Good Fences Make Good Neighbors: Evidence on the Effects of Property Rights

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Abstract

This paper uses the introduction of barbed wire fencing to the American Plains in the late 19th century to estimate the effects of property rights on farmers' production decisions. Farmers were both formally and informally required to build fences to secure their land. From 1880 to 1900, the introduction and universal adoption of barbed wire reduced the cost of fencing, relative to wooden fences, most in counties with the least woodland. Over that period, counties with the least woodland experienced substantial relative increases in the improvement intensity of farmland, the value of farmland, and the productivity and production share of crops most in need of protection. This substantial increase in agricultural development appears to reflect increased security of property rights due to barbed wire fencing. Some states' previous efforts to reduce the need for fencing are not found to have had similar effects, however, suggesting a difficulty protecting property rights in sparsely settled areas through legislation and the court system.

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The assignment and enforcement of property rights are thought to encourage economic efficiency [Coase 1960] and to be an important determinant of product choices, investment levels, production methods [Cheung 1970], and macroeconomic performance [North 1981; Acemoglu and Johnson 2005]. Coase presents the example of a farmer and a cattle-raiser, in which the costless assignment and tradeability of property rights leads to the efficient allocation of resources. Much attention has focused on the role of land rights in agricultural development, where more secure rights might improve economic efficiency by increasing farmers' investments.[1] The typical positive correlation between investment and property rights, however, may reflect the endogenous determination of property rights [Demsetz 1967; Miceli et al. 2001].[2]

Valid causal estimation is dependent upon plausibly exogenous variation in property rights, mainly either from instrumental variables [Besley 1995; Brasselle et al. 2002] or land rights policies [Jacoby et al. 2002; Banerjee et al. 2002]. These exogeneity assumptions are typically most plausible for micro-level variation in property rights, but this variation may overstate the effects of larger reforms or macro-level differences.[3]

This paper attempts to estimate the effects of property rights on farmers' production decisions, using a widespread and plausibly exogenous decrease in the cost of establishing and enforcing property rights: the introduction of barbed wire fencing to the American Plains in the late 19th century. At that time, farmers were required to build fences to protect their land and crops from others' livestock. Without fences, farmers were apt to suffer substantial damages and typically had no formal right to compensation from the livestock's owner. Fences may also have decreased farmers' susceptibility to land expropriation by providing an informal mechanism for delineating and substantiating land claims. Both effects of fencing are tantamount to an increase in farmers' property rights in the standard security model of property rights [Besley 1995].[4]

Before barbed wire, fence construction on the Plains had been severely restricted by high costs in areas that lacked locally available fencing materials. Due to high transportation costs from Eastern wooded areas, small sections of local woodland provided a vital source

[1] See Besley [1995] for a discussion of three mechanisms: decreased expropriation raises the expected return on investment; an improved ability to collateralize land increases access to credit; and lower costs of trading land raise the expected return on investment.

[2] Unobserved factors, such as land quality, may influence both investment and property rights. Investment may increase the legitimacy of land claims or otherwise make the land more worthwhile to secure. Goldstein and Udry [2005] discuss an opposite example where fallowing land may jeopardize ownership claims.

[3] When property rights vary across land plots within small areas, observed effects may reflect sorting of producers or substitution in production that would not occur if property rights were made more widely available.

[4] In contrast to other sources of variation in property rights, fencing did not affect farmers' formal land ownership and, thus, had little effect on farmers' ability to trade the land or use it as collateral.

of timber for fencing on the Plains. The introduction and universal adoption of barbed wire from 1880 to 1900 had its greatest effect in areas with the least woodland that had been most costly to fence.[5]

Using decennial data from the Census of Agriculture, I estimate that counties with the least woodland experienced large increases in agricultural development from 1880 to 1900, relative to counties with sufficient woodland for farmers to have accommodated previous fencing material shortages. Estimated increases were particularly substantial along intensive margins of agricultural production. Controlling for constant differences among counties and state-wide shocks to all counties, the fraction of county farmland that was improved increased by 19 percentage points in counties with the least woodland.

From 1880 to 1890, average crop productivity increased by 23% in counties with the least woodland, controlling for crop-specific differences among counties and crop-specific state-wide shocks to all counties. The increased productivity was entirely in crops most susceptible to damage from roaming livestock, as opposed to hay. In addition, farmers shifted cropland allocations toward these more at-risk crops. Crop production changed little from 1890 to 1900, indicating that farmers adjusted more rapidly along these margins.

Agricultural development increased along these intensive margins, even as counties with the least woodland expanded along the extensive margin of total farmland. The estimates are robust to controlling for changes over time that are correlated with counties' distance West and distance from St. Louis; counties' region, subregion, or soil group; or counties' initial intensity of land improvement. By contrast, estimated increases along the extensive margin of total farmland are more sensitive to these robustness checks.

Improvements in production were reflected in increased land values in the six Plains states analyzed, totaling roughly 0.9% of national GDP. In all, these estimates lend support to historical accounts that "without barbed wire the Plains homestead could never have been protected from the grazing herds and therefore could not have been possible as an agricultural unit" [Webb 1931, p.317].

The historical setting provides a rare opportunity to compare the effects of the *de facto* improvement in property rights enforcement provided by barbed wire with the effects of contemporaneous *de jure* efforts by some state legislatures. In the early 1870's, some states and counties adopted "herd laws" that shifted formal fencing responsibilities to livestock owners. In contrast to the large estimated effects of barbed wire, these reforms appear to

[5]Barbed wire fencing need not affect property rights in other contexts with different legal structures or geographical characteristics; rather, these factors combined to make barbed wire particularly important for property rights protection in the United States' Plains in the late 19th century. See, for example, Anderson and Hill [1975].

have had little effect. In this historical context when settlement was sparse, it appears that the herd laws were weakly enforced and farmers continued to require fencing for protection.

Attributing the estimated effects of barbed wire to the increased security of property rights requires that barbed wire affected agricultural development only by increasing property rights enforcement. I examine the potential for two other effects of cheaper fencing: the direct encouragement of cattle production and/or the joint production of crops and cattle. There is little evidence of a positive effect of barbed wire on cattle production, however, and joint production is found to have decreased. This fails to contradict the hypothesis that barbed wire's effects operated mainly through an increase in property rights enforcement.

The paper is organized as follows. Section I reviews historical accounts of the need for alternative fencing materials in timber-scarce areas and the introduction of barbed wire fencing. Section II nests these historical accounts in a more stylized theoretical framework. Section III describes the data and presents summary statistics. Section IV develops the empirical methodology. Section V presents the main estimation results and explores their robustness. Section VI examines other potential confounding factors. Section VII analyzes states' reforms to fencing requirements. Section VIII concludes.

I History of Barbed Wire and the Great Plains

I.A Timber Shortages Constrained Property Rights Enforcement

Breaking with English common law, legal codes in the United States in the 19th century had long required the construction of a "lawful fence"[6] to secure farmland [Kawashima 1994]. Without such a fence, a farmer had no formal entitlement to compensation for damages inflicted by roaming livestock. In practice, fences were necessary to protect crops and they required substantial investment. In 1872, fencing capital stocks in the United States were roughly equal to the value of all livestock, the national debt [U.S. House 1872], or the railroads. Annual fencing repair costs were greater than the combined annual tax receipts at all levels of government [Galveston News 1873, as cited in Webb, pp.288–289].

Fencing became increasingly costly as settlement moved into areas with little woodland. As early as 1841, agricultural journals discussed the lack of timber for fencing as the major barrier to the settlement of Western regions [Bogue 1963a, p.74]. An 1871 report, prepared as a guide for immigrants, focused on three main characteristics of farmland in Plains counties: its price, the amount of timber, and the amount fenced [U.S. House 1871].

[6] The exact requirements for a lawful fence varied by state, but a fence was generally required to be strong enough to prevent the intrusion of a roaming animal. Some laws also required that the animal's owner be shown to have contributed to the damages through particular negligence or maliciousness.

> When the frontier line left the timbered region and came onto the Prairie Plains, the pioneers found there neither timber nor stone. There was nothing with which to fence the land. ... Without fences [they] could have no crops; yet the expense of fencing was prohibitive, especially in the Plains proper. [Webb, p.281, p.287]

> When he sought to fence his crops against marauding livestock, the prairie farmer faced the timber problem at its most acute. [Bogue 1963b, p.7]

During the early period of settlement there was little conflict between those growing crops and those raising cattle, but that was because farmers were mostly forced out of necessity to remain elsewhere. Much potential conflict existed [Alston et al. 1998], which is the relevant factor in farmers' location and production decisions.[7]

High transportation costs made it impractical to supply areas without woodland with the required amounts of timber for fencing [Kraenzel 1955, p.129; Hayter 1939; Bogue 1963b, p.7], though systematic data on transportation costs are unavailable. In low-woodland areas, "the scarcity of wood and its consequent high cost encouraged experimentation" [Primack 1969, p.287]. There was some use of hedge fences, yet these were found to be too difficult and costly to grow and control. Smooth iron wire fences were available, yet they were easily broken by animals, prone to rust, and broke (sagged) in cold (hot) weather.

Writing about central Iowa, Bogue [1963b, p.6] further describes which counties were most affected by timber shortages:

> Where timber and prairie alternated, locations in or near wooded areas were relatively much more attractive.... [T]here developed a landholding pattern of which the timber lot was an intricate part. Settlers on the prairie purchased five or ten acres along the stream bottoms or in the prairie groves and drove five, ten or fifteen miles to cut building timber or to split rails during the winter months.

Smaller counties were roughly 30 miles on each side, so farmers traveling 5–15 miles for timber would still have been mostly within their home county. For simplicity and transparency, I assume that farmers' access to wooden fence materials depended on the amount of woodland in their home county.

The empirical analysis will examine continuous variation in county woodland levels, but Bogue's description provides some useful benchmark values for the level of woodland in a county. For a standard homestead farm size of 160 acres, a county would need to be

[7] Differences in the ability to prevent encroachment are key, rather than differences in the observed initial equilibrium levels of encroachment. The empirical analysis does not define counties with a "property rights problem" as those with both livestock and cropland, as this is endogenously determined by many unobserved local factors. Instead, the paper focuses on local woodland as an exogenous determinant of fencing availability and the cost of securing farmland.

roughly 4% woodland for each farm to acquire 5–10 acres of woodland. Based on this calculation, counties are assigned to the following three woodland categories: low (0–4%), medium (4–8%), and high (8–12%). The designated "low" counties roughly represent those most constrained by timber scarcities, while "medium" counties could have partially adjusted with this landholding pattern and then have been less affected along with "high" counties. The exact cutoffs for these categories are not relevant for the results; rather the continuous estimates will be evaluated at three corresponding benchmark levels (0%, 6%, 12%) in order to assist in interpreting the estimated magnitudes.

I.B The Arrival of Cheap Barbed Wire Fences, 1880 to 1900

Crude versions of enhanced wires were patented as early as 1867, but the most practical and ultimately successful design for barbed wire was patented in 1874 by Glidden, a farmer in DeKalb, Illinois. Glidden's design, which featured two twisted strands of wire that held metal barbs in place, had three important characteristics: barbs prevented cattle from breaking the fence; twisted wires tolerated temperature changes; and the design was easy to manufacture. Glidden sold a half-stake in the patent for only a few hundred dollars to Ellwood, a hardware merchant in DeKalb, and the two started the first commercial production of barbed wire, producing a few thousand pounds per year by hand [Hayter].

Barbed wire was cheaper than wooden fencing, particularly in timber-scarce areas, and it had lower labor requirements.[8] Correspondence from Glidden and Ellwood in 1875 reflected the close relationship between local woodland and the demand for barbed wire: "where lumber is reportedly dearer, the wire would probably sell for more" [Webb p.310]. Given current prices, they did "not expect the wire to be much in demand where farmers can build brush and pole fences out of the growth on their own land" [Hayter].

In 1876, the country's largest plain wire manufacturer (Washburn & Moen) bought half of Glidden's business for $60,000 cash, plus royalties, and began the first large-scale production of barbed wire. By 1879, they had produced nine million pounds.[9] In contrast to Glidden's sale to Ellwood, Washburn & Moen's purchase showed an awareness of barbed

[8] In Iowa, wooden fences varied in total construction costs per rod from $0.91–$1.31 in 1871, while barbed wire fences cost $0.60 in 1874 and below $0.30 in 1885 [Bogue 1963b, p.8]. Other reports quote barbed wire fences as costing $0.75 per rod in Indiana in 1880, while hedge fences cost $0.90 per rod and were wasteful of the land [Primack 1977, p.73]. Primack [1977, p.82] estimates that a rod of barbed wire took 0.08, 0.06, and 0.04 days to construct in 1880, 1900, and 1910. The labor requirements for constructing wooden fences were constant throughout this period: 0.20, 0.34, and 0.40 days for board, post and rail, and Virginia rail.

[9] This process began in 1875 when Washburn & Moen, headquartered in Massachusetts, sent an agent to investigate unusually large orders from DeKalb, Illinois. They acquired barbed wire samples and contracted an expert machinist to design automatic machines for its production.

wire's potential. Even the initial level of demand was sufficient to ensure "enormous profits" [Webb, p.309].[10]

Newspaper advertisements began to appear in Kansas and Nebraska in 1878 and 1879 [Davis 1973, pp.133–134] and there was a series of public demonstrations in the early 1880s. Once the effectiveness of barbed wire was proved, "Glidden himself could hardly realize the magnitude of his business. One day he received an order for a hundred tons; 'he was dumbfounded and telegraphed to the purchaser asking if his order should not read one hundred pounds' " [Webb, p.312].

Table 1 provides statistics on the timing of barbed wire's introduction and its universal adoption. Panel A shows a sharp increase around 1880 in the annual production of barbed wire. Panel B shows the resulting transformation in regional fence stocks. Before 1880, fences were predominately made of wood. From 1870 to 1880, there were some small increases in wire fencing, including both smooth wire and barbed wire. After 1880, there were rapid increases in barbed wire fencing. Total fencing increased most in the Plains and Southwest regions where there were more timber-scarce areas. Wood fencing also initially increased, however, highlighting that it would be inappropriate to attribute all regional increases in fencing and economic activity to the introduction of barbed wire.

Even as the quality of barbed wire improved and consumers became increasingly aware of its effectiveness in the early 1880s, falling input costs and manufacturing improvements drove down prices: \$20 (1874), \$10 (1880), \$4.20 (1885), \$3.45 (1890), and \$1.80 (1897).[11] Panel C of Table 1 shows that all new fences constructed after 1900 were made of barbed wire, so further price declines or quality improvements would not have had a differential effect across counties with varying access to wooden fences. Thus, the differential effects of barbed wire on farmers' fencing costs were predominately from 1880 to 1900.[12]

The empirical approach presented here requires that the introduction of barbed wire fencing was exogenous, i.e., that its rapid rise around 1880 was not caused by the anticipated development of low-woodland areas. This assumption appears plausible for two main reasons. First, from a microeconomic perspective, the demand for fencing alternatives had already been high for decades and Glidden-Ellwood appear not to have anticipated the tremendous

[10] McFadden [1978] provides details on the development of these businesses, with the 1899 incorporation of the American Steel and Wire Company of New Jersey leading to the monopolization of the barbed wire industry.

[11] Prices are per hundred pounds [Webb p.310]. Hayter reports similar prices for 1874 and 1893.

[12] Even by 1890, new fence construction in much of the country was entirely of barbed wire, yet there was still some wooden fence construction in the Prairie and the Southwest. This likely reflects less-developed distribution networks, as well as ranchers' opposition to enclosure and fence-cutting wars that were resolved in the late 1880s [McCallum and McCallum 1965, pp.159–166; Webb, pp.312–316].

market demand for barbed wire. Second, from a more macroeconomic perspective, the necessary cheap steel was only becoming available around 1880.

Barbed wire's widespread commercial success was made possible by unrelated developments in the industrial steel sector. The production of strong rust-free barbed wire required steel, which became dramatically cheaper as the Bessemer-steel process became widely used (patented in England in 1855). Figure 1 shows prices for iron, steel, and barbed wire. Barbed wire's introduction and mass-production follows the sharp decline in steel prices in the 1870s.[13] Primack [1969] summarizes:

> Outcries about the burdens of fencing by agriculturists in the 1850 to 1880 period seem amply justified. A need was revealed and the problem was resolved, not by changing laws and institutions but rather by technological change. This solution had to wait for the development of cheap steel in the industrial sector. Then a solution was found in wire fencing, cheap in both money and labor costs. [p.289]

II Theoretical Framework

To provide these historical accounts a more formal theoretical structure for clarity and estimation purposes, consider a farmer in each county c and time period t choosing a level of investment I_{ct} and property rights enforcement R_{ct} to maximize profits. The farmer produces output $F(I_{ct}, q_{ct})$, where q_{ct} denotes the quality of the land or a composite of other characteristics. $F(\cdot,\cdot)$ is increasing in both arguments and $F_{12}(\cdot,\cdot) > 0$. Following Besley [1995], an expected percentage of output is lost in each period, $\tau(R_{ct}) \in [0,1]$, and it is decreasing in the level of property rights enforcement, $\tau'(R_{ct}) < 0$. Investment and property rights are each produced at some cost, $C_{ct}(I_{ct})$ and $C_{ct}(R_{ct})$. Thus, farmers choose I_{ct} and R_{ct} to maximize:

$$(1-\tau(R_{ct}))F(I_{ct}, q_{ct}) - C_{ct}(I_{ct}) - C_{ct}(R_{ct}). \tag{1}$$

An optimal interior solution satisfies two first-order constraints:

$$C'_{ct}(I_{ct}) = F_1(I_{ct}, q_{ct})(1-\tau(R_{ct})) \tag{2}$$

$$C'_{ct}(R_{ct}) = -\tau'(R_{ct})F(I_{ct}, q_{ct}). \tag{3}$$

[13] Previously discussed historical accounts provided additional price observations for barbed wire, indicated with X's, though pre-mass production prices are off the chart. Note that the 1899 increase in barbed wire prices coincides with the monopolization of the barbed wire industry, though the Spanish-American War may have contributed to the observed increases in prices for barbed wire, steel, and iron.

In equation (2), the marginal cost of investment is set equal to the amount of marginal return that the farmer expects to retain. In equation (3), the marginal cost of property rights is set equal to the marginal increase in retained total output. These equations generate three relationships of interest. First, the optimal choice of investment is increasing in the level of property rights because a greater proportion of the returns would be kept. Second, the optimal choice of property rights is increasing in the level of investment because there is an added incentive to keep the output. Third, higher land quality would directly increase both property rights and investment by raising total production and the marginal return to investment. The empirical identification problem is that an observed correlation between I_{ct} and R_{ct} could reflect more than one of these three effects.

It may be possible, however, to identify the direct effect of property rights on investment by examining the effect of changes in the marginal cost of producing property rights. Equation (2) defines the optimal choice of investment, $I^*_{ct}(R^*_{ct}, q_{ct})$, and inserting that function into equation (3) defines $R^*_{ct}(q_{ct}, C'_{ct}(R^*_{ct})$. Given some equilibrium marginal cost P_{ct} of establishing property rights, it follows that $\frac{dI^*}{dP} = \frac{\partial I^*}{\partial R^*} \cdot \frac{\partial R^*}{\partial P}$. Thus, an estimate of $\frac{dI^*}{dP}$ would identify $\frac{\partial I^*}{\partial R^*}$ up to some negative term, $\frac{\partial R^*}{\partial P}$. Empirical analyses rarely have a natural or comparable unit of measurement for property rights, in which case a "reduced form" estimate of $\frac{dI^*}{dP}$ is as informative about the underlying causal relationship $\frac{\partial I^*}{\partial R^*}$ as if divided by a "first-stage" estimate of $\frac{\partial R^*}{\partial P}$.

To relate the marginal cost of producing property rights to the introduction of barbed wire, assume further that property rights are produced through the use of some combination of timber and barbed wire, $R_{ct} = R(T_{ct}, B_{ct})$. The price of barbed wire (p^B_t) is assumed to be decreasing over time, but constant across counties.[14] The price of timber in each county (p^T_c) is assumed to be constant over time, but decreasing in the percentage of the county that is woodland, i.e., $p^T_c = g(W_c)$ and $g'(W_c) < 0$.[15] The cost of producing property rights is the minimum obtainable value from choosing B_{ct} and T_{ct} to minimize

$$p^B_t \cdot B_{ct} + p^T_c \cdot T_{ct}, \text{ subject to: } R_{ct}(T_{ct}, B_{ct}) = \overline{R}. \tag{4}$$

If timber fences are initially constructed and they are not a perfect complement to barbed wire, a decrease in the price of barbed wire that results in its construction would decrease the marginal cost of producing property rights more in counties with less woodland and

[14] While demand for barbed wire was higher in timber-scarce regions, the market for barbed wire became sufficiently competitive and spread throughout the country that differences in local prices would have been minimal.

[15] Local timber prices may have changed over time, at least in part due to barbed wire, but the subsequent universal adoption of barbed wire implies that changes in timber prices had little differential effect on fencing costs.

higher timber prices, i.e., $\frac{\partial^3 C}{\partial p^T \partial p^B \partial R} > 0$. Once timber fences were no longer constructed, further price declines would have no differential effect across counties with different woodland levels.[16] Thus, barbed wire would encourage higher levels of property rights protection in timber-scarce areas in the period from its widespread introduction to its universal adoption (1880–1900).

III Data and Summary Statistics

III.A Data Construction

The dataset is drawn from the United States Census of Agriculture and includes county-level data by decade from 1870 to 1920 [Gutmann 2005]. The analysis is restricted to Plains states for which data are available in every census from 1870 to 1920: counties in Minnesota, Iowa, Nebraska, Kansas, Texas, and Colorado. Data in these counties are first available in 1870 and data on land improvement are available through 1920. Some county boundaries changed over this period, and the data are adjusted to hold the 1870 geographical units constant (see Data Appendix).[17]

Figure 2 shows the sample counties, shaded to represent initial woodland levels that are held fixed in the empirical analysis.[18] Because the empirical analysis will include state-by-decade fixed effects, the relevant variation is mostly in Iowa, southern Minnesota, and the eastern parts of Kansas and Nebraska. Non-sample counties in these states are mainly excluded because of unavailable data in 1870 and 1880.

The empirical analysis focuses initially on two measures of farmers' land-use: the percent of county land that is in farms, including land for crops and livestock;[19] and the percent

[16] This case represents a corner solution to equation (4).

[17] Data starting in 1870 are not available for other Plains states, such as Oklahoma, South Dakota, and North Dakota. Partial data from states further East are available from other sources, but local variation in woodland had less influence on the availability of fencing materials and the remaining woodland would have been more likely to reflect differences in previous land development.

[18] Data are available for the number of acres of woodland in farms, so county woodland levels are defined as initial acres of woodland in farms per county acre. This is not ideal because low woodland may reflect low initial settlement. For this reason, initial woodland levels are calculated using 1880 data when settlement was higher. Because wooded areas in these counties were initially most desirable, it seems plausible that most county woodland would be reflected in this measure. The empirical results are similar when using 1870 woodland levels. Later woodland levels are potentially endogenous to changes in agricultural development, but these results are also similar.

[19] The definition of land in farms differs very slightly in some periods, but generally "describes the number of acres of land devoted to considerable nurseries, orchards and market-gardens, which are owned by separate parties, which are cultivated for pecuniary profit, and employ as much as the labor of one able-bodied workman during the year. To be included are wood-lots, sheep-pastures, and cleared land used for grazing, grass or tillage, or lying fallow. Those lands not included in this variable are cabbage and potato patches, family

of land in farms that is improved.[20] The percent of county land in farms represents the extensive margin, which mainly reflects farmers' expected returns to converting land from the public domain. The percent of farmland improved represents the intensive margin, which may reflect farmers' willingness to sink investments into the future productivity of that land. Improved land could be plowed for crops or otherwise prepared for livestock, but the definition appears to exclude land that is simply fenced.

In focusing on the improvement intensity of farmland, this paper is similar to most farm-level studies of property rights that analyze whether a given plot of farmland has been improved in some way. An increase in this measure may reflect that farmers substituted toward improvement-intensive activities, where profitability is typically more sensitive to expropriation risk.[21]

The data are available by decade, so there is limited flexibility in analyzing responses to the exact timing of barbed wire's introduction. Because the mass distribution of barbed wire was just beginning by 1880 and fencing stocks had yet to respond substantially, all 1880 county outcomes represent the end of the pre-barbed wire period.[22] Because new fence construction was entirely barbed wire by 1900, at the latest, 1900 marks the moment when barbed wire no longer had a differential effect.

III.B Summary Statistics

The average amount of woodland in the sample is 10%, but most counties have lower woodland levels: 39% have 0–4% woodland, 15% have 4–8% woodland, 11% have 8–12% woodland, and 35% have more than 12% woodland. At the lower, middle, and upper end of the first three categories, three benchmarks (0%, 6%, 12%) represent meaningful points in the distribution of woodland levels: 20% of the sample has less than 1% woodland; the median woodland level is 6%; and 12% is among the higher typical levels of woodland.

Over the entire sample region, counties with different woodland levels are not evenly balanced geographically. Thus, the main results all focus on specifications that include a full set of state-by-decade fixed effects. To account for geographic differences within states,

vegetable-gardens, ornamental lawns, irreclaimable marshes, and considerable bodies of water" [Gutmann 2005].

[20] The clearest definition of improved land is from the 1920 Census: "All land regularly tilled or mowed, land in pasture which has been cleared or tilled, land lying fallow, land in nurseries, gardens, vineyards, and orchards, and land occupied by farm buildings" [Gutmann 2005].

[21] If it were true that investment increased property rights but property rights did not encourage investment [Brasselle et al.], then the intensity of land improvement should decrease when barbed wire offered a cheaper alternative for protecting property rights.

[22] Land-use measures were reported for the Census year and productivity is imputed from production and acreage in the previous year.

I present results from specifications that also control for distance West, distance from St. Louis, or finer regional groupings.

Table 2 reports average county characteristics in 1880 for all sample counties and within the first three woodland categories. Prior to barbed wire's introduction, low-woodland counties tended to be larger but lagged behind in settlement, land value, and agricultural production. Less of the farmland in low-woodland counties was improved or used for crops. Low-woodland counties had somewhat less cropland in corn and more in hay, which is less susceptible to damage from livestock. Overall, crop choices are fairly balanced across the three categories, however, which somewhat mitigates concerns that crop-specific technology or price shocks could have large differential effects by woodland percentage.

Total fencing expenditures were lower in low-woodland counties, but were roughly 4% of the total output value across each woodland percentage group. Given higher per unit costs in low-woodland areas, this would suggest a lower intensity of fencing in those areas.[23] Medium-woodland county averages generally fall between those for low-woodland and high-woodland counties, but are much closer to the latter.

IV Measurement Framework

IV.A Estimation Setup: A Discrete Example

The estimation strategy is most easily described in a discrete example with two county types and two time periods. Assume that farmers in low-woodland counties with $W_c \in (0, 0.04)$ have a high timber price p_H^T, while farmers in medium-woodland counties with $W_c \in (0.04, 0.08)$ have a medium timber price p_M^T. Furthermore, the price of barbed wire is infinite in the first time period and is p^B in the second time period, with $p^B < p_H^T$. A potential estimator for the effect on the production outcome, Y, from a decrease in the cost of property rights protection is then:

$$(\widehat{Y}_{c=L,t=2} - \widehat{Y}_{c=L,t=1}) - (\widehat{Y}_{c=M,t=2} - \widehat{Y}_{c=M,t=1}). \tag{5}$$

For this difference-in-difference estimator to be unbiased, farmers' production decisions must depend additively on unobserved factors, such that:

$$Y_{ct}^*(R_{ct}^*, q_{ct}) = F(R_{ct}^*) + \gamma_t + \mu_c + \epsilon_{ct} \tag{6}$$

[23] Data on fencing expenditures was only collected in 1880.

and $\mathrm{E}[\epsilon_{ct}] = 0$. The assumption is that farmers in counties with different amounts of woodland would have, on average, made the same production changes if not for an increase in property rights protection due to barbed wire's introduction. The analysis in section II was substantially simplified by excluding some variables from each function, such as in separating the costs of property rights and investment, but any potential for estimation bias can be thought of as a violation of this assumption.

It is impossible to test this identification assumption directly, but additional time periods and greater variation in county types can be used to form indirect tests. First, the same estimator for two periods before the introduction of barbed wire tests whether investment decisions in these two types of counties had been trending similarly. Second, the same estimator for two periods after the universal adoption of barbed wire would test for other sources of differences, given that further price declines would not have differential effects. Any differential trends before barbed wire's introduction or after its universal adoption may or may not have occurred between those periods, but the results can be tested for robustness to each scenario.

A third specification test is based on the presumption that local wooden fencing costs depended on local woodland in a non-linear and convex manner. Once settlers were able to acquire the needed acres of woodland, as described by Bogue, one would expect further woodland to have made less difference in the cost of fencing materials.[24] If high-woodland counties with $W_c \in (0.08, 0.12)$ had a low timber price p_L^T that was much closer to p_M^T than was p_H^T, then the estimate from equation (5) should be greater than a similar estimate comparing medium- and high-woodland counties. This test is performed by the difference-in-difference-in-difference estimator:

$$
\begin{aligned}
(7) \qquad [(\widehat{I}_{c=L,t=2} - \widehat{I}_{c=L,t=1}) \;&-\; (\widehat{I}_{c=M,t=2} - \widehat{I}_{c=M,t=1})] \\
&-\; [(\widehat{I}_{c=M,t=2} - \widehat{I}_{c=M,t=1}) - (\widehat{I}_{c=H,t=2} - \widehat{I}_{c=H,t=1})].
\end{aligned}
$$

The intuition for this analysis can be seen in a plot of the average improvement intensity of farmland, broken out by decade and county woodland group. In Figure 3, medium- and high-woodland counties are shown to have changed similarly over the entire period. Low-woodland counties also changed similarly, except for large relative increases during the period of adjustment to barbed wire (1880–1900). This analysis of woodland categories is intended only to illustrate the intuition for the methodology, whereas the later empirical analysis

[24] In particular, as more wooded areas become scattered throughout a county, the distance to the nearest plot would tend to fall at a decreasing rate. Also, it was increasingly difficult to adjust the type of wooden fence to substitute away from using as much timber [Primack 1977, p.70].

examines continuous variation in woodland levels and provides a more thorough treatment of potential confounding factors.

IV.B Main Estimating Equation

For the main empirical analysis, county-level production outcomes are first-differenced to control for any county characteristics that are constant over time.[25] State-by-decade fixed effects α_{st} are included to control for state-specific shocks that have an equal effect on all counties in the state. To allow flexibly for changes over time to be correlated with county woodland levels, included for each decade is a fourth-degree polynomial function of a county's woodland level in 1880. For each production outcome, the estimated equation is:

$$Y_{ct} - Y_{c(t-1)} = \alpha_{st} + \sum_{t=2}^{T}(\beta_{1t}W_c + \beta_{2t}W_c^2 + \beta_{3t}W_c^3 + \beta_{4t}W_c^4) + \epsilon_{ct}. \tag{8}$$

The estimated β's summarize how changes over each decade in production outcome Y varied by county woodland level W.

V Estimation Results

V.A Land Improvement and Land Settlement

Equation (8) is estimated for the fraction of farmland improved in each county. The full set of estimated β's is prohibitively difficult to interpret numerically, but the results can be seen in Figure 4.[26] The solid line reports the estimated change over the indicated time period for a county with that woodland level, relative to the estimated change for a county with 0% woodland.[27] The two dashed lines report 95% confidence intervals around the estimates.

[25] Estimating equation (8) with county fixed effects instead yields identical estimates, but their standard errors tend to be higher by 8–10% because the untransformed error terms are closer to being a random walk than serially uncorrelated. To see this, consider that if equation (8) were estimated for each time period without first-differencing Y, changes over time in the estimated coefficients would still not depend on fixed county characteristics. That is, whether some county with high woodland always had a high outcome level would not influence estimated changes in the dependence of that outcome on woodland. Thus, adding county fixed effects to the regression does not affect differences in the estimated coefficients across periods, though it does increase their precision by reducing unexplained variation. Those exact differences in estimated coefficients are obtained by first-differencing Y and, in this case, it further reduces the unexplained variation in Y.

[26] For conciseness, the displayed results are limited to woodland levels less than 0.12 or 12%, though equation (8) is estimated for the entire distribution of woodland levels.

[27] Due to the inclusion of state-decade fixed effects, the estimated results are only interpretable relative to some defined benchmark woodland level.

From 1880 to 1890 and 1890 to 1900, counties with the least woodland made large relative gains in the improvement intensity of farmland. By contrast, there were no substantial relative changes at low woodland levels before 1880, after 1900, or at higher woodland levels from 1880 to 1900.

In order to display and interpret these results numerically, the estimated changes are evaluated at representative woodland levels: the most affected low-woodland county, with 0% woodland; the average medium-woodland county, with 6% woodland; and the least affected high-woodland county, with 12% woodland. The predicted change for a county with 0% woodland relative to the predicted change for a county with 6% woodland is analagous to a difference-in-difference estimate for counties with those exact woodland levels, but the parameterized regression uses available data from counties with similar woodland levels.

Columns 1 and 2 of Table 3 report the evaluated numerical results from estimating equation (8) for the fraction of farmland improved. In each decade, the coefficient in column 1 corresponds exactly to the difference in the graphed solid line at 0 and 0.06 in Figure 4.

The estimated magnitude is interpreted as follows: the top coefficient in column 1 reports that acres of improved land per acre of farmland increased from 1870 to 1880, on average, 1.5 percentage points more in a county with 0% woodland than in a county with 6% woodland.[28] From the same regression, column 2 reports the predicted change for a county with 6% woodland relative to a county with 12% woodland. In parentheses is the standard error for each coefficient, corrected for heteroskedasticity and clustered at the county level. In brackets is the t-statistic of the absolute difference between the coefficients comparing 0% vs. 6% and 6% vs. 12%. For example, the coefficients in the first row of columns 1 and 2 are not statistically different with a t-statistic of 0.22.

From 1880 to 1900, the improvement intensity of farmland increased by a statistically significant and substantial 19 percentage points in counties with 0% woodland relative to counties with 6% woodland (Table 3, column 1). Recall that from its widespread introduction in 1880 to its universal adoption by 1900, barbed wire most increased the availability of fencing in counties with the least woodland. By contrast, there are few substantial estimated changes before 1880, after 1900, or between higher woodland levels from 1880 to 1900. This result is clear in Figure 5, which plots the estimated cumulative changes after 1870.

It lends credibility to the results that there are few substantial changes apart from the estimated increases at low woodland levels from 1880 to 1900. Depending on assumptions about other agricultural changes, the reported relative changes from 1880 to 1900 could themselves be differenced across and/or within time periods. If the relative trends from

[28] That is, a county with 0% woodland that had 50% of its farmland improved would have, in expectation, caught up to a county with 6% woodland that initially had 51.5% of its farmland improved.

1870 to 1880 would have continued, the adjusted increase from 1880 to 1900 would be 16 percentage points for a county with 0% woodland relative to a county with 6% woodland.[29] If estimated changes at higher woodland levels (6% vs. 12%) reflect other contemporaneous changes that were linearly correlated with woodland levels, the adjusted change from 1880 to 1900 would be 17 percentage points.[30] Under both assumptions, the adjusted change from 1880 to 1900 would again be 19 percentage points.[31]

The increase in the improvement intensity of farmland came despite substantial amounts of land being converted from the public domain to private farmland. Columns 3 and 4 of Table 3 report the results from estimating equation (8) for the fraction of county land in farms. In these baseline estimates, settlement increased by 26 percentage points from 1880 to 1900 in counties with 0% woodland relative to counties with 6% woodland. There were also some relative increases from 1870 to 1880, however, and from 1880 to 1900 counties with 6% woodland made substantial relative gains on counties with 12% woodland. These estimated changes in settlement are quite large, perhaps implausibly so, and are indeed more sensitive to robustness checks than are the estimated changes in improvement intensity.

Robustness Tests

Table 4 presents the results from specification tests that include control variables meant to capture other changes in Western agricultural development. The results are condensed to show only the estimated changes from 1880 to 1890 and from 1890 to 1900 in counties with 0% woodland relative to counties with 6% woodland. For completeness, the full results for Table 4 are shown in Appendix Tables 1, 2, and 3. As a basis for comparison, column 1 of Table 4 reports the corresponding estimates from Table 3.

(i) Westward Development. One concern is that the baseline estimates could be confounded with an independent push toward increased westward development. From Figure 2, counties with less woodland tend to be further West than counties with more woodland, even within states.

To address this concern, equation (8) is estimated with a control variable for the distance West of each county center, interacted with each decade.[32] Column 2 of Table 4 reports the

[29] This 16 percentage point change reflects the increase from 1880 to 1890, plus the increase from 1890 to 1900, minus two times the increase from 1870 to 1880.

[30] This 17 percentage point change reflects the increase from 1880 to 1900 for a county with 0% woodland relative to a county with 6% woodland, minus the change from 1880 to 1900 for a county with 6% woodland relative to a county with 12% woodland.

[31] This 19 percentage point change reflects the increase from 1880 to 1900 for a county with 0% woodland relative to a county with 6% woodland (minus two times the increase from 1870 to 1880), minus the change from 1880 to 1900 for a county with 6% woodland relative to a county with 12% woodland (minus two times the increase from 1870 to 1880).

[32] To be precise, "distance West" refers to the x-coordinate of the county centroid on an equal area map projection of the United States.

primary results from this specification, while the full results are reported in columns 2a–2d of Appendix Table 1.

For the improvement intensity of farmland (Panel A), the baseline results are quite robust to controlling for Westward development in each time period. For the amount of farmland (Panel B), the estimated magnitudes fall by roughly half. Indeed, there are substantial Westward settlement effects in each decade from 1870 to 1900 (not shown in the tables). By contrast, there is very little Westward change in the improvement intensity of farmland from 1880 to 1900, though some moderate insignificant increases from 1870 to 1880.

The "Westward development" of the United States may not have been just a move West, but also an expansion from the middle. To allow for this possibility, an additional control variable is included for the distance of each county center to St. Louis (the "Gateway to the West"), interacted with each decade. Column 3 of Table 4 reports these results, which are similar to controlling only for distance West. Note that for both specifications, Appendix Table 1 reports little substantive change in the improvement intensity of farmland before 1880, after 1900, or between higher woodland levels from 1880 to 1900.

Linear distance coefficients are easiest to interpret, but these robustness results are similar when controlling for non-linear changes in Westward development (distance West squared, distance West cubed, distance from St. Louis squared, distance from St. Louis cubed).[33] In these specifications, Colorado and Texas are contributing to the estimation of the distance controls even though these states contribute little to the estimation of the woodland variables. These robustness results are also similar when excluding sample counties in Colorado and Texas, so that the distance controls and woodland variables are estimated primarily on the same sample of counties.

Overall, it does not seem that Westward development accounted for the estimated increases in land improvement from 1880 to 1900 in counties with the least woodland. By contrast, Westward development may account for a substantial portion of the baseline estimated increase in total farmland.

(ii) Regional Development. Another concern is that low-woodland counties may be in different resource regions or soil groups, where they could be affected differently by changes in product prices and technologies [see, e.g., Olmstead and Rhode 2002]. To explore this possibility, the county boundary files were merged with two maps indicating land resource regions and subregions, and great soil groups.[34] Separate variables are defined for the percent

[33]Note that whenever I refer to results being similar, that refers both to the coefficients and their precision.

[34]Land resource regions and subregions were mapped in the 1966 U.S. Department of Agriculture Handbook 296. Soil groups were mapped by the U.S. Soil Conservation Service in 1951 and were retained in the National Archives Record Group 114, item 148. These maps were scanned, traced in GIS software, and digitally merged to 1870 county boundaries.

of each county area falling into each region, subregion, or soil group. Within the sample of counties, there are 11 regions, 43 subregions, and 19 soil groups. The soil groups appear also to capture general differences in climate and other environmental factors; in particular, one soil group effectively corresponds to the presence of a major river.

To allow for differential growth patterns across each region, equation (8) is estimated with an additional quadratic time trend for each of the 11 regions.[35] The primary results are reported in column 4 of Table 4. Similarly, columns 5 and 6 of Table 4 report the primary results when controlling for quadratic time trends for each of the 43 subregions and 19 soil groups, respectively.

For the improvement intensity of farmland, the results are fairly robust to each of these specifications. The estimated magnitudes decline most when controlling for quadratic time trends for each of the 43 subregions, but by less than one standard error. The estimates are substantively similar to the baseline, remain statistically significant, and are statistically greater than the estimates at higher woodland levels. Appendix Table 2 reports the full results, which are also similar. For the total amount of farmland, the estimated increases are less robust but still substantial and statistically significant.

Instead of including quadratic time trends, it is possible to include a decade fixed effect for each region, subregion, or soil group. Although demanding of the data, especially for the 43 subregions, the results are mostly consistent with the baseline results.[36]

In summary, it appears that the baseline results cannot be explained by broad differences in the regional balance among counties with different levels of woodland. Estimated changes in improvement intensity are robust to finer regional controls, while changes in total farmland appear to be more sensitive.

(iii) Convergence in Agricultural Development. Another concern is that the baseline estimates could be confounded with convergence in agricultural development, whereby counties with lower initial levels of land improvement or settlement may have naturally experienced higher subsequent growth. Counties with little woodland initially lagged behind counties with more woodland, though there were only small relative increases from 1870 to 1880 when these initial differences were greatest.

[35] To be precise, the first-differenced analog of a quadratic time trend is included.

[36] When including region-by-decade controls, the results are similar. When including soil-by-decade controls, the changes from 1880 to 1900 are similar but there is also a substantial increase in improvement intensity from 1870 to 1880. In contrast to the 1880 to 1900 increases, however, this 1870 to 1880 increase is not statistically greater than the increase at higher woodland levels. When including subregion-by-decade controls, improvement intensity has similar increases from 1890 to 1900 but only a small insignificant increase from 1880 to 1890. There is a moderate increase from 1870 to 1880, but not statistically greater than at higher woodland levels.

To address this concern, equation (8) is estimated with an additional fourth-degree polynomial function of the county's fixed 1870 outcome level, interacted with each decade.[37] This effectively restricts the analysis to counties with different woodland levels but similar outcome levels in 1870.[38] The primary results are reported in column 7 of Table 4, while the full results are in Appendix Table 3.

For the improvement intensity of farmland, the estimated increases from 1880 to 1900 are approximately three-fourths their original size, statistically significant, and statistically greater than changes at higher woodland levels (Table 4, column 7, Panel A). These increases reverse the substantial relative decline before barbed wire's introduction and smaller but statistically significant declines after barbed wire's universal adoption (Appendix Table 3, column 1).[39] For the amount of total farmland, by contrast, the estimates are substantially smaller and now statistically insignificant. These increases would only seem substantial if the negative pre-trend from 1870 to 1880 were subtracted from the subsequent changes.

Overall, these estimates are consistent with previous findings that counties with the least woodland experienced relative increases in land improvement from 1880 to 1900. However, it casts some doubt on whether previously estimated increases in farmland settlement should indeed be attributed to these counties' lower levels of woodland.

(iv) Functional Form and the Exclusion of State-Decade F.E. The baseline estimates are not sensitive to using different polynomial functional forms to model the dependence of agricultural outcomes on woodland. As long as the functional form is sufficiently flexible to capture the basic non-linearity appearing in figure 4, the evaluated effects at benchmark woodland levels are similar.

Figure 6 displays the raw data underlying the main results, stripping away the regression methodology. For each sample county, the change from 1880 to 1900 in the improvement intensity of farmland is plotted against that county's 1880 woodland level. Counties with

[37]The estimates are similar for alternative polynomial functions of the initial outcome level, but it is appealing to use the same function for both the initial outcome level and woodland level.

[38]This robustness check has some statistical appeal, but it is less motivated by economic theory. Two counties with the same initial outcome level and different woodland levels might be expected to differ along important dimensions, in order for farmers in the lower woodland county to be compensated for the lack of woodland. For example, prior to barbed wire, farmers might only improve as much land in a county with little woodland as in a county with more woodland if the county with little woodland had higher quality soil to justify the higher costs of fencing. The ideal empirical analysis would control for all important differences in county characteristics, but this partial statistical correction may be counterproductive in identifying counties with different woodland levels that were otherwise similar.

[39]For the improvement intensity of farmland, it is worth noting the results when controlling for the initial outcome level and implementing the other specification changes discussed above. The results are generally similar to those reported in Appendix Table 3, with the notable exception that the estimated increase from 1880 to 1890 varies between zero and its original baseline estimate.

the least woodland tended to experience large increases from 1880 to 1900, while counties with more woodland were relatively unchanged.

The estimated changes from 1880 to 1900 decrease by roughly 20–40% when the state-by-decade fixed effects are replaced with decade fixed effects, which might be surprising if one expected movement to low-woodland states in response to lower fencing costs. This is entirely driven by Colorado, however, which is far from most previous settlement and has low average woodland. When Colorado is dropped from the sample, the baseline results are similar and the estimates increase 5–20% when the state-by-decade fixed effects are replaced with decade fixed effects.

Summary of Robustness Tests

Throughout the different specifications discussed in these subsections, the baseline results are fairly robust for the estimated changes in the improvement intensity of farmland. Counties with the least woodland generally experienced large relative increases in land improvement from 1880 to 1900. Similar increases did not occur before 1880, after 1900, and did not occur at higher woodland levels from 1880 to 1900. Changes in total farmland are less robust to alternative specifications, in particular, controlling for Westward settlement and convergence in settlement.

V.B Crop Productivity and Crop Choice

All cropland is "improved" by definition, so the previous estimates do not address whether farmers adjusted crop production along the intensive margin. Given the secure protection of property rights, the optimal allocation of land need not favor crops over livestock, as Coase discusses. In the absence of secure property rights, however, the returns to certain crops would likely be more sensitive to the threat of uncompensated damage by others' livestock. Farmers might reduce investments in crop growing, harvest produce early, or otherwise adjust production in ways that contribute to sub-optimal productivity. This section presents results on changes in crop productivity, as a summary measure of all unobserved adjustments in crop production.

Beginning in 1880, county-level data are available on the total production and acreage for each of the six main crops on the Plains (corn, wheat, hay, oats, barley, rye).[40] Productivity for each crop p in each county c is defined as its total production divided by the total acreage devoted to that crop. For ease of interpretation, productivity in each decade is normalized

[40] Cotton is excluded from the analysis, as data are only available for Texas and the boll weevil blight severely impacted cotton productivity. Using the same technique as before, the data are adjusted to maintain the 1880 geographical boundaries.

by its value in 1880.[41] Measurement error creates some extreme outliers, so the upper and lower centiles of the normalized productivity distribution are dropped.[42]

To implement the analysis, equation (8) is slightly modified: state-decade fixed effects are replaced with crop-state-decade fixed effects, and the equation is first-differenced by crop-county. For this baseline analysis, data from all crops are stacked so that the change in productivity across woodland levels is constrained to be the same for all crops:

$$\frac{Y_{pct} - Y_{pc(t-1)}}{Y_{pc1880}} = \alpha_{pst} + \sum_{t=2}^{T}(\beta_{1t}W_c + \beta_{2t}W_c^2 + \beta_{3t}W_c^3 + \beta_{4t}W_c^4) + \epsilon_{pct}. \tag{9}$$

Columns 1 and 2 of Table 5 present baseline results, evaluated at the same representative woodland levels as before. From 1880 to 1890, average productivity across all six crops increased 23.4% more in a county with 0% woodland than in a county with 6% woodland.[43] Over this same period, crop productivity increased by only 1.8% more in a county with 6% woodland than in a county with 12% woodland; a statistically smaller change with a t-statistic of 3.31. To give a sense of the large magnitude of this 23.4% increase, total US crop production increased by roughly 1.7% annually from 1880 to 1920. US crop yields increased by only 0.23% annually from 1880 to 1920, though this is likely to understate productivity growth due to compositional changes in cropland.[44]

In contrast to previous land-use results, these estimated increases did not continue through the 1890s: crop productivity decreased by a statistically insignificant 4.6% from 1890 to 1900, leaving it 18.8% higher than in 1880. One interpretation is that the more-immediate reaction to barbed wire's availability was to secure cropland. Even as barbed wire became more widely used from 1890 to 1900, productivity would only increase if cropland became more secure which, in turn, could only happen if farmers had continued to cultivate substantial amounts of land without fences after 1890.

To explore the timing of these effects, equation (8) is estimated for the fraction of farmland planted in crops. Columns 3 and 4 of Table 5 report the results. From 1880 to 1890,

[41] This gives similar results to analyzing changes in the log of productivity, but the estimates are always relative to productivity in 1880.

[42] This drops values less than 0.36 or greater than 6.4. The results are not sensitive to these cutoffs, as long as the clearly extreme observations are dropped.

[43] An alternative specification would weight observations by the number of county acres devoted to that crop in 1880. This specification yields similar estimates, with the coefficient increasing from 23.4% to 26.9%. The standard error changes only minimally, from 5.7% to 5.8%. Without differences in efficiency motivating the weighting, it seems more transparent to focus simply on the unweighted results.

[44] These numbers were estimated using indexes of total US crop production and yield per acre harvested for twelve major crops (NBER Macrohistory Database, files a01005aa and a01297). The production index was computed by weighting the production of each commodity by average farm prices from 1910-1914, and both indexes are then defined relative to a base year. To obtain the average annual increase, the natural log of each index is regressed on a time trend from 1880 to 1920.

the allocation of farmland to crops increased by 12 percentage points in a county with 0% woodland relative to a county with 6% woodland, with little change between higher woodland levels. From 1890 to 1900, there was little change in the allocation of farmland to crops.

It appears that farmers' initial reaction (1880–1890) was mainly to expand crop production, both in terms of a greater intensity of cultivation and a greater fraction of farmland allocated to crops. Then, from 1890 to 1900, increases in the improvement intensity of farmland were driven mainly by improvements to pasture land or land otherwise not currently planted in crops.

Extensions and Robustness Tests

(i) At-Risk Crops vs. Hay. A natural extension of these results exploits crop-level differences in vulnerability to livestock damage. While cattle eat hay (various grasses), fields of hay are more resistant to livestock damage before being harvested. Fields of hay can even be intended for grazing at certain times of the year. The other crops (corn, wheat, oats, barley, rye) would yield substantially less grain if they were trampled, so it would be more critical to protect them from others' livestock.[45]

Restricting the analysis to these five crops more at-risk of damage, columns 5–6 report the results from estimating equation (9). From 1880 to 1890, productivity increased by 29% in counties with the least woodland and the results are otherwise similar. By contrast, there was no change in hay productivity from 1880 to 1890 (not shown). Columns 7–8 report the results from estimating equation (8) for the fraction of cropland allocated to these more at-risk crops. Indeed, from 1880 to 1890, more cropland became allocated to these five crops instead of to hay.

(ii) Cropland Composition. Estimated changes in productivity could be confounded by compositional changes in cropland, to the extent that farmland differs in productivity within a county. This seems unlikely, however, to explain the observed large increases in productivity from 1880 to 1890. The typical response would be to expand production into otherwise unprofitable and lower quality land. This would lead the empirical analysis to understate the increase in productivity for a fixed plot of land. If production expanded into less-wooded areas of counties that were inherently more productive, it could contribute to the observed increases in productivity. This is likely of little substantive importance, though, as very little of the land in farms was actually wooded: in 1880, less than 6% of the land in farms was wooded in 76% of the counties with less than 6% woodland. The settlement

[45]Even controlled grazing would typically lower grain yields by 25–79% [Smith et al. 2004]. Wheat, oats, barley, and rye could be grown for hay instead of for grain, but would then be managed differently. The Census defines data for these crops as that which is grown for grain.

of new farmland is sometimes associated with short-term productivity benefits, but these increases in productivity mostly persisted.

(iii) Regional Development. In an attempt to account for potential region-specific technological improvements, this subsection briefly reports on robustness checks using the previously defined land resource regions, subregions, and soil groups. The estimated increases in productivity from 1880 to 1890 are robust to the inclusion of crop-specific quadratic time trends by region, subregion, or soil group.[46] The estimated increase in cropland intensity from 1880 to 1890 is robust to including quadratic time trends by region or soil group; by subregion, the increase is reduced by one-third but is statistically significant.[47]

(iv) Westward Development. Another potential concern is that there could be a Westward trend associated with cropland management. The estimated increase in cropland intensity from 1880 to 1890 is robust to controlling for distance West and distance from St. Louis in each decade, with or without the inclusion of Colorado and Texas. Recall that excluding Colorado and Texas forces the distance control variables to be estimated on the same set of counties that mostly identify the changes associated with woodland levels.

When excluding Colorado and Texas, the crop productivity results are robust to including the distance controls in each decade. The productivity results are sensitive, however, to these control variables when including Colorado and Texas: there is no 1880 to 1890 increase and productivity is quite variable in later periods. Given this difference in results, it seems appropriate to place more emphasis on the results when the woodland variables of interest and the distance control variables are primarily estimated on the same sample of observations.

Summary of Extensions and Robustness Tests

Counties with the least woodland appear to experience a substantial increase in crop productivity following the introduction of barbed wire. These productivity increases are concentrated among those crops most at-risk without fencing. Farmland was increasingly allocated to crops and, in particular, more at-risk crops. These results are mostly robust to the inclusion of regional control variables, but there are some notable exceptions: the inclusion of crop-subregion-decade fixed effects, and controlling for distance West and from St. Louis when the sample includes Colorado and Texas.

[46] When allowing for crop-decade fixed effects by region or soil group, the 1880 to 1890 increase is roughly half its original size and marginally statistically significant. Productivity across woodland levels is also less stable in subsequent periods. Notably, the results are not robust to controlling for crop-decade-subregion fixed effects, though that is quite demanding of the data.

[47] These results are also similar when replacing the quadratic trends with decade fixed effects by region, soil group, or subregion.

V.C Land Value

One can gauge the monetary value of barbed wire to farmers, by estimating the resulting change in land values. While land improvement and crop productivity may have increased substantially, these changes would have come at considerable cost to farmers. Changes in land values may capitalize the net benefit to agricultural production, if land markets were well-functioning. In this era, there was a large amount of land speculation and taxes were paid on the value of land [Gates 1973], so it appears plausible that farmers would have some sense of their lands' value when asked by Census enumerators.[48]

In each period, "land value" data are available for the combined value of farmland, buildings, and fences.[49] However, land appears to have been the largest component of this measure. In 1900 and 1910, the value of buildings averaged between 13% and 17% of the total for low-, medium-, and high-woodland counties. Fence stock values are unknown, but the costs of building and repairing fences in 1879 averaged 1% of the total value of land, buildings, and fences.

The natural log of land value is analyzed because technology, prices, and property rights are typically modeled to have multiplicative effects on the total value of production. Additive shocks would have a larger percentage effect in areas with low initial levels, so equation (8) is estimated controlling for differences in initial land values.[50] For example, given similar large increases in settlement across all counties from 1870 to 1880, land values would increase by a larger percentage in low-woodland counties that averaged lower initial land values.

Table 6 presents the results. Land values increased substantially from 1880 to 1900 in counties with 0% woodland relative 6% woodland, though only the change from 1880 to 1890 was statistically greater than the relative increases at higher woodland levels. By contrast, before 1880 and after 1900, there were either relative declines or small changes.

Focusing on the more robust increase from 1880 to 1890, this represents an economically substantial change. The 1880 to 1890 change of 0.406 log points is an increase of 50% above 1880 levels. This is approximately 1.7 times the 1880 value of all agricultural products in low-woodland counties. If we assume that barbed wire had no effect on counties with more than 6% woodland, these estimates imply that the overall monetary benefit of barbed wire to

[48] If farmers were very quick to update reported valuations, they may have partly anticipated the arrival of barbed wire by the 1880 Census. Unsettled land would still have been valued at zero, though, so much of the response would still not occur until newly desirable lands were settled.

[49] Additional data are obtained from Haines and ICPSR [2005].

[50] Included is an additional fourth-degree polynomial function of log land value in 1870, interacted with each decade. Without these additional controls, the estimates fit a clear pattern of economic convergence for both low- and medium-woodland counties: there are large relative increases from 1870 to 1880 that then decline over time. This specification is subject to the same concerns as before, but it adjusts for this otherwise dominant pattern of convergence.

farmers in sample counties was $103 million with a standard error of $32 million, in 1880 US dollars.[51] This is approximately 0.9% of total US GDP in 1880 [Historical Statistics 2006]. Throughout various robustness checks, this total estimated value ranges from $67 million to $139 million and is always statistically significant.[52]

VI Analysis of Potential Confounding Factors

VI.A Other Shocks Correlated with Woodland Levels

The empirical results would not identify the effects of barbed wire to the extent that other factors caused counties with less woodland to change differently from 1880 to 1900. As a complement to the previous robustness checks, this section provides qualitative evidence on other potential sources of differential changes.

One concern is that a shock to the timber market might have differentially affected farming in counties with different amounts of woodland.[53] However, the timber market in all sample counties was a very small sector of the economy: in 1870, forest products averaged only 0.6% of the total value of all farm products. These counties had such little woodland that any changes in its use would have had limited effects on overall land-use. Land improvement in the Plains did not generally involve clearing woodland because there was already so much open land.

Two other potential confounding factors were the various land acts and the railroads. Due to the lack of fencing materials, however, the 1862 "homestead law was a snare and a delusion" [Webb, p.286]. Subsequent revisionary land acts were generally ill-suited to the region, poorly enforced, and are thought to have played little role in the successful settlement of the Plains [Webb, pp.424–431].[54] Furthermore, most railroad construction in the sample region had been completed by 1873, when the railroad industry faced a panic due to excessive construction and low usage on the Plains.[55] Webb summarizes:

[51] Sixty-four counties had between 0% and 1% woodland, with an average of 0.42% woodland and $1.7 million of land value in 1880. For an average county with 0.42% woodland, land values increased by an estimated 43% relative to a county with 6% woodland. This gives an overall effect of approximately $47 million ($64 \times \$1.7\text{m} \times 43\%$). Summing across the woodland bins (1–2%, 2–3%, 3–4%, 4–5%, 5–6%) yields an estimate of $103 million with a standard error of $32 million.

[52] These include controlling for quadratic time trends or decade fixed effects by region, subregion, or soil group; distance West by decade; distance West and distance from St. Louis by decade.

[53] Indeed, barbed wire may have lowered demand for timber by replacing wooden fences. Barbed wire could also have increased demand for timber because of increases in settlement. Farmers would still have required some timber for buildings and fence posts.

[54] See Libecap [2006] for an analysis of land allocation policies in these and more western regions.

[55] The construction of spur lines is quite endogenous to settlement, so it would be difficult to interpret a formal analysis controlling for spur construction even if that data were available.

> We have noted that the agricultural frontier came to a standstill about 1850, and that for a generation it made but little advance into the sub-humid region of the Great Plains. It was barbed wire and not the railroads or the homestead law that made it possible for farmers to resume, or at least accelerate, their march across the prairies and onto the Plains. [pp.316–317]

Other potential confounding factors are changes in technology. The post-Civil War period saw many technological improvements and mechanization began to increase in the 1900s, but the rise of barbed wire from 1880 to 1900 appears to coincide with a notable lack of other major advances [Rasmussen 1962, Primack 1977]. Olmstead and Rhode discuss biological innovations in wheat, but the 1880 to 1890 period does not stand out. Windmills were used increasingly during this period to obtain water in areas that were often also low in woodland. Knowledge of windmills had existed for a long time, however, and modern industrialized production was widespread by the 1860s. Webb concludes that the increased use of windmills was caused by the introduction of barbed wire and increased cultivation of water-scarce areas [Webb, p.341, p.348]. For the sample region, note also that most conflict with Native Americans had ended by this time.

VI.B Evidence on Potential Other Effects of Barbed Wire

The empirical results would not identify only the effects of property rights if barbed wire had important effects through other channels. Even if land were perfectly secure and there was no threat of uncompensated damage by others' livestock, cheaper fencing might have some effect on agricultural production. If fencing allowed greater control over cattle feeding and breeding, it might increase the productivity of land for raising livestock. By enabling the joint production of cattle and crops, fencing might also improve production possibilities.[56]

If these effects were substantively important, then barbed wire should lead to an increase in cattle production and/or the joint production of cattle and crops. The security of property rights might also affect these outcomes, but these tests are designed to address whether non-property right effects could be driving the earlier results.[57] Empirical estimates suggest that barbed wire did not increase cattle production and decreased the joint production of cattle and crops. This finding is consistent with the notion that barbed wire mainly affected agricultural outcomes through greater enforcement of property rights.

To test for increases in cattle production, equation (8) is estimated for the number of cattle per five county acres.[58] The estimated magnitudes can be roughly compared to pre-

[56] For example, if nearby lands varied in their suitability for cattle and crops.

[57] If so, it seems reasonable to expect that non-property right effects should also dominate along these dimensions.

[58] Data on cattle are first available in 1880, so county regions are held constant at their 1880 boundaries.

viously estimated changes in land-use, as it requires approximately five acres of land for a cow to graze in this region.

Columns 1 and 2 of Table 7 present the results. From 1880 to 1890, there was no substantial increase in cattle production for a county with 0% woodland relative to a county with 6% woodland. The estimated coefficient implies that approximately 0.39% less of the county land became devoted to cattle production. By contrast, cattle production increased moderately in all subsequent periods and at higher woodland levels from 1880 to 1890. In all, there is little indication that barbed wire specifically led to increased cattle production, especially of a magnitude that could account for the previously estimated effects.[59]

It is less clear how to estimate changes in the joint production of cattle and crops, because the exact amount of land in each county devoted to cattle is unobserved.[60] As a possible solution, I assume that all farmland not used for crops is either used for cattle or other purposes that are not systematically changing over time within states. Based on this assumption, I define a specialization index equal to the squared difference between the percentage of county farmland devoted to crops and the average over all counties in that decade and state: $I_{ct} = (M_{ct} - \overline{M_{st}})^2$. This index increases when a county with an above-average percentage of farmland devoted to crops increases that proportion, and vice versa. Changes in this index are estimated using equation (8), which controls for average county deviations from the mean and state-by-decade shocks.

Columns 3 and 4 of Table 7 present the results. From 1880 to 1890, counties with 0% woodland became increasingly specialized, relative to counties with 6% woodland. The estimated magnitude is difficult to interpret, but it is large relative to the index mean and standard devation. Throughout various robustness checks, this increase is either similar or larger and always statistically significant.[61] Thus, it does not appear that barbed wire encouraged the joint production of cattle and crops.

Overall, the empirical estimates fail to contradict the hypothesis that barbed wire's effects operated mainly through an increase in property rights enforcement.

[59] These results are similar when controlling for quadratic time trends by region, region-decade fixed effects, distance West by decade, or distance West and distance from St. Louis by decade. When controlling for quadratic time trends or decade fixed effects by soil group or subregion, there are some increases in cattle production from 1880 to 1890. These increases are never substantively or statistically greater than at higher woodland levels, and the magnitudes are not greater than in later periods.

[60] The assumption of five acres per cow is too rough for these purposes, as acreage requirements vary with the environment, production methods, desired cattle quality, and desired sustainability.

[61] These include controlling for quadratic time trends or decade fixed effects by region, subregion, or soil group; distance West by decade; distance West and distance from St. Louis by decade.

VII Evidence on States' Legal Reforms

Prior to barbed wire's introduction, there were contentious political debates over whether settlers should be granted full land protection without having to build a fence. In contrast to the example of a farmer and cattle-raiser considered by Coase, individual cattle-raisers would mainly have been unable to provide effective guarantees to the farmer.[62] Plains state legislatures considered passing "herd laws" that would make livestock owners formally responsible for damages to farmers' unfenced crops.

These legislative debates highlight the property rights problem, but contentious debates do not imply that legislative responses could be effective. "Herd laws" would only be effective if enforced sufficiently to provide the credible promise of compensation if farmers' crops were damaged. Webb argues that formal laws often had little practical influence on the Plains.

Table 8 reports the results from separately estimating equation (8) in Kansas and Nebraska, two states to implement versions of these reforms described by Kawashima and Davis [1973].[63] The empirical estimates are less precise within individual states, but the bulk of the evidence indicates that the legal reforms were not effective.

Nebraska adopted a state-wide herd law in 1871, which should have benefited farmers more in counties with less woodland and higher fencing costs. From 1870 to 1880, however, the improvement intensity of farmland declined substantially in a county with 0% woodland relative to a county with 6% woodland. It was not until 1890, after the introduction of barbed wire, that counties with the least woodland showed substantial increases in land improvement. Note that the coefficients are imprecisely estimated at higher woodland levels because 90% of the sample counties in Nebraska had less than 6% woodland.

Kansas gave counties the option of adopting a herd law in 1872. I do not know exactly which counties adopted the herd law, but it was generally not adopted in counties with little woodland where the small proportion of crop growers had weak political influence [Webb, p.500; Sanchez and Nugent 2000; Kawashima]. Settlement increased more in lower-woodland counties from 1870 to 1880, however, and there was no change in land improvement. It was not until 1880 to 1890, after the introduction of barbed wire, that land improvement increased in counties with the least woodland. Kansas then adopted a state-wide herd law in 1889, which should have benefited farmers in lower-woodland counties, but land improvement declined from 1890 to 1900.

Davis argues that herd laws provided many of the benefits that were subsequently reinforced by the introduction of barbed wire, but most evidence comes from newspaper ad-

[62] Because of the large number of current and potential cattle-raisers, transaction costs were prohibitive.

[63] Texas also adopted a county-option policy in 1870, but the results are mostly noise because the sample has only a small number of counties in Texas with little woodland.

vocacies for legal reform. There is little evidence that the laws were strictly enforced and, as one would expect, cattle owners resisted making compensating payments for damages. Once barbed wire was introduced, those same newspapers wrote that "every farm needs *some* fencing" and as "soon as a farmer is able, he fences his farm. There must be an apparent benefit" [Davis, p.134]. Farmers made substantial investments in fencing before the legal reforms, after the legal reforms, and after the introduction of barbed wire. These laws may have had some small influence or they might not have been so hotly debated, but their passage appears to reflect changes in local political power rather than a major influence on farmers' decisions. In the absence of physical barriers, formal laws appear to have provided farmers little refuge from roaming livestock.

VIII Conclusion

In the 19th century American Plains, fences were required to secure farmland. Initially, fences were prohibitively expensive in areas with little local woodland. In this historical context, the introduction of barbed wire fencing encouraged property rights protection most in areas with the least woodland. This paper tests the hypothesis that this increase in property rights protection played an important role in the agricultural development of the American Plains.

Between barbed wire's introduction and its universal adoption, counties with the least woodland are estimated to have experienced substantial relative increases in agricultural development. Increases along *intensive* margins appear to have been dominant: farmland became more intensely improved, a greater percentage of farmland was allocated to crops, and crop productivity increased. Estimated increases in land values suggest that these effects were associated with substantial economic gains. On balance, these findings appear to be robust to a range of specification tests.

Overall, the results here suggest that secure property rights over land may have an important role in facilitating agricultural development. In contrast to the typical policy reform, however, these results reflect changes in property rights that largely fall outside formal institutional channels. Indeed, the apparent ineffectiveness of contemporaneous legal reforms may indicate a difficulty protecting property rights in sparsely settled areas through legislation and the court system.

Data Appendix

The data was converted into time-invariant geographical units using ArcView (GIS) software and the Historical United States Boundary Files [Carville et al. 1999].[64] The conversion process is designed to obtain data for each 1870 county when the data are subsequently reported for different county definitions. This turns out not to be particularly important for the empirical results, because most counties that change borders are excluded from the sample for other reasons (Figure 2). Still, this process is qualitatively important for the data to make sense and to give each original 1870 county equal weight.

This process is now described for converting 1920 data into the 1870 county definitions. The 1870 map is intersected with the 1920 map and each 1920 county is assigned the identification number of its 1870 county origin. When the 1920 county falls within more than one 1870 county, each piece of the 1920 county is assigned its unique 1870 origin along with the area of that piece. This information is then matched to the Census data, where the adjusted data for each 1920 piece are found by multiplying the original 1920 Census value by that piece's relative size. Finally, the 1920 data for each 1870 county region are found by summing across all 1920 pieces that make up the region.[65]

When counties in later periods fall within more than one original 1870 region, it is impossible to assign the exact measure of the variable in that period to each original region. This procedure assumes that each variable is evenly distributed across the county area. This introduces no additional measurement error for the typical changes in county borders over this time, whereby a single county split into subsections. In practice, the digital map projections are imperfect, resulting in small sections of counties being assigned to different original regions, but the effect on the total variable measures is very small. For the six states of interest, roughly 85% of counties in every period have less than 1% of their area in a second original region.

In the final data, counties will not have the exact same number of acres in different periods. Slight changes in the map projections or data collection procedures would create small differences. There are some very large differences, by hundreds of thousands or millions of acres, that must be due to data coding errors or mismatches regarding when large border changes took place. Counties for which the final standard deviation of the number of acres is greater than 50,000 are dropped (3% of the sample).

[64] The map files are available at the beginning of each decade. In each period, 3–9 census counties are dropped because they do not match to the map files.

[65] The summed measure is considered to be missing when data for any piece is missing.

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Table 1. Statistics on Barbed Wire Production, Fence Stocks, and New Fence Construction

A. Annual Production, thousands of tons

1911 Encyclopedia	1874	1875	1876	1877	1878	1879	1880	1890	1900	1907
Britannica	0.005	0.3	1.5	7	13	25	40	125	200	250
Webb 1931, p.309	1874	1875	1876	1877	1878	1879	1880		1901	
	0.005	0.3	1.3	6	12	23	37		~ 250	
Hayter 1939						1880-1884		1888	1895	
						80 - 100		150	157	

B. Fence Stocks, millions of rods (1 rod ≈ 5 meters)

	1850	1860	1870	1880	1890	1900	1910
North Central							
Total	228	303	359	427	443	493	483
Wood	226	285	320	369	279	192	75
Stone	2	3	3	3	0	0	0
Hedge	0	9	22	26	27	30	27
Wire	0	6	14	30	137	271	382
South Central							
Total	175	230	245	344	531	685	701
Wood	171	219	235	330	425	411	280
Stone	3	5	4	7	0	0	0
Hedge	0	5	2	3	0	0	0
Wire	0	2	3	3	106	274	420
Prairie							
Total	5	22	41	80	255	607	718
Wood	4	17	23	40	130	176	7
Stone	0	1	2	2	0	0	0
Hedge	0	3	13	26	3	18	22
Wire	0	1	4	12	122	413	689
Southwest							
Total	39	78	94	162	280	710	749
Wood	38	71	80	123	174	312	187
Stone	1	2	2	2	0	0	0
Hedge	0	2	4	5	0	0	0
Wire	0	4	9	32	106	398	562

C. New Fence Construction, percentage

	1850-59	1860-69	1870-79	1880-89	1890-99	1900-09
North Central						
Wood	79	66	73	3	0	0
Stone	1	0	0	0	0	0
Hedge	12	21	6	1	0	0
Wire	8	13	22	96	100	100
South Central						
Wood	90	94	100	50	0	0
Stone	2	0	0	0	0	0
Hedge	4	1	1	0	0	0
Wire	3	5	0	50	100	100
Prairie						
Wood	71	39	38	45	18	0
Stone	5	4	0	0	0	0
Hedge	18	45	38	0	0	0
Wire	6	12	24	55	82	100
Southwest						
Wood	84	56	63	42	32	0
Stone	2	3	0	0	0	0
Hedge	5	11	2	0	0	0
Wire	9	29	35	58	68	100

Notes: "Wood" fences include three types: Virginia worm, post and rail, and board. "Wire" fences are the smooth iron variety from 1850-1870 and include barbed wire from 1880 on. Panel B is excerpted from Primack 1977, table 23, pp. 206-208. Panel C is excerpted from Primack 1977, table 26, pp. 83-84.

Table 2. Mean County Characteristics in 1880, by County Woodland Group

	All Counties (1)	Low Woodland, 0% – 4% (2)	Medium Woodland, 4% – 8% (3)	High Woodland, 8% – 12% (4)	P-value (2) vs. (3) (5)	P-value (3) vs. (4) (6)
1870 county boundaries						
# counties	377	147	57	43	--	--
Land-use outcomes:						
Acres of land in farms,	0.53	0.42	0.59	0.65	0.000	0.257
per county acre	(0.26)	(0.26)	(0.28)	(0.26)		
Acres of improved land,	0.54	0.55	0.64	0.65	0.032	0.835
per acre in farms	(0.23)	(0.20)	(0.28)	(0.24)		
Other characteristics:						
Acres in county	550,718	645,898	470,219	430,631	0.018	0.348
	(526,638)	(801,941)	(239,127)	(180,333)		
Acres of land in farms	237,407	188,967	242,318	254,210	0.002	0.548
	(113,987)	(125,574)	(104,289)	(92,210)		
Acres of improved land	133,995	108,404	170,818	177,500	0.000	0.751
	(91,561)	(82,723)	(110,841)	(98,161)		
Value of land, buildings,	3,192,401	2,294,290	4,271,744	4,776,354	0.000	0.467
and fences	(2,851,257)	(1,750,834)	(3,635,498)	(3,245,953)		
Value of all products	838,986	593,556	1,060,637	1,158,761	0.000	0.548
	(659,730)	(452,311)	(867,683)	(756,448)		
Cost of building and	33,514	23,267	41,589	40,162	0.000	0.782
repairing fences	(24,120)	(18,173)	(31,547)	(19,616)		
1880 county boundaries						
# counties	490	246	61	44	--	--
Acres of cropland,	0.31	0.29	0.38	0.42	0.009	0.415
per acre in farms	(0.20)	(0.19)	(0.25)	(0.19)		
Acres of cropland	71,436	54,350	102,594	114,472	0.000	0.448
	(65,041)	(54,606)	(85,283)	(73,867)		
% acreage for each crop:						
Corn	40.2	34.3	51.1	42.6	0.000	0.060
	(22.4)	(23.6)	(24.0)	(21.3)		
Wheat	23.2	28.5	22.6	24.1	0.033	0.711
	(19.6)	(19.0)	(19.5)	(19.7)		
Hay	18.3	26.2	13.7	14.6	0.000	0.662
	(20.5)	(24.5)	(9.2)	(10.8)		
Oats	7.6	8.2	6.7	8.6	0.050	0.037
	(6.5)	(7.9)	(4.3)	(4.6)		
Barley	1.0	1.4	1.2	1.0	0.589	0.664
	(1.7)	(1.8)	(2.6)	(1.6)		
Rye	0.5	0.6	0.6	0.5	0.773	0.499
	(0.9)	(1.0)	(0.9)	(0.7)		

Notes: In the top panel, the sample is the same as in Figure 2 and Table 3 (377 counties in a balanced panel). In the bottom panel, the sample is the same as in Tables 5 and 7 (490 counties in a balanced panel). Missing data for crop acreage is treated as a zero. P-values are calculated based on standard errors that are adjusted for heteroskedasticity.

Table 3. Estimated Changes in the Improvement Intensity of Farmland and Settlement, Evaluated at Representative Woodland Levels

		Acres of Improved Land, per acre in farms		Acres of Land in Farms, per county acre	
	Woodland:	0% vs. 6%	6% vs. 12%	0% vs. 6%	6% vs. 12%
		(1)	(2)	(3)	(4)
	Decade:				
Before Barbed Wire	1870 - 1880	0.015	0.023	0.039	0.028**
		(0.040)	(0.013)	(0.026)	(0.010)
		[0.22]		[0.41]	
After Barbed Wire's Introduction	1880 - 1890	0.100**	– 0.004	0.129**	0.048**
		(0.030)	(0.012)	(0.023)	(0.009)
		[4.12]		[3.81]	
	1890 - 1900	0.086**	0.020*	0.128**	0.057**
		(0.020)	(0.009)	(0.026)	(0.009)
		[3.40]		[3.13]	
After Barbed Wire's Universal Adoption	1900 - 1910	– 0.019	0.004	– 0.022	– 0.014
		(0.011)	(0.006)	(0.024)	(0.009)
		[2.25]		[0.36]	
	1910 - 1920	0.003	0.006	0.024	– 0.003
		(0.010)	(0.004)	(0.016)	(0.007)
		[0.31]		[1.59]	
	R^2	0.4432		0.5012	
	Observations	1885		1885	

Notes: For the indicated outcome variable, this table reports estimates from equation 8 in the text. The estimated polynomial function of woodland is evaluated at three woodland levels (0%, 6%, 12%) and the reported estimates represent the difference in predicted changes between the two indicated woodland levels. Each cell can be interpreted as a difference-in-difference coefficient: the change over that period for an average county with 0% woodland relative to the change for a county with 6% woodland (or a county with 6% woodland relative to a county with 12% woodland). Robust standard errors clustered by county are reported in parentheses: ** denotes statistical significance at 1% and * at 5%. In brackets is the t-statistic of the difference between the two contemporaneous estimates comparing changes at different woodland levels.

Table 4. Estimated 1880-1890 and 1890-1900 Changes for 0% Woodland Counties vs. 6% Woodland Counties, Robustness to Different Specifications

		Additional Controls for:					
	Baseline Specification	Distance West	Distance West and Distance From St. Louis	Quadratic Time Trends by Region	Quadratic Time Trends by Subregion	Quadratic Time Trends by Soil Group	1870 Outcome Differences
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Acres of Improved Land, per acre in farms							
1880 - 1890	0.100**	0.094**	0.119**	0.100**	0.087**	0.120**	0.065*
	(0.030)	(0.034)	(0.031)	(0.029)	(0.031)	(0.031)	(0.033)
	[4.12]	[3.76]	[4.54]	[3.76]	[3.29]	[4.36]	[2.90]
1890 - 1900	0.086**	0.094**	0.106**	0.087**	0.070**	0.094**	0.076**
	(0.020)	(0.026)	(0.026)	(0.020)	(0.021)	(0.021)	(0.021)
	[3.40]	[3.33]	[3.64]	[3.22]	[2.61]	[3.50]	[2.95]
R^2	0.4432	0.4458	0.4589	0.4773	0.5095	0.4864	0.5735
Observations	1885	1885	1885	1885	1885	1885	1885
Panel B: Acres of Land in Farms, per county acre							
1880 - 1890	0.129**	0.068*	0.083**	0.106**	0.078**	0.121**	0.031
	(0.023)	(0.027)	(0.026)	(0.025)	(0.024)	(0.025)	(0.029)
	[3.81]	[1.95]	[2.33]	[2.48]	[1.87]	[3.54]	[1.26]
1890 - 1900	0.128**	0.079*	0.066*	0.116**	0.097**	0.122**	0.062
	(0.026)	(0.031)	(0.032)	(0.026)	(0.027)	(0.026)	(0.039)
	[3.13]	[1.56]	[1.27]	[2.48]	[1.92]	[2.91]	[0.99]
R^2	0.5012	0.5583	0.5716	0.5418	0.5737	0.5352	0.5606
Observations	1885	1885	1885	1885	1885	1885	1885

Notes: This table reports on a series of specification tests for the results in Table 3. Only the primary results are shown here: the estimated changes from 1880-1890 and 1890-1900 for counties with 0% woodland relative to counties with 6% woodland. The full results are shown in Appendix Tables 1–3. For comparison, the results from Table 3 are reported in column 1. Column 2 controls for a county's distance West, interacted with each decade. Column 3 controls for a county's distance West and distance from St. Louis, interacted with each decade. Column 4 controls for a quadratic time trend for each of 11 Regions. Column 5 controls for a quadratic time trend for each of 43 Subregions. Column 6 controls for a quadratic time trend for each of 19 Soil Groups. Column 7 controls for a fourth-degree polynomial of a county's 1870 outcome level, interacted with each decade.

Table 5. Estimated Changes in Crop Productivity and Crop Intensity

		All Crops				At-Risk Crops			
		Productivity		Acres of Cropland, per acre in farms		Productivity		Acres of At-Risk Crops, per acre of cropland	
	Woodland:	0% vs. 6%	6% vs. 12%	0% vs. 6%	6% vs. 12%	0% vs. 6%	6% vs. 12%	0% vs. 6%	6% vs. 12%
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Decade:								
After Barbed Wire's Introduction	1880 - 1890	0.234**	0.018	0.121**	0.015**	0.292**	0.036	0.058*	0.000
		(0.057)	(0.025)	(0.015)	(0.005)	(0.067)	(0.027)	(0.023)	(0.007)
		[3.31]		[8.01]		[3.47]		[2.84]	
	1890 - 1900	– 0.046	– 0.003	– 0.013	– 0.011**	– 0.057	– 0.012	0.007	– 0.005
		(0.039)	(0.018)	(0.009)	(0.004)	(0.046)	(0.021)	(0.015)	(0.006)
		[0.97]		[0.24]		[0.86]		[0.91]	
After Barbed Wire's Universal Adoption	1900 - 1910	0.054	– 0.019	0.039**	0.004	0.058	– 0.027	0.020	– 0.015
		(0.035)	(0.018)	(0.010)	(0.004)	(0.039)	(0.019)	(0.019)	(0.009)
		[1.70]		[3.44]		[1.81]		[1.75]	
	1910 - 1920	– 0.036	0.014	0.010	0.001	0.011	0.038	0.016	0.005
		(0.042)	(0.025)	(0.007)	(0.004)	(0.049)	(0.029)	(0.015)	(0.009)
		[0.95]		[1.06]		[0.44]		[0.63]	
	R^2	0.3949		0.3922		0.4000		0.2777	
	Observations	9104		1960		7320		1960	

Notes: For changes in productivity, estimates are from equation 9 in the text. For changes in cropland, estimates are from equation 8 in the text. Estimated coefficients are presented in the same form as in Table 3.

Table 6. Estimated Changes in Land Value

	Woodland:	Value of Land in Farms, per county acre: 0% vs. 6% (1)	Value of Land in Farms, per county acre: 6% vs. 12% (2)
	Decade:		
Before Barbed Wire	1870 - 1880	– 0.364*	– 0.224**
		(0.151)	(0.053)
		[1.11]	
After Barbed Wire's Introduction	1880 - 1890	0.406**	0.074*
		(0.105)	(0.037)
		[3.99]	
	1890 - 1900	0.213**	0.126**
		(0.072)	(0.027)
		[1.45]	
After Barbed Wire's Universal Adoption	1900 - 1910	– 0.101	0.013
		(0.073)	(0.027)
		[2.07]	
	1910 - 1920	0.044	0.018
		(0.063)	(0.024)
		[0.50]	
	R^2	0.7569	
	Observations	1880	

Notes: Estimates are from equation 8 in the text and are reported in the same form as in Table 3.

Table 7. Estimated Changes in Cattle Production and County Specialization

		Number of Cattle, per five county acres		Degree of Specialization in Crops or Cattle	
	In 1880:				
	Mean	0.2034		0.0175	
	Std. deviation	0.1570		0.0248	
	Woodland levels:	0% vs. 6%	6% vs. 12%	0% vs. 6%	6% vs. 12%
		(1)	(2)	(3)	(4)
	Decade:				
After Barbed Wire's Introduction	1880 - 1890	– 0.0039	0.0247**	0.0117**	– 0.0007
		(0.0137)	(0.0066)	(0.0039)	(0.0012)
		[2.01]		[3.50]	
	1890 - 1900	0.0567**	0.0355**	0.0007	– 0.0070**
		(0.0150)	(0.0071)	(0.0032)	(0.0020)
		[1.29]		[2.05]	
After Barbed Wire's Universal Adoption	1900 - 1910	0.0437**	– 0.0122	– 0.0023	0.0021
		(0.0140)	(0.0065)	(0.0025)	(0.0014)
		[3.50]		[1.48]	
	1910 - 1920	0.0348**	– 0.0064	– 0.0015	– 0.0023
		(0.0102)	(0.0052)	(0.0020)	(0.0014)
		[3.32]		[0.28]	
	R^2	0.5823		0.1681	
	Observations	1960		1960	

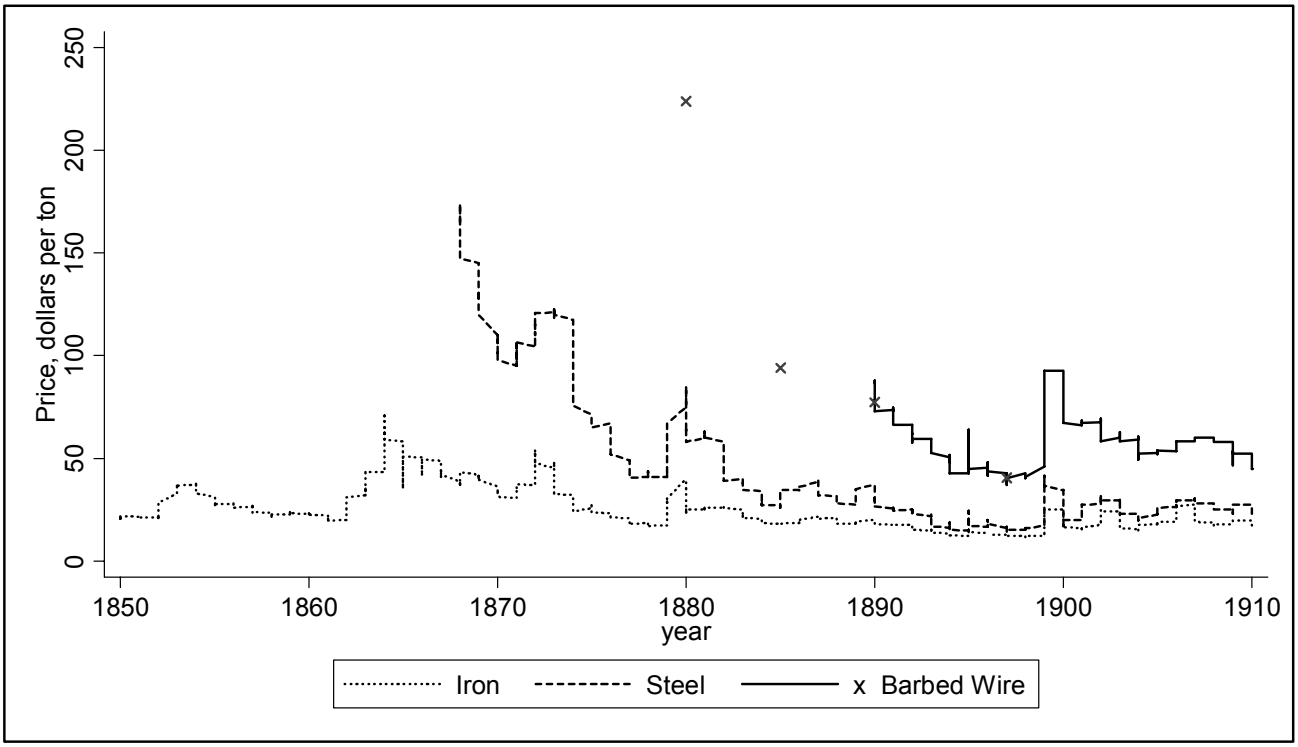
Notes: For the indicated outcome variable, estimates are from equation 8 in the text and are reported in the same form as in Table 3.

Table 8. Estimated Changes in Improvement Intensity and Settlement, Nebraska and Kansas

	Acres of Improved Land, per acre in farms		Acres of Land in Farms, per county acre	
Woodland:	0% vs. 6%	6% vs. 12%	0% vs. 6%	6% vs. 12%
	(1)	(2)	(3)	(4)
Panel A: Nebraska				
1870 - 1880	– 0.216*	0.301	0.034	0.640
	(0.104)	(0.367)	(0.174)	(0.742)
1880 - 1890	0.294**	– 0.350	0.060	0.206
	(0.062)	(0.299)	(0.063)	(0.189)
1890 - 1900	– 0.069*	0.335*	0.175**	– 0.120
	(0.033)	(0.161)	(0.057)	(0.239)
1900 - 1910	0.063	– 0.339	– 0.008	0.220
	(0.035)	(0.181)	(0.043)	(0.148)
1910 - 1920	– 0.001	0.014	0.033	– 0.011
	(0.026)	(0.075)	(0.019)	(0.107)
R^2	0.8129		0.7534	
Observations	155		155	
Panel B: Kansas				
1870 - 1880	– 0.027	0.011	0.479**	0.045
	(0.163)	(0.045)	(0.102)	(0.035)
1880 - 1890	0.307**	0.053*	– 0.135*	0.116**
	(0.060)	(0.026)	(0.066)	(0.030)
1890 - 1900	– 0.091	0.008	0.017	0.027
	(0.051)	(0.028)	(0.031)	(0.024)
1900 - 1910	0.017	– 0.018	0.080*	– 0.023
	(0.041)	(0.026)	(0.037)	(0.030)
1910 - 1920	0.028	– 0.018	0.037	– 0.029*
	(0.030)	(0.015)	(0.019)	(0.013)
R^2	0.5283		0.7959	
Observations	255		255	

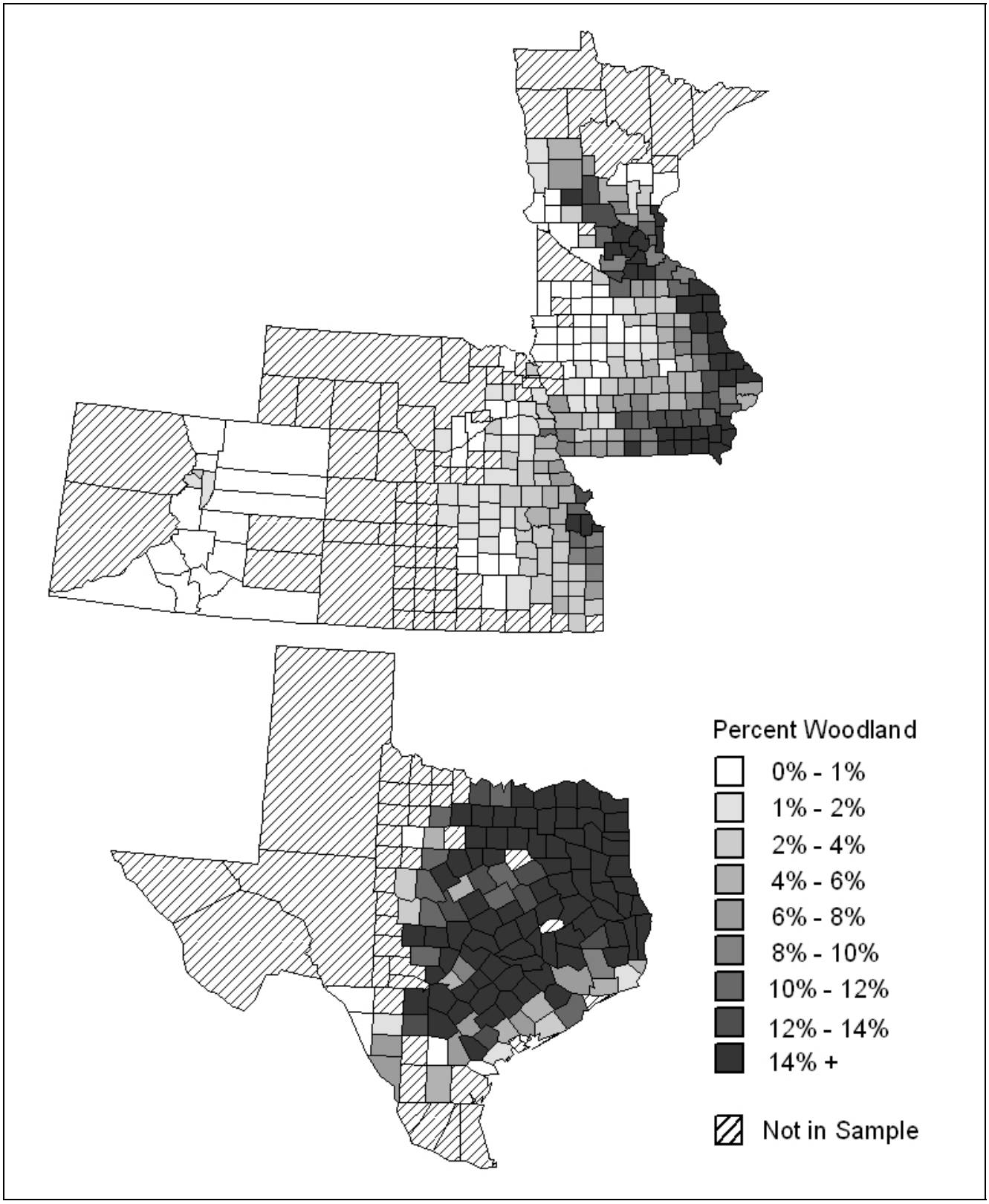
Notes: Panels A and B report the estimated effects from Table 3 for Nebraska only and Kansas only, respectively.

Figure 1. Declining Steel Prices and the Introduction of Barbed Wire



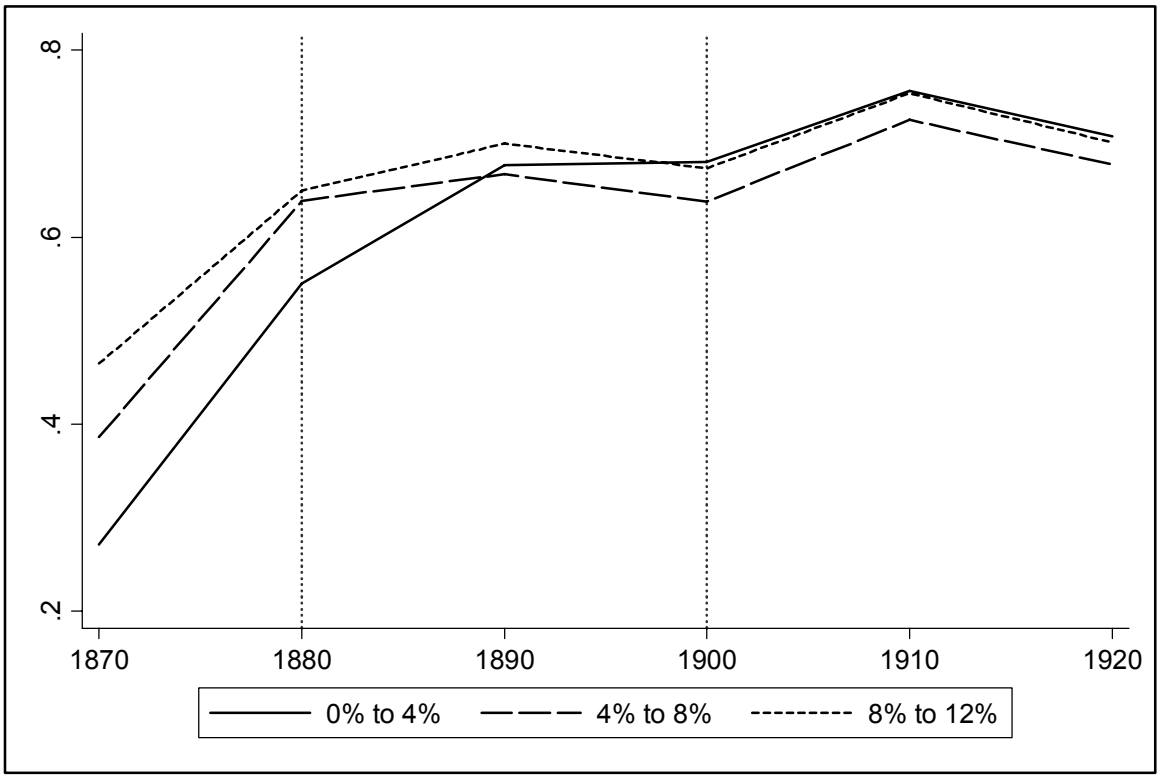
Notes: Nominal price data was obtained from the NBER Macrohistory Database. "Barbed Wire" is the price of galvanized barbed wire in Chicago, with four additional prices denoted by X's [Webb; Hayter]. In 1874, the price of barbed wire was approximately $450 per ton. Before 1890, "Steel" is the price of Bessemer steel rails in PA. After 1890, "Steel" is the price of Bessemer steel billets in PA. "Iron" is the price of pig iron in PA.

Figure 2. Sample Counties by Defined Woodland Levels



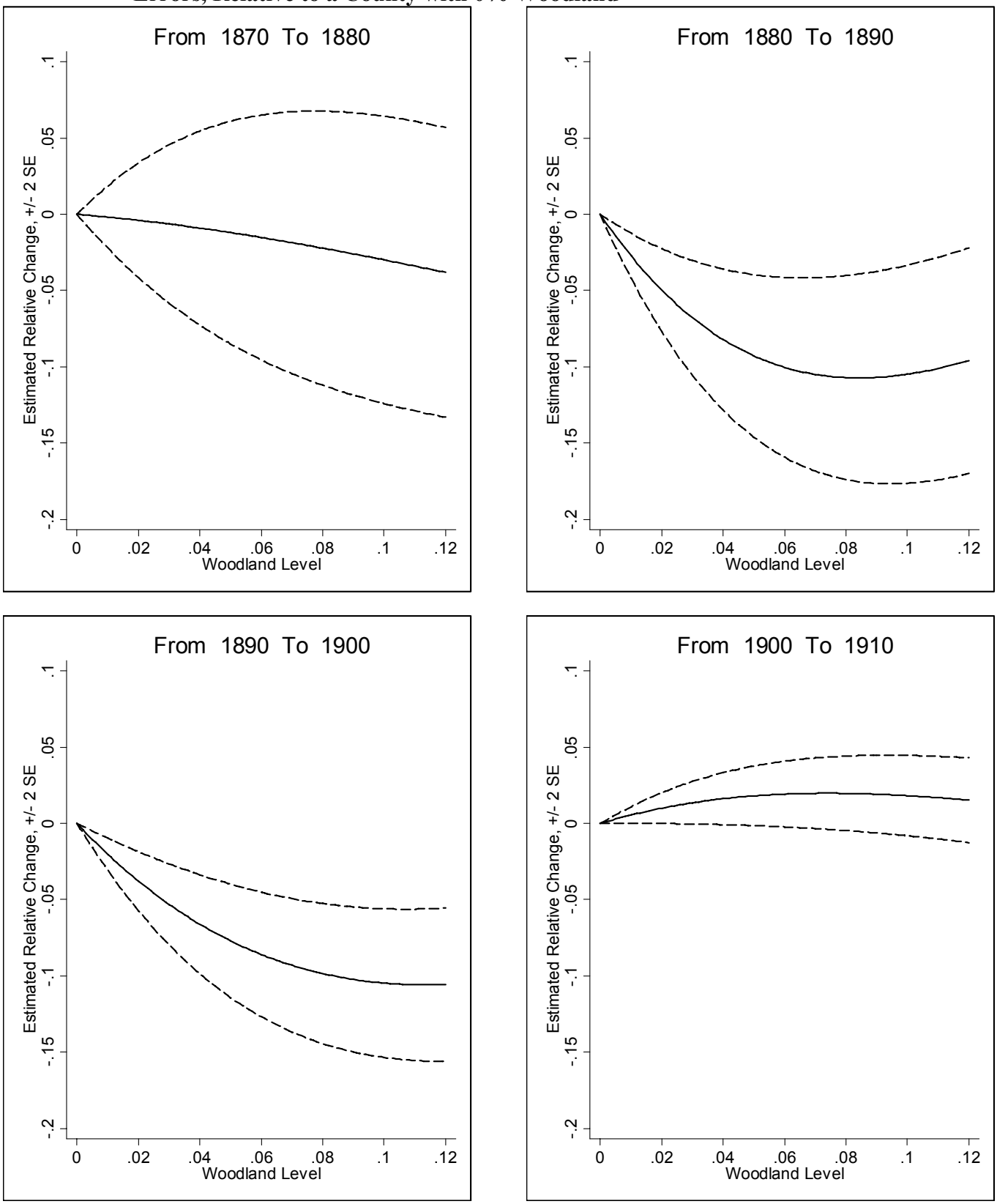
Notes: This figure displays the 377 sample counties based on 1870 geographical boundaries, shaded to represent their level of woodland.

Figure 3. Acres of Improved Land (per farm acre), by County Woodland Group and Decade



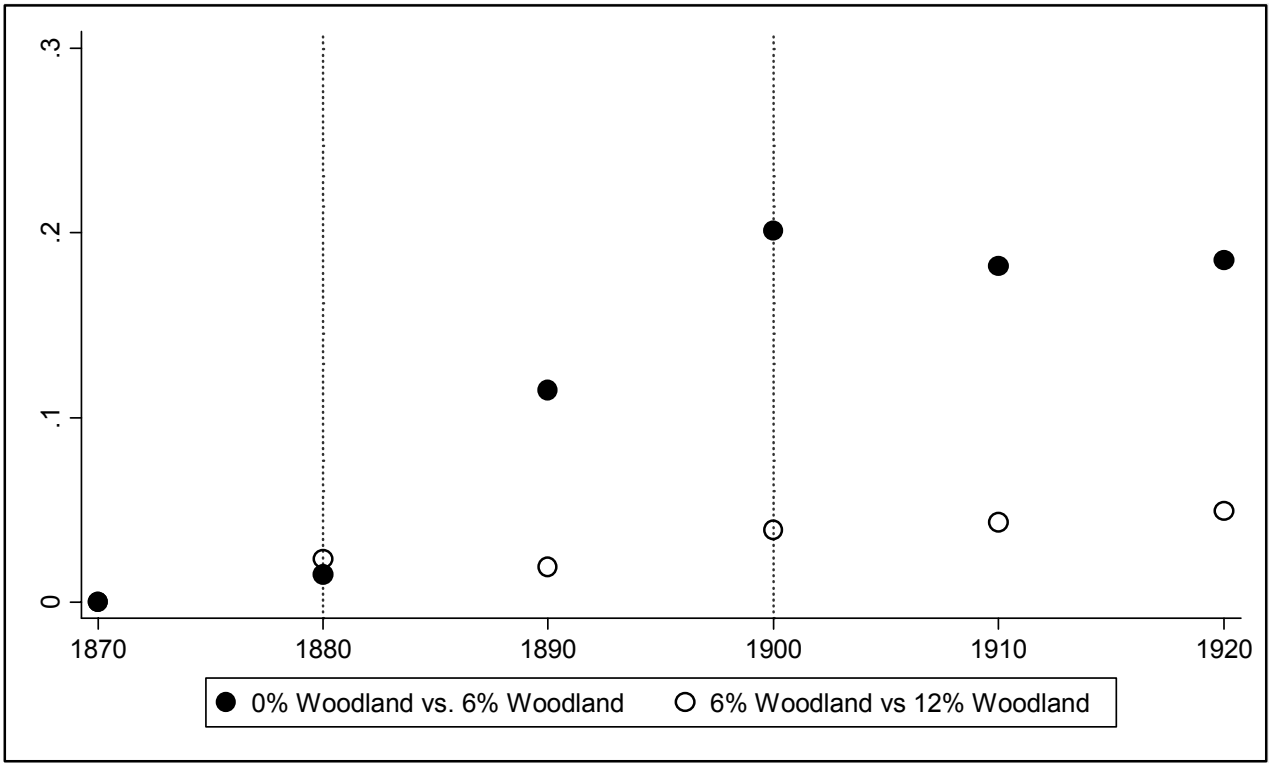
Notes: For counties in these three woodland groups, this figure displays the average number of improved acres of land per acre of farmland in each time period. The two vertical dotted lines represent the approximate date of barbed wire's introduction to farmers (1880) and barbed wire's universal adoption by farmers (1900).

Figure 4. Estimated Changes in the Improvement Intensity of Farmland, +/- 2 Standard Errors, Relative to a County with 0% Woodland



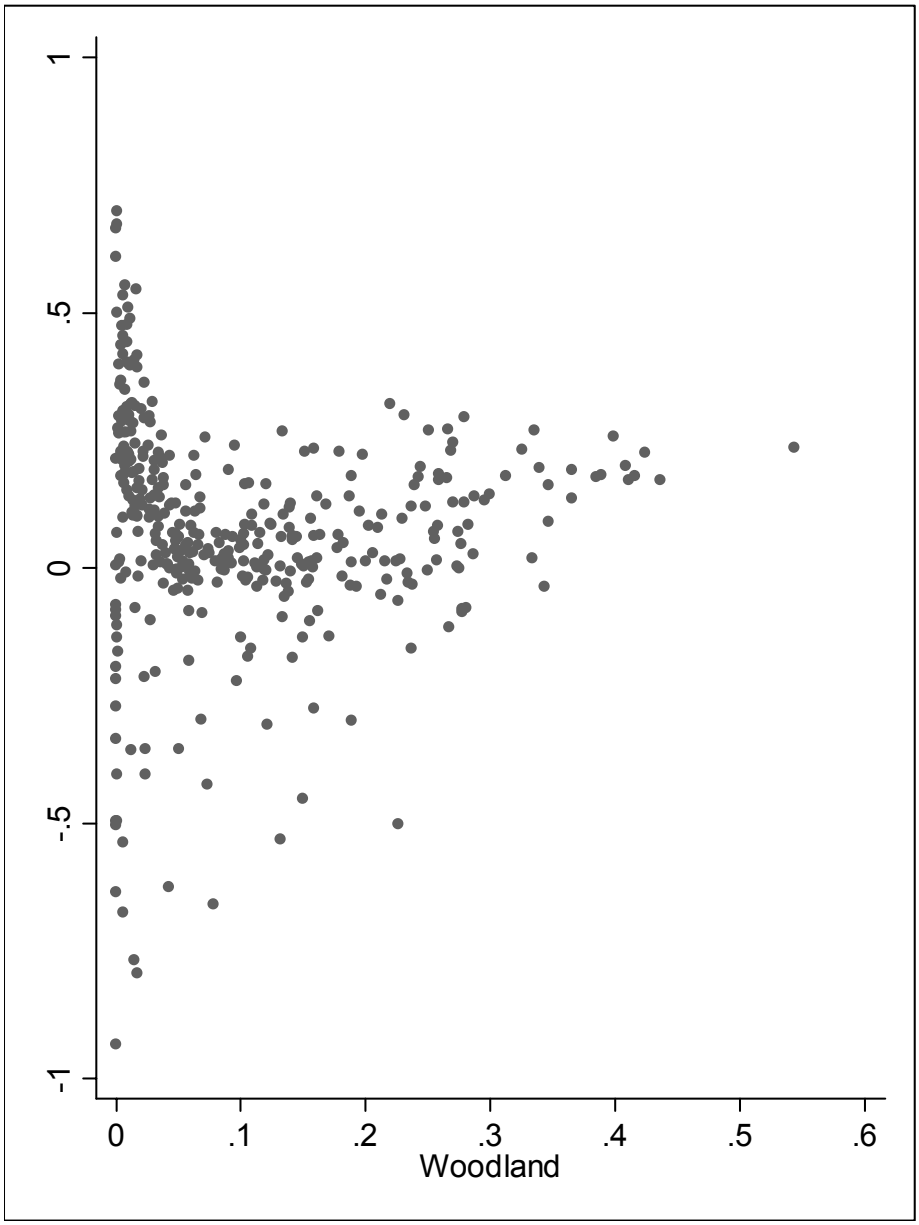
Notes: From estimating equation 8 for the acres of improved land per acre of farmland, these figures report the change in a county with each woodland level relative to the change for a county with 0% woodland, plus or minus 2 standard errors.

Figure 5. Estimated Cumulative Change in the Improvement Intensity of Farmland



Notes: This figure displays the cumulative estimated changes in acres of improved land per acre of farmland, as reported in Table 3, columns 1 and 2. The two vertical dotted lines represent the approximate date of barbed wire's introduction to farmers (1880) and barbed wire's universal adoption by farmers (1900).

Figure 6. County Changes in the Improvement Intensity of Farmland, 1880 to 1900



Notes: This figure shows the change from 1880 to 1900 in acres of improved land per acre of farmland, where each point represents a single county. This change is plotted against that county's 1880 woodland level.

Appendix Table 1. Estimated Changes in the Improvement Intensity of Farmland and Settlement, Controlling for Westward Development

	Distance West				Distance West and from St. Louis			
	Improved Land, per acre in farms		Land in Farms, per county acre		Improved Land, per acre in farms		Land in Farms, per county acre	
Woodland:	0% - 6%	6% - 12%	0% - 6%	6% - 12%	0% - 6%	6% - 12%	0% - 6%	6% - 12%
	(2a)	(2b)	(2c)	(2d)	(3a)	(3b)	(3c)	(3d)
Decade:								
1870 - 1880	– 0.006	0.016	– 0.050	– 0.003	– 0.005	0.016	– 0.042	0.001
	(0.044)	(0.013)	(0.024)	(0.009)	(0.046)	(0.013)	(0.025)	(0.009)
	[0.55]		[2.02]		[0.52]		[1.82]	
1880 - 1890	0.094**	– 0.007	0.068*	0.026**	0.119**	0.006	0.083**	0.033**
	(0.034)	(0.014)	(0.027)	(0.010)	(0.031)	(0.013)	(0.026)	(0.009)
	[3.76]		[1.95]		[4.54]		[2.33]	
1890 - 1900	0.094**	0.023	0.079*	0.040**	0.106**	0.029*	0.066*	0.034**
	(0.026)	(0.012)	(0.031)	(0.011)	(0.026)	(0.011)	(0.032)	(0.011)
	[3.33]		[1.56]		[3.64]		[1.27]	
1900 - 1910	– 0.009	0.008	– 0.009	– 0.009	– 0.015	0.005	0.007	– 0.001
	(0.016)	(0.008)	(0.023)	(0.010)	(0.015)	(0.008)	(0.024)	(0.009)
	[1.42]		[0.01]		[1.75]		[0.34]	
1910 - 1920	0.006	0.007	0.033	0.000	0.003	0.006	0.023	– 0.005
	(0.013)	(0.005)	(0.017)	(0.008)	(0.014)	(0.004)	(0.019)	(0.007)
	[0.08]		[1.95]		[0.22]		[1.53]	
R^2	0.4458		0.5583		0.4589		0.5716	
Obs.	1885		1885		1885		1885	

Notes: This Table presents the full results from Table 4, columns 2 and 3.

Appendix Table 2. Estimated Changes in the Improvement Intensity of Farmland and Settlement, Controlling for Regional Changes

	Quadratic Time Trends by Region				Quadratic Time Trends by Subregion				Quadratic Time Trends by Soil Group			
	Improved Land, per acre in farms		Land in Farms, per county acre		Improved Land, per acre in farms		Land in Farms, per county acre		Improved Land, per acre in farms		Land in Farms, per county acre	
Woodland:	0% - 6%	6% - 12%	0% - 6%	6% - 12%	0% - 6%	6% - 12%	0% - 6%	6% - 12%	0% - 6%	6% - 12%	0% - 6%	6% - 12%
	(4a)	(4b)	(4c)	(4d)	(5a)	(5b)	(5c)	(5d)	(6a)	(6b)	(6c)	(6d)
Decade:												
1870 - 1880	0.013	0.039**	0.006	0.034**	0.004	0.031**	– 0.032	0.016	0.047	0.033**	0.029	0.022*
	(0.040)	(0.013)	(0.024)	(0.010)	(0.035)	(0.012)	(0.026)	(0.010)	(0.035)	(0.011)	(0.025)	(0.010)
	[0.73]		[1.22]		[0.82]		[1.94]		[0.45]		[0.29]	
1880 - 1890	0.100**	0.006	0.106**	0.052**	0.087**	0.000	0.078**	0.039**	0.120**	0.003	0.121**	0.043**
	(0.029)	(0.011)	(0.025)	(0.009)	(0.031)	(0.012)	(0.024)	(0.009)	(0.031)	(0.012)	(0.025)	(0.010)
	[3.76]		[2.48]		[3.29]		[1.87]		[4.36]		[3.54]	
1890 - 1900	0.087**	0.025**	0.116**	0.060**	0.070**	0.019*	0.097**	0.053**	0.094**	0.024*	0.122**	0.055**
	(0.020)	(0.009)	(0.026)	(0.010)	(0.021)	(0.010)	(0.027)	(0.010)	(0.021)	(0.010)	(0.026)	(0.010)
	[3.22]		[2.48]		[2.61]		[1.92]		[3.50]		[2.91]	
1900 - 1910	– 0.016	0.005	– 0.023	– 0.012	– 0.038**	– 0.001	– 0.033	– 0.014	– 0.024*	0.006	– 0.026	– 0.013
	(0.011)	(0.006)	(0.024)	(0.010)	(0.011)	(0.006)	(0.027)	(0.010)	(0.011)	(0.006)	(0.023)	(0.009)
	[1.98]		[0.44]		[3.36]		[0.75]		[2.76]		[0.58]	
1910 - 1920	0.008	0.001	0.034*	– 0.004	– 0.019	– 0.004	0.033	0.000	– 0.014	0.005	0.022	0.000
	(0.011)	(0.005)	(0.017)	(0.006)	(0.014)	(0.005)	(0.021)	(0.007)	(0.013)	(0.005)	(0.016)	(0.007)
	[0.58]		[2.17]		[1.14]		[1.63]		[1.55]		[1.26]	
R^2	0.4773		0.5418		0.5095		0.5737		0.4864		0.5352	
Obs.	1885		1885		1885		1885		1885		1885	

Notes: This Table presents the full results from Table 4, columns 4 – 6.

Appendix Table 3. Estimated Changes in the Improvement Intensity of Farmland and Settlement, Controlling for Initial Outcome Differences

	Improved Land, per acre in farms		Land in Farms, per county acre	
Woodland:	0% - 6%	6% - 12%	0% - 6%	6% - 12%
	(7a)	(7b)	(7c)	(7d)
Decade:				
1870 - 1880	– 0.098**	– 0.003	– 0.086**	– 0.032**
	(0.034)	(0.013)	(0.029)	(0.011)
	[3.44]		[2.15]	
1880 - 1890	0.065*	– 0.015	0.031	0.003
	(0.033)	(0.012)	(0.029)	(0.013)
	[2.90]		[1.26]	
1890 - 1900	0.076**	0.017	0.062	0.034*
	(0.021)	(0.009)	(0.039)	(0.015)
	[2.95]		[0.99]	
1900 - 1910	– 0.026*	0.002	– 0.045	– 0.026
	(0.012)	(0.006)	(0.037)	(0.015)
	[2.62]		[0.64]	
1910 - 1920	– 0.005	0.004	0.012	– 0.009
	(0.012)	(0.005)	(0.022)	(0.010)
	[0.71]		[0.98]	
R^2	0.5735		0.5606	
Obs.	1885		1885	

Notes: This Table presents the full results from Table 4, column 7.