (share). The number of a county's noble estates that were owned by commoners (*Bürgerliche*) in 1856, divided by the number of all noble estates in the county in 1856, constructed using county-level data reported by Rauer (1857).

Napoleonic occupation (dummy). A binary variable that assumes a value of one for counties that were under Napoleonic occupation for either 6 or 12 years from Acemoglu et al. (2010).

Crown and state domains (share). The total land area across a county's real estates that either belonged to the Crown and members of the royal family or belonged to the state in 1861, including domains and forests (*Eigenthum des Staats: Domainen und Forsten*), divided by the total land area across all real estates (*Ertragfähige Liegenschaften*) in the county in 1861, constructed using county-level data reported by Meitzen (1868, vol. 4).

Kulm estates (share). The number of a county's noble estates that were constituted under the Kulm law (*Kölmische Güter*) or whose legal constitution was consistent with the Kulm law (*den kölmischen gleichartige*) in 1856, divided by the number of all noble estates in the county in 1856, constructed using county-level data reported by Rauer (1857).

Commercial city (dummy). A binary variable that assumes a value of one for counties that harbored a university in 1517 or an urban center that maintained status as either an Imperial City (*Reichsstadt*) or a member of the Hanseatic League (*Hansestadt*) in 1517, and zero otherwise. The coding of this variable is based on county-level information obtained from the data set of Becker

and Woessmann (2009). The primary sources of their information include Eulenburg (1904), for the locations of universities; Oestreich and Holzer (1973), for cities that participated in the Imperial Diet; and Hammel-Kiesow (2000), for cities that participated in the Hanseatic Diet.

Born outside county 1871 (share). The number of a county's inhabitants in 1871 that were born outside the county, divided by the county's population in 1871, constructed using county-level data reported by the Königlich Preussisches Statistisches Bureau (1861–1934, vol. 30).

Skilled employment 1849. The total number of foremen and skilled manual workers employed in factories and crafts in a county in 1849 (namely, workers corresponding to categories 6 and 7 of the HISCLASS historical social class scheme, based on the HISCO historical international standard classification of occupations), divided by the county's male population of working age (17 to 45) in 1849, constructed using county-level data reported by the Statistisches Bureau zu Berlin (1851–1855, vols. 1, 5, 6a).

Enrollment rate 1864. The total number of enrolled students across a county's public elementary schools (*Öffentliche Elementarschulen*), private elementary schools (*Privat-Elementarschulen*), public middle schools for boys or girls (*Öffentliche Mittelschulen für Söhne oder Töchter*), and private middle schools for boys or girls (*Private Mittelschulen für Söhne oder Töchter*) in 1864, divided by the county's population of children of recommended schooling age (6 to 14) in 1864, constructed using county-level data reported by the Königlich Preussisches Statistisches Bureau (1861–1934, vol. 10).[I.5]

Literacy rate 1871. The number of a county's inhabitants aged 10 and above that were able to read and write in 1871, divided by the county's population aged 10 and above in 1871, constructed using county-level data reported by the Königlich Preussisches Statistisches Bureau (1874).

All types of factories 1849. The total number of factories across all manufacturing sectors (textiles, metals, paper, chemicals, food-processing, etc.) in a county in 1849, divided by the county's population (in thousands) in 1849, constructed using county-level data reported by Statistisches Bureau zu Berlin (1851–1855, vol. 6a).

Steam engines 1875. The total number of steam engines (*Dampfmaschinen*) across manufacturing establishments in a county in 1875, divided by the county's population (in thousands) in 1875, constructed using county-level data reported by the Königlich Preussisches Statistisches Bureau (1861–1934, vol. 40).

Motorized engines 1875. The total number of all types of motorized engines (*Umtriebsmaschinen und Arbeitsmaschinen*) across manufacturing establishments in a county in 1875, divided by the county's population (in thousands) in 1875, constructed using county-level data reported by the Königlich Preussisches Statistisches Bureau (1861–1934, vol. 40).

I.1.2 Additional variables employed in appendix sections

Wind mills 1819. The total number of wind mills, including post mills (*Bockmühlen*) and smock mills (*holländische Mühlen*), used for the grinding of grains into flour, grits, or pearl barley in a

[I.5] For a small number of counties in our sample, our measure of the enrollment rate in 1864 exceeds unity, reflecting the enrollment of students that are either residents of neighboring counties or above 14 years of age or both.

county in 1819, divided by the county's population (in thousands) in 1821 (the population census year closest to 1819), constructed using county-level data reported by Mützell (1823-1825, vol. 6).

Horse mills 1819. The number of horse mills (*Rossmühlen*) in a county in 1819, divided by the county's population (in thousands) in 1821 (the population census year closest to 1819), constructed using county-level data reported by Mützell (1823-1825, vol. 6).

Other types of mills 1819. The total number of non-grain-processing mills, including oil mills (*Oelmühlen*), fulling mills (*Walkmühlen*), saw mills powered by either water or wind (*Sägemühlen auf Wasser oder Wind*), and paper mills (*Papiermühlen*), in a county in 1819, divided by the county's population (in thousands) in 1821 (the population census year closest to 1819), constructed using county-level data reported by Mützell (1823-1825, vol. 6).

All types of mills 1819. The total number of water mills, wind mills, horse mills, and other types of mills (as defined above) in a county in 1819, divided by the county's population (in thousands) in 1821 (the population census year closest to 1819), constructed using county-level data reported by Mützell (1823-1825, vol. 6).

Brick and glass factories 1819. The total number of brick works (*Ziegeleien*), lime kilns (*Kalkbrennereien*), and glass works (*Glashütten*) in a county in 1819, divided by the county's population (in thousands) in 1821 (the population census year closest to 1819), constructed using county-level data reported by Mützell (1823-1825, vol. 6).

All types of looms 1819. The total number of (hand-powered) looms for weaving cloth (*Gehende Weberstühle zu Tüchern und Zeugen aller Art*) from silk and half-silk (*in Seide und Halbseide*), cotton (*in Baumwolle und Halbbaumwolle*), wool (*in Wolle und Halbwolle*), and linen (*Leinen*), hosiery knitting looms (*Strumpfweberstühle*), and band weaving looms (*Bandstühle, Zahl der Gänge*), plus the total number of looms in secondary employment (*Gehende Weberstühle als Nebenbeschäftigung*) for the processing of linen (*Leindwand*), shag (*grobes wollenes Zeug*), and other types of fabrics (*andere Stuhlwaaren*) in a county in 1819, divided by the county's population (in thousands) in 1821 (the population census year closest to 1819), constructed using county-level data reported by Mützell (1823-1825, vol. 6).

Terrain slope. The average slope of the terrain in a county, constructed using geospatial elevation information reported in Data Basin's "30 arc-second DEM of Europe" data set (https://databasin.org/datasets/7a286ca8a7fa492a9f95d58324ca918c), which is, in turn, derived from the U.S. Geological Survey's GTOPO30 data set (EROS, 1996). GTOPO30 is a global digital elevation model (DEM) that provides elevation information at a resolution of 30 arc seconds. The measurement of this variable proceeds by first calculating for each grid cell the maximum of the elevation difference in angular degrees between itself and each of its eight neighboring cells and then averaging this information across all grid cells in a county.

Unskilled wages 1810-19. The average daily wage rate in Mark of unskilled male "seasonal fill" workers (day laborers) employed in a county's public forestry sector during the 1810–1819 time period, constructed by aggregating forestry-level wage data (for 88 public forestries) reported by the Königlich Preussisches Statistisches Bureau (1861–1904, vol. XY).

Longitude (degrees). The eastwest position of a county's centroid measured in decimal degrees.

River density. The total length of rivers in km in a county, divided by the total area in km^2 of a county. Constructed using geospatial information from "HydroRIVERS" available at https://www.hydrosheds.org/page/hydrorivers (Lehner and Grill, 2013).

Carboniferous area (share). The share of a county's land area that contains geological strata (including subterranean coal beds) created during the Carboniferous period, constructed using geospatial geological information from the "1:5 Million International Geological Map of Europe and Adjacent Areas (IGME 5000)" (Asch, 2005).

Civil servants 1849 (share). The number of a county's inhabitants that are civil servants in state and legal administration in 1849, divided by the county's population in 1849, constructed using county-level data reported by the Statistisches Bureau zu Berlin (1851–1855, vols. 1, 5, 6a).

Religious diversity 1849. Herfindahl index, calculated from shares of religious groups (Protestants, Catholics, Greek Orthodox, Mennonites, and Jews) in the total population of a county's population in 1849, constructed using county-level data reported by the Statistisches Bureau zu Berlin (1851–1855, vol. 1).

Linguistic diversity 1900. Herfindahl index, calculated from shares of linguistic groups (21 mother tongues, including Masurish, Kassubian, Wendish, Marish, Czech, Russian, Lithuanian, and Hungarian) in the total population of a county's population in 1900, constructed using county-level data from Königlich Preussisches Statistisches Bureau (1861–1934, vol. 177c).

Sex ratio 1816 (working age). The number of a county's inhabitants that are male and between age 15 and 45, divided by the number of a county's inhabitants that are female and between age 15 and 45, constructed using county-level data by Mützell (1823-1825, vol. 6).

I.2 Variables in the panel analysis

Emancipation cases. The logged average annual number of emancipation cases settled in a district during a given 5-year period in the 1850–1898 time horizon, constructed using annual district-level data for this time horizon reported by Meitzen (1868, vol. 6).[I.6] The settled emancipation cases include those in which former service and duty payers (*Dienst- und Agabenpflichtige, welche abgelöst haben*) redeemed their lifetime servile duties under the Dissolution Ordinance of 1821 (*Ablösungsordnung*) as well as cases of redemption under the Commutation Law of 1850. The time intervals considered are 1850–1854, 1855–1859, 1860–1864, . . . , 1895–1898.

Redemption costs. The logged first principal component of the average annual amounts (per settlement) associated with four different types of compensation payments made by peasants to redeem their lifetime labor services in the emancipation cases settled in a district during a given 5-year period in the 1850–1898 time horizon, constructed using annual district-level data for this time horizon reported by Meitzen (1868, vol. 6). The settled emancipation cases considered are those in which former service and duty payers (*Dienst- und Agabenpflichtige, welche abgelöst haben*) redeemed their lifetime servile duties under the Dissolution Ordinance of 1821 (*Ablösungsordnung*).

[I.6] Consistently with our cross-sectional analysis, we exclude the district of Stralsund (i.e., the former Swedish Pomerania) from our flexible panel analysis, because the emancipation process in this district was influenced by radically different institutions.

The four types of compensation payments included in the principal component analysis are "capital" (*Kapital*), measured in Prussian Thaler; "cash annuities" (*Geldrente*), measured in Prussian Thaler; "rye annuities" (*Roggenrente*), measured in Prussian Scheffel; and "land" (*Land*), measured in Prussian Morgen.

Water mills 1819. The number of water mills used for the grinding of grains into flour, grits, or pearl barley in a district in 1819, divided by the district's population (in thousands) in 1821 (the population census year closest to 1819), constructed by aggregating up county-level data reported by Mützell (1823-1825, vol. 6) to the district level.

Initial population. The logged population of a district in the initial year of a given 5-year period in the 1850–1898 time horizon, constructed using district-level population census data reported by the Statistisches Bureau zu Berlin (1851–1855, various vols.) and the Königlich Preussisches Statistisches Bureau (1861–1934, various vols.) for various years of this time horizon (censuses were conducted, roughly, every 3 years until 1871 and every 5 years from 1875 onward). The variable employed is based on a log-linear interpolation of population observed at the district level across these various censuses. The time series extracted from the interpolation corresponds to the years 1850, 1855, 1860, . . . , 1895.

Lagged uprisings. The number of violent protests, each involving at least 20 participants, in a district during a given 5-year period in the 1845–1894 time horizon, constructed using data reported by Tilly (1990) on the location and timing of such protests. The time intervals considered are 1845–1849, 1850–1854, 1855–1859, . . . , 1890–1894.

Servile duties. The logged first principal component of the average amounts (per settlement) associated with two different types of labor services redeemed in the emancipation cases settled in a district during a given 5-year period in the 1850–1898 time horizon, constructed using annual district-level data for this time horizon reported by Meitzen (1868, vol. 6). The settled emancipation cases considered are those in which former service and duty payers (*Dienst- und Agabenpflichtige, welche abgelöst haben*) redeemed their lifetime servile duties under the Dissolution Ordinance of 1821 (*Ablösungsordnung*). The two types of labor services included in the principal component analysis are "draft animal services" (*Spanndienste*) and "hand labor services" (*Handdienste*), both measured in days.

TABLE I.1: Descriptive statistics for the main variables in the cross-sectional analysis

	Obs.	Mean	Std. dev.	Min.	Max.
Serf emancipation 1821–48	261	0.06	0.07	0.00	0.52
Water mills 1819	261	1.23	0.77	0.00	3.78
Terrain slope	261	0.66	0.64	0.07	3.91
Terrain slope^2	261	0.84	1.93	0.01	15.30
Average temperature	261	8.09	0.82	5.66	9.72
Average precipitation	261	6.34	1.13	4.89	10.70
Distance to navigable river	261	0.32	0.26	0.00	1.39
Soil suitability (cereals)	261	4.20	0.75	1.63	6.28
Sandy soil (share)	261	0.28	0.23	0.00	0.81
East Elbe (dummy)	261	0.75	0.44	0.00	1.00
Population density 1816	261	0.10	0.06	0.02	0.42
Urbanization rate 1816	261	0.24	0.13	0.00	0.86
Urban artisans 1819 (share)	261	0.06	0.02	0.00	0.12
Urban traders 1819 (share)	261	0.02	0.01	0.00	0.06
Family size 1849	261	5.09	0.32	4.08	5.88
Knight estates (share)	261	1.25	1.11	0.00	7.46
Protestants 1816 (share)	261	0.68	0.37	0.00	1.04
Other ethnic group 1861 (share)	261	0.17	0.28	0.00	0.90
Partible inheritance law (dummy)	261	0.12	0.33	0.00	1.00
Enrollment rate 1816	261	0.60	0.21	0.03	0.95
Servile duties (PCA)	261	0.00	1.00	−0.63	6.28
Road 1848 (dummy)	261	0.75	0.43	0.00	1.00
Railway 1848 (dummy)	261	0.31	0.46	0.00	1.00
Coalfield (dummy)	261	0.08	0.27	0.00	1.00
Number of uprisings 1816–47	261	0.30	0.85	0.00	9.00
Napoleonic occupation (dummy)	261	0.32	0.47	0.00	1.00
Commoner estates (share)	261	0.42	0.24	0.00	1.00
Crown and state domains (share)	261	0.08	0.09	0.00	0.50
Kulm estates (share)	261	0.04	0.13	0.00	0.90
Commercial city (dummy)	261	0.08	0.27	0.00	1.00
Born outside county 1871 (share)	261	0.21	0.07	0.05	0.52
Redemption costs	261	−0.30	0.64	−1.06	2.90
Skilled employment rate 1849	261	0.25	0.11	0.05	0.62
Enrollment rate 1864	261	0.75	0.11	0.44	1.20
Literacy rate 1871	261	0.61	0.12	0.26	0.75
All types of factories 1849	261	2.38	1.71	0.37	16.98
Steam engines 1875	261	0.85	0.94	0.02	6.39
Motorized engines 1875	261	3.01	1.39	0.66	8.63
Wind mills 1819	261	0.96	1.27	0.00	8.79
Horse mills 1819	261	0.08	0.14	0.00	1.37
Other types of mills 1819	261	0.63	0.54	0.00	3.29
Brick and glass factories 1819	261	0.36	0.27	0.00	2.53
All types of looms 1819	261	23.25	27.82	0.00	174.70

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