DAE
7/12/07
9:00 AM

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

Richard A. Hornbeck*
MIT

January 2007

Abstract

This paper uses the introduction of barbed wire fences to the American Midwest 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 exclusive land-use rights, yet preferred wooden fences had been prohibitively expensive in areas with little woodland. The introduction and universal adoption of barbed wire fences encouraged property rights protection most in counties with the least woodland. Over that time, low-woodland counties are estimated to have undergone substantial relative increases in land settlement, land improvement, the improvement-intensity of farmland, land values, and the productivity and production share of crops most in need of protection. Some States' previous efforts to reduce the need for fencing are not found to have been similarly effective, however, suggesting a difficulty in protecting property rights through legislation alone.

JEL: D23, N51, O12, Q15

*I especially thank Michael Greenstone, as well as Daron Acemoglu, Josh Angrist, David Autor, Abhijit Banerjee, Dora Costa, Esther Duflo, Claudia Goldin, Tal Gross, Raymond Guiteras, Jeanne Lafortune, Philip Oreopoulos, and Peter Temin, for their comments. I also thank Daniel Sheehan for assistance with GIS software and the World Economy Lab for financial support. hornbeck@mit.edu

The assignment and enforcement of property rights is often thought to induce production decisions to approach the social optimum [Coase 1960] or, otherwise, to be an important determinant of product choices, investment levels, production methods [Cheung 1970], and macroeconomic performance [North 1981; Acemoglu and Johnson 2005]. Observed correlations between economic outcomes and property rights are unlikely to identify causal relationships, however, because property rights are established endogenously [Demsetz 1967]. Much attention has focused on the role of land rights in agrarian economies, where more secure rights might improve economic efficiency by increasing farmers' investment.[1] The typical positive correlation between investment and property rights, however, may reflect land quality or other factors influencing both investment and property rights [Miceli et al. 2001]. Investment itself may increase property rights directly by conferring greater legitimacy to land claims[2] or indirectly by making the land more worthwhile to secure.

The predominant solution to this endogeneity problem has been the use of instrumental variables [Besley 1995; Brasselle et al. 2002]. Similar approaches use variation in land rights policies [Jacoby et al. 2002; Banerjee et al. 2002]. In all cases, the source of variation in property rights must be uncorrelated with unobserved production determinants and must not affect production decisions through other channels. An additional complication is that micro-level variation in property rights protection may identify different effects than those of larger reforms or macro-level differences.[3] When property rights protection varies across relatively 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.

This paper aims to address these empirical challenges by examining a widespread decrease in the cost of establishing and enforcing property rights: the introduction of barbed wire fences to the late 19^{th} century American Midwest. 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]

[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] While investments are typically thought to improve land tenure security, Goldstein and Udry [2005] discuss a counter-example where fallowing land may jeopardize ownership claims.

[3] See Acemoglu and Johnson [2005] for a review of macro-level estimation approaches and new evidence.

[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.

Fence construction and the property rights it conferred had been severely restricted in areas with high fencing costs, i.e., areas lacking locally available fencing materials. In the Midwest, timber was not widely traded or a substantial economic output, but local woodland was a vital source of fencing materials due to high transportation costs. Where fencing costs had been high due to a lack of woodland, "the introduction of barbed wire greatly reduced the cost of activities aimed at enclosing one's land. To the homesteader whose land was invaded by cowboys and their herds which trampled down crops, barbed wire 'defined the prairie farmer's private property' " [Anderson and Hill 1975, p.172, quoting Cooke 1973, p.237].[5] The introduction and universal adoption of barbed wire from 1880–1900 had its greatest effect in areas with the least woodland that had been most costly to fence.

Using decennial data from the Census of Agriculture, I find that counties with the least woodland also experienced large increases in agricultural activity from 1880–1900, relative to counties with enough woodland for farmers to have accommodated previous fencing material shortages. Controlling for county and state-by-decade unobservables, the proportion of county land that was settled in farms increased by 26 percentage points, the proportion of county land that was improved increased by 30 percentage points, and the proportion of county farmland that was improved increased by 19 percentage points. The estimated increases remain substantial when controlling flexibly for an unrelated pattern of economic convergence. Controlling for crop-by-county and crop-by-state-by-decade unobservables, average crop productivity increased by 19%. This productivity increase was concentrated among those crops most susceptible to damage from roaming livestock. Furthermore, farmers shifted production toward these more at-risk products. Increases in land-use and production capabilities also appear to have been reflected in increased land values. In all, these estimates substantiate 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].

Attributing these large increases in economic activity to the advent of barbed wire requires that counties with different levels of woodland would have changed similarly if not for the introduction of barbed wire. This type of assumption is typically most plausible when the compared places are ex-ante similar. The results are robust to controlling for initial outcome differences, but these counties may differ along other important dimensions. The relevant variation in county woodland is at low levels, however, so county land is mostly compared based on its proximity to woodland, rather than differences in the use of actual

[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 Midwest United States in the late 19$^{\text{th}}$ century.

woodland whose soil or other characteristics might differ substantially. Indeed, the mixture of crops is not very different across counties with different woodland levels. The empirical methodology provides some indirect tests of this parallel trend assumption, and a number of other historical events appear unlikely to explain such large relative changes from 1880–1900.

Furthermore, attributing the estimated effects of barbed wire to the expanded availability of property rights requires that barbed wire only affected these economic activities by increasing property rights enforcement. I examine the potential for two main additional effects of cheaper fencing: the encouragement of both cattle production and 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, suggesting that barbed wire's effects operated mainly through an increase in property rights enforcement.

The historical setting provides a rare opportunity to compare the effects of this *de facto* improvement in property rights enforcement to 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 are not found to have had systematic benefits. This is likely because the herd laws were weakly enforced, offering little true security in the absence of physical barriers.

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 provides additional evidence on the main challenges to the identification assumptions. 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, the United States' legal code in the 19$^{\text{th}}$ century had long required the construction of a "lawful fence"[6] to establish exclusive land-use rights [Kawashima 1994]. Without such a fence, a farmer had no formal entitlement to compensa-

[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.

tion for damages inflicted by roaming livestock. In practice, fences were necessary to protect crops and they required substantial expenditures. A special report in 1872 found that national capital investments in fences were roughly equal both to the value of all livestock and to the national debt [U.S. House 1872]. A subsequent newspaper editorial added that investments in fencing had exceeded those in the railroads and that the annual 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].

The commission of this report reflected an increasing interest in the rising cost of fences as settlement moved into areas with little woodland.

> 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. The result was that in these early days fields were always opened up in the timbered region near the streams or wood lots where rails could be procured .... [The] American frontiersman on the Plains was faced by a most serious problem. Without fences he 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 1963, p.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, p.7]. Systematic data on transportation costs are unavailable, but substantial costs are also implied by reports of farmers seeking land near available timber.

Writing about central Iowa, Bogue [p.6] provides more specific guidance in determining 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.

The smaller counties were roughly 25–40 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. Furthermore, for a standard homestead farm size of 160 acres, this landholding pattern indicates that every settler could have acquired 5–10 acres of woodland in a county that was roughly 4% woodland.

Based on this calculation, counties are assigned to the following three woodland categories for the subsequent analysis: 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.

As standard economic theory would suggest, "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. Methods of securing property rights were not limited to fencing and there arose a variety of customs and agreements over resource use, often enforced by associations or other forms of collective action [Anderson and Leal 2001; Bogue].

In the political arena, there was widespread debate over whether settlers should be granted exclusive land-use rights without having to build fences, shifting the burden of fencing to cattle owners.[7] There were some such attempts, though fencing requirements were rarely relaxed in low-woodland areas because the small proportion of crop growers had little political influence [Webb, p.500; Sanchez and Nugent 2000; Kawashima]. These reforms' effectiveness depended on the ability of local law enforcement to protect landholders' exclusive rights in the absence of a fence. As Webb generally argues, though, formal laws had little practical influence and this paper's empirical results support that impression.

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

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: the barbs prevented cattle from breaking the fence; the twisted wires tolerated temperature changes; and the design was easy to manufacture. Glidden sold a half-stake in the patent for a few hundred dollars to Ellwood, a hardware merchant in DeKalb, and they began the first commercial production of barbed wire, producing a few thousand pounds per year by hand [Hayter].

Barbed wire was a cheaper material than wood for building fences, particularly in timber-scarce areas, and it had lower labor requirements.[8] Correspondence from Glidden and Ell-

[7] In contrast to the example of a farmer and cattle-owner considered by Coase, this shift in responsibility could not occur in the marketplace because cattle-owners did not own exclusive land-use rights either.

[8] 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 "worm" rail.

wood to two sales agents in 1875 reflected the close relationship between local woodland and the demand for barbed wire: "[we] think probably in Southwestern Texas, where lumber is reportedly dearer, the wire would probably sell for more" [Webb p.310]. Also, "[we do] 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 and think the time spent in canvassing such territory very nearly lost even if some sales are made" [Hayter]. 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, 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].

Barbed wire's path to mass production began in 1875 when the Washburn & Moen Manufacturing Company, the largest manufacturer of plain wire and headquartered in Massachusetts, sent an agent to investigate unusually large orders from DeKalb, Illinois.[9] The company acquired barbed wire samples and contracted an expert machinist to design automatic machines for its production. In 1876, 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, Washburn & Moen had incorporated the Bessemer-steel process, which made the wire stronger and resistant to rust, and had produced over nine million pounds (four thousand tons).

There was some competition among producers of barbed wire, but the industry's primary difficulty was spreading awareness of the product. Advertisements began to appear in newspapers 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, the demand was tremendous. "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, however, 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

[9] The following two paragraphs follow an account by Webb, pp.307–312.

increased, however, highlighting that it would be inappropriate to attribute all regional increases in fencing and other economic activity to the introduction of barbed wire.

Even as the quality of the barbed wire improved and consumers became increasingly aware of its effectiveness in the early 1880s, falling manufacturing costs drove down prices: $20 (1874), $10 (1880), $4.20 (1885), $3.45 (1890), and $1.80 (1897).[10] 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. 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 seems likely to reflect less-developed distribution networks. Initial opponents of barbed wire and conflicts over fence-cutting in the Plains region may also have delayed adoption until their resolution in the late 1880s [McCallum and McCallum 1965, pp.159–166; Webb, pp.312–316]. Thus, the differential effects of barbed wire on fencing costs were predominately from 1880 to 1900.

Subsequent empirical analysis requires the introduction of barbed wire to have been exogenous, i.e., that its rapid rise around 1880 was not caused by expected changes in land settlement, land improvement, or crop productivity. In general, technological improvements may be encouraged by their demand, but the demand for fencing alternatives had been high for decades. Furthermore, Glidden's low original selling price to Ellwood and their correspondence reflect little anticipation of the tremendous market demand for barbed wire. Washburn & Moen showed a keen awareness of barbed wire's potential, though even the initial level of demand was sufficient to ensure "enormous profits" [Webb, p.309]. Washburn & Moen moved as fast as possible to improve production methods, but it inevitably took a few years for the industry to ramp up production and spread awareness of the product through public demonstrations. Barbed wire's success also required the unrelated development of the Bessemer-steel process, which was still cutting-edge at that time, having been patented in England in 1855. 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]

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

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:

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

The optimal solution satisfies two first-order constraints:

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

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

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. As long as the solution is a maximum,[11] the optimal choice of investment is increasing in the level of property rights because a greater proportion of the returns would be kept; the optimal choice of property rights is increasing in the level of investment because there is an added incentive to keep the output; and higher land quality would directly increase both property rights and investment by raising total production and the marginal return to investment. The identification problem is that an observed correlation between I_{ct} and R_{ct} could reflect more than one of these 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

[11] It is a maximum when $F_{11}(I_{ct}, q_{ct})(1 - \tau(R_{ct})) < C''_{ct}(I_{ct})$ and $-\tau''(R_{ct})F(I_{ct}, q_{ct}) < C''_{ct}(R_{ct})$.

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_t^B) is assumed to be decreasing over time, but constant across counties.[12] The price of timber in each county (p_c^T) is assumed to be constant over time, but decreasing in percentage of the county that is woodland, i.e., $p_c^T = g(W_c)$ and $g'(W_c) < 0$.[13] The cost of producing property rights is the minimum obtainable value from choosing B_{ct} and T_{ct} to minimize

$$p_t^B \cdot B_{ct} + p_c^T \cdot T_{ct}, \text{ subject to: } R_{ct}(T_{ct}, B_{ct}) = \overline{R}. \tag{4}$$

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 higher timber prices, i.e., $\frac{\partial^3 C}{\partial p^T \partial p^B \partial R} > 0$. If timber fences were then no longer constructed, further price declines would have no differential effect.[14] 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 1870–1930 [Gutman 2005]. The analysis is restricted to those States in the Great Plains region for which data are available in every period from 1870–1930, which leaves only counties in Minnesota, Iowa, Nebraska, Kansas, Texas, and Colorado (shaded

[12] While there was some historical recognition that 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.

[13] 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. The potential for changes in timber prices to affect economic activity directly is analyzed in section VI.A.

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

regions in Figure 1). County boundaries changed dramatically over this period, so the data are adjusted to hold the geographical unit of observation constant (see Data Appendix).[15]

The adjusted data are only available at the beginning of each decade, which limits 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 are considered to represent the end of the pre-barbed wire period.[16] This would be particularly true for outcomes that require a period of adjustment. Similarly, 1900 is assumed to represent the end of the period in which barbed wire had a differential effect.

Before turning to the effects on crop production and land values, the empirical analysis will initially focus on three measures of farmers' land-use: the percent of county land that is in farms,[17] the percent of county land that is improved,[18] and the percent of land in farms that is improved. Farmers' decisions to settle land reflect positive expected profits, so an increase in settlement would be a first indication of the increased potential returns discussed by Cheung and others. An increase in land improvement is more direct evidence of a willingness to sink investments into the future productivity of that land. Importantly, the definition of improved land requires the land itself to be physically improved, rather than simply fenced.

Changes in land improvement per acre of farmland address three interesting effects. First, an increase would indicate that farmers substituted toward improvement-intensive activities, where profitability is typically more sensitive to expropriation risk. Second, the timing of adjustments in improvement-intensity indicate the extent to which farmers adjusted along the intensive vs. extensive margins. Third, if it were true that investment increased property

[15]Data from other Plains States are not available back to 1870 and there were few distinct counties in 1870. Partial data from other 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.

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

[17]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 vegetable-gardens, ornamental lawns, irreclaimable marshes, and considerable bodies of water" [Gutman 2005]. It is unclear how often the extremely large, partially nomadic, western ranches would have been included in this variable. The outcome would be best interpreted as "fixed settlement" or, more literally, land deemed sufficiently "settled" by the census taker.

[18]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" [Gutman 2005].

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.

The Census reports only the number of acres of woodland in farms, so the amount of woodland available to farmers in each county is defined as the number of acres of woodland in farms, divided by the number of acres in that county. This is potentially problematic because some counties might appear to have little woodland when, in fact, they were only sparsely settled.[19] For this reason, the amount of woodland is calculated based on 1880 data when settlement was higher than in 1870, though the results are very similar when using 1870 woodland data.[20] Given that wooded areas were initially the most desirable in these counties, most of the locally available woodland is likely to be included in this measure. While some woodland might have already been cut down for its timber, it would not have been necessary in this region to clear large amounts for cropland.

III.B Summary Statistics

The average amount of woodland per county in the sample is 10%, but most counties have lower woodland levels: 39% have 0–4% woodland, 15% have 4–8% woodland, and 11% have 8–12% woodland. The empirical analysis makes use of these three woodland categories and, in particular, three benchmark values of 0%, 6%, and 12%. These benchmarks 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.

Table 2 reports average county characteristics in 1880 for all sample counties and within these three woodland groups. Low-woodland counties tend to be larger, but lag behind in measures of land-use, land value, and agricultural production. Medium-woodland county averages generally fall between those for low-woodland and high-woodland counties, but are much closer to the later. Total fencing expenditures are lower in low-woodland counties, but are roughly 4% of the total output value across each group. Given higher per unit costs in low-woodland areas, this would suggest a lower intensity of fencing in those areas.[21] Less of the farmland in low-woodland counties is used for crops. Low-woodland counties use less land for corn and more for hay, as a percentage of total cropland. Crop production choices

[19] Note, however, that the results are robust to controlling for convergence in land-use.

[20] Woodland data are not available for 1890 or 1900, but remaining woodland after the introduction of barbed wire would generally be considered an outcome variable of the subsequent expansion in settlement and land improvement.

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

are fairly balanced across these groups, however, which somewhat mitigates concerns that crop-specific technology or price shocks could have large differential effects.

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 production outcome Y from a decrease in the cost of property rights protection is then:

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

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

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

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 and potential bias corrections. 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 fence prices 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.[22] 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:

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

The intuition for this analysis and basic unadjusted results can be seen in plots of land-use averages, broken out by time period and county woodland category. Figure 2 shows that settlement and land improvement changed similarly over the entire period in medium- and high-woodland counties. Low-woodland counties also trended similarly, except for large relative increases during the period of adjustment to barbed wire (1880–1900). This pattern is particularly clear in the middle panel, which displays changes in the number of improved farm acres per county acre. These figures illustrate the key identification assumption for estimating changes in land-use: without barbed wire, the increases in low-woodland counties from 1870–1880 would have slowed along with the increases in medium- and high-woodland counties. These figures also motivate later robustness checks, which control for the differences in initial outcome levels.

In the extreme case that $p_L^T = p_M^T$, barbed wire would have no differential effect across medium- and high-woodland counties. That seems unlikely, but the specification test from equation (7) would then provide an unbiased estimate under the new assumption:

$$(8) \qquad Y_{ct}^*(R_{ct}^*, q_{ct}) = F(R_{ct}^*) + \psi_t[2 \cdot 1\{c = L\} + 1\{c = M\}] + \gamma_t + \mu_c + \epsilon_{ct},$$

where $1\{\cdot\}$ equals one if the bracketed statement is true. This assumption allows counties with different woodland levels to trend differently, but restricts the change for low-woodland counties relative to medium-woodland counties to be the same as the change for medium-woodland counties relative to high-woodland counties.[23]

[22] 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].

[23] In the continuous analogue of this procedure, the use of equal-sized ranges of woodland implies that a zero would be estimated if changes over time were only linearly correlated with woodland.

IV.B Estimation Strategy

While this discrete approach is illustrative, examining the full distribution of county woodland levels makes more efficient use of the data and is more transparent than somewhat arbitrary group cutoffs. An initial graphical exercise provides a clear view of the raw data and useful guidance for the regression methodology. In Figure 3, each county's level of land settlement from 1870–1900, having subtracted off its average value over the entire 1870–1930 period, is plotted against its fixed 1880 level of woodland. Figures 4 and 5 display the same information, but for the fraction of county land that is improved and the fraction of farmland that is improved, respectively. To assist the interpretation, a fourth-degree polynomial function is fitted to the data in each period.[24]

The data are somewhat noisy in 1870, but a concave relationship between each land-use measure and woodland is clearly established by 1880. This relationship largely disappears by 1890 and has flipped to convex by 1900, particularly for the two measures of land improvement. These shifts reflect counties with little available timber making large gains in all three measures from 1880–1900, relative to counties with more woodland. Upward shifts in the level of the plots reflect positive changes over time for all counties, on average.[25] After 1880, the twisting of the polynomial function is large relative to that general upward shift, particularly for the two land improvement outcomes. This indicates the high degree to which overall changes in land-use depended on local woodland.

The fourth-degree polynomial functions were seen to fit the raw data well, so a similar regression approach is used to quantify the results' magnitudes, statistical properties, and robustness. County-level production outcomes are first-differenced to control for fixed county characteristics. State-by-decade fixed effects α_{st} are included to control for state-specific time shocks. For each production outcome, the estimated equation is:

$$Y_{ct} - Y_{c(t-1)} = \alpha_{st} + \sum_{t=2}^{T}(\beta_{1t}W_c + \beta_{2t}W_c^2 + \beta_{3t}W_c^3 + \beta_{4t}W_c^4) + \epsilon_{ct}. \tag{9}$$

The estimated β's summarize how changes in production outcome Y varied by county woodland level W. Note that the β's are allowed to differ in each time period. Estimating equation (9) with county fixed effects instead yields identical estimates, but their standard errors tend

[24]For clarity, this polynomial is only shown for woodland values less than 0.3 because it varies considerably above that level due to outliers in the woodland distribution.

[25]For the time effects to be observable, these plots are shown without controlling for state-by-decade fixed effects, though the dependence of land-use on woodland is slightly clearer when they are included.

to be higher by 8–10% because the untransformed error terms are closer to being a random walk than serially uncorrelated.[26]

The full set of regression coefficients is difficult to interpret, but the desired result is how an outcome changed in low-woodland counties relative to medium- and high-woodland counties. The simplicity of the previous discrete estimators is maintained by evaluating the predicted changes at indicative woodland values: 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. Figures 3–5 showed that the functional relationship was fairly simple, but the predicted changes are easier to interpret than changes in the estimated polynomial function.

V Estimation Results

V.A Land Settlement and Land Improvement

From estimating equation (9), each column in Table 3 reports the predicted change in land-use for a county with one amount of woodland, relative to a county with another level of woodland. Each coefficient can be interpreted as if it were a difference-in-difference estimate for the two indicated time periods and woodland levels. For example, the first coefficient in column 1 reports that acres of settlement per county acre increased from 1870–1880, on average, 0.044 more in a county with 0% woodland than in a county with 6% woodland. That is, a county with 0% woodland that was 20% settled would have, in expectation, caught up to a county with 6% woodland that was initially 24.4% settled. Similarly, the first coefficient in column 2 indicates that a county with 6% woodland that was initially 24.4% settled would have, in expectation, caught up to a county with 12% woodland that was 27.4% settled. The standard error for each coefficient, corrected for heteroskedasticity and clustered at the county level, is reported in parentheses. In brackets below each coefficient comparing counties with 6% woodland and 12% woodland is the t-statistic of its absolute

[26] If equation (9) 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.

difference from the contemporaneous coefficient comparing counties with 0% woodland and 6% woodland. For example, the coefficients in the first row of columns 1 and 2 are not statistically different with a t-statistic of 0.54.

All three outcome variables experienced substantial and statistically significant increases after 1880 in counties with 0% woodland relative to counties with 6% woodland. From 1880–1900, settlement increased by 26 percentage points, land improvement increased by 30 percentage points, and the intensity with which farmland was improved increased by 19 percentage points. After 1900, when barbed wire had been universally adopted, these increases ceased and the change in levels was maintained. Counties with 6% woodland made some gains from 1880–1900, relative to counties with 12% woodland, but these were less than the relative gains at lower woodland levels. The general pattern of these results can be seen in Figure 6, which plots the cumulative predicted changes after 1870 for each outcome variable.

The exact effect attributed to barbed wire depends on assumptions about other economic shocks and whether these reported coefficients should themselves be differenced. If relative changes from 1870–1880 would have continued regardless, that pre-trend should be subtracted from the estimated changes from 1880–1900. If the estimated changes between counties with 6% and 12% woodland reflect other contemporaneous shocks, as in equation (8), it would be appropriate to subtract that coefficient from the estimated changes at lower woodland levels. If both scenarious were true, then the coefficients should be differenced both across- and within-periods. Changes after 1900 could also indicate some previous differential trend that should be taken into account. Across all specifications in the paper, preferred estimates do not incorporate these further adjustments, but it is important that the core results are robust under these alternative scenarios.

The estimated effects are particularly robust to these different assumptions for the ratio of improved land to settled land. This outcome variable most closely resembles those analyzed in other studies of property rights that focus on whether a given plot of farmland has been improved in some way. For this ratio, there are few changes in the data apart from a strong shift toward more improvement-intensive activities from 1880–1900 in counties with 0% woodland, relative to counties with 6% woodland. Despite substantial expansion along the extensive margin of settlement, increases in the intensity of improvement reveal increases along the intensive margin to have been much larger. Given an increased ability to secure land, it appears that a great push to settle land did not come at the expense of that land being improved in the short-term.

The results are robust to a variety of changes in the empirical specification. The estimates are not sensitive to the polynomial functional form, as long as it is sufficiently flexible to capture the basic non-linearity in Figures 3–5. The estimates change only slightly when pre-barbed wire woodland levels are set using data from other periods.[27] The estimated increases from 1880–1900 decrease by roughly 30% when the state-by-decade fixed effects are dropped, which might be surprising if one expected a positive cross-state response to lower fencing costs. Inter-state changes are most likely to be confounded for Colorado, given its distance from most previous settlement. When Colorado is excluded from the sample, the baseline results are similar and the estimates increase 5–20% when the state-by-decade fixed effects are dropped.

Because counties with less woodland initially lagged behind others, the effects of barbed wire could be confounded with a general trend toward convergence. This effect should have been at least as large from 1870–1880, however, when low-woodland counties also initially lagged behind others. As a more formal check of the results, equation (9) is estimated with an additional fourth-degree polynomial function of the county's fixed 1870 land-use level interacted with each time period:[28]

$$(10) \qquad Y_{ct} - Y_{c(t-1)} = \alpha_{st} + \sum_{t=2}^{T}(\beta_{1t}W_c + \beta_{2t}W_c^2 + \beta_{3t}W_c^3 + \beta_{4t}W_c^4) + \sum_{t=2}^{T}(\gamma_{1t}Y_{c1870} + \gamma_{2t}Y_{c1870}^2 + \gamma_{3t}Y_{c1870}^3 + \gamma_{4t}Y_{c1870}^4) + \epsilon_{ct}.$$

Table 4 reports analogous estimates to those in Table 3. For conciseness, the coefficients on the initial outcome terms are not shown because they have no direct causal interpretation; rather, these control variables are only relevant to the extent that they affect the woodland coefficients. For the estimates on the woodland terms, the general pattern of results is similar to before. The estimated magnitudes from 1880–1900 drop by roughly 40%, but most are still substantial, statistically significant, and pass the same robustness checks. The one notable exception is the lack of an increase in land settlement from 1880–1890. There is also some new evidence for negative changes from 1870–1880.[29]

It is useful to verify the robustness of the results to allowing for a general pattern of convergence, but one reason why these counties had low initial outcome levels was the lack of fencing materials, for which home county woodland levels are an imperfect proxy. If much

[27] Using data from 1870, the only meaningful difference is that improved land per acre of farmland decreased by 7 percentage points from 1870–1880 in a county with 0% woodland relative to a county with 6% woodland. Using data from 1910, 1920, or 1930 is problematic but yields similar results, except that increases in land settlement from 1870–1880 were roughly equal to increases from 1880–1890 and 1890–1900.

[28] The estimates are not sensitive to including alternative polynomial functions of the initial outcome level, but it is appealing to allow the same flexibility for both the initial land-use level and woodland level.

[29] Measurement error in the initial outcome level may make it difficult to interpret estimated changes between the first and second time period.

of the observed convergence was due to unmeasured variation in the need for barbed wire, these estimates would understate barbed wire's true effect. Furthermore, pre-barbed wire counties with the same land-use and different woodland levels would be expected to differ along other dimensions, in order for farmers to be compensated for the lack of woodland. Thus, controlling for pre-barbed wire county characteristics that are an outcome of farmers' optimal decision-making may be counterproductive in identifying counties that would have trended similarly.

V.B Crop Productivity and Crop Choice

All cropland is defined as improved, so the previous analysis does not address whether farmers adjusted crop production methods along the intensive margin. Cheung and others discuss how producers may respond to lower property rights by reducing investments, harvesting the produce earlier, or making a number of other adjustments that would be reflected in sub-optimal productivity. Equation (9) is modified slightly to analyze crop productivity as a summary statistic for all unobserved production adjustments.

County-level data on total production and acreage for a variety of crops (barley, corn, cotton, hay, oats, rye, wheat) are first available in 1880, so data in all subsequent periods are adjusted to 1880 county geographical boundaries. 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 each decade, productivity is divided by its value in 1880 to normalize the data.[30] Mis-measurement creates some extreme values for productivity, so the upper and lower centiles of the normalized productivity distribution are dropped.[31] The previous state-decade fixed effects are replaced with crop-state-decade fixed effects and the equation is run in first differences for each crop-county pair:

$$(11) \qquad \frac{Y_{pct} - Y_{pc(t-1)}}{Y_{pc1880}} = \alpha_{pst} + \sum_{t=2}^{T}(\beta_{1t}W_c + \beta_{2t}W_c^2 + \beta_{3t}W_c^3 + \beta_{4t}W_c^4) + \epsilon_{pct}.$$

Columns 1 and 2 of Table 5 present the baseline results, where data on all crops are stacked and the effect of woodland on productivity is constrained to be the same across all crops. From 1880–1890, average productivity across all seven crops increased 19.3% more in a county with 0% woodland than in a county with 6% woodland. The increase was concentrated at low woodland levels, but did not continue: from 1890–1900, relative

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

[31]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.

productivity decreased by 1.8%, leaving it 17.5% higher than in 1880. There were also relative productivity gains in the 1920s, however, indicating a potential for confounding factors to have similarly large estimated effects.

In contrast to before, these estimated positive effects did not continue into the 1890s. One potential explanation is that the primary initial reaction to barbed wire's partial availability was to secure current cropland. Even as barbed wire became more widely used, productivity would only increase as cropland became more securely held if farmers had continued to cultivate land without fences after 1890. Along with the estimated increases in improvement per farm acre, this would imply that adjustment along the intensive margin was faster and greater than that along the extensive margin.

These baseline results are extended by exploiting crop-level differences in vulnerability to cattle damage. Of the analyzed crops, cattle would be least inclined to eat or trample cotton fields. While cattle certainly eat hay (various grasses), hay fields are resistant to cattle damage and, at certain times of the year, can be intended for grazing. The other crops (corn, wheat, oats, barley, rye) would not be used for grazing, as it would substantially lower grain yields, and it would be more important that they be protected from roaming cattle.[32]

Columns 3–8 of Table 5 report results from separately estimating equation (11) for these three groups of crops. For those crops most at risk of cattle damage, the estimates are similar to before, and productivity increased by 27.3% from 1880–1890. In contrast, relative productivity for hay was unchanged from 1880–1890.[33] Cotton productivity declined substantially, but the analysis is very imprecise due to a lack of low-woodland counties that grew any cotton in Texas.

If land within these Midwestern counties was not homogeneous, the effect of changes in farmers' production methods would be confounded with changes in the productivity of land under production. The typical response to a decrease in production costs would be a shift by farmers toward otherwise unprofitable and lower quality land, which would bias downwards the estimated effect on productivity from farmers' adjustments in production methods. If areas within counties that were further from woodland were more productive, however, the incentive to move into less-wooded areas could increase productivity. This effect would tend to be at least as strong when comparing higher woodland levels, but productivity increases

[32] Wheat, oats, barley, and rye could be grown for hay instead of for grain, but would then be managed differently. If grown for grain, grazing would typically lower yields by 25–79% [Smith et al. 2004]. The Census defines production data for these crops as that which is produced for grain. Before 1925, the Census did not specifically ask about rye only produced for grain, but other questions on hay production are likely to have included rye grown for hay.

[33] There appears to have been a poor hay harvest in 1920 in low-woodland areas.

were much smaller. Furthermore, for the relevant counties, 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. Thus, little cultivated land would actually have been previous woodland or very close to woodland.

If barbed wire did indeed encourage productivity improvements, one would expect farmers to substitute production toward those more-productive activities. Table 6 reports results from estimating equation (9) for outcome variables that would reflect such substitution: the percentage of land in farms used for growing any crop (columns 1–2), the percentage of cropland used for growing crops more at-risk of damage by cattle (columns 3–4), and the percentage of cropland used for crops less at-risk of damage by cattle (columns 5–8).[34] Indeed, farmers are estimated to have allocated greater portions of land to those activities that were made more productive: a greater proportion of farmland became used for crops and a greater proportion of cropland became used for more at-risk crops. Just as for the changes in productivity, this change in land allocation occurred from 1880–1890, again indicating a primary response along the intensive margin.

V.C Value of Land, Buildings, and Fences

This section aims to quantify the value of farmers' adjustments to barbed wire. Estimated increases in settlement may reflect an increase in the desirability of owning land, but changes in land value per county acre could place a monetary figure on that increase. One potential difficulty is that measurement of land values is more subjective than measurement of land-use and production, particularly if there were few market transactions to guide farmers' valuations. There was a large amount of land speculation at that time, however, and taxes were paid on the value of land [Gates 1973].[35]

The only available measure in each period, though, is the combined value of farmland, buildings, and fences.[36] Thus, the gains indicated by measured increases in land value would be partly lost to increased construction costs. Land does appear, however, to have been the largest component of this measure. In 1900 and 1910, when more data are available,

[34] For columns 1–2, total cropland is defined as the sum of all measured crops in each period. Other crop types are included when measured by the Census and all non-measured or missing values are treated as zeros. For columns 3–8, cropland is defined similarly, but holding the set of analyzed crops fixed at these seven originally measured crops. Cotton is only ever reported to be grown in Texas, so the analysis of cotton is restricted to only counties in Texas. Columns 7–8 then report farmers' changes in cotton production, conditional on cotton being in the relevant choice set.

[35] 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 most of the response would not occur until newly desirable lands were settled.

[36] These three components are mentioned, but the variable may include other improvements. Data in additional periods are drawn from Haines and ICPSR [2005].

the value of buildings averaged between 13% and 17% of the total for low-, medium-, and high-woodland counties. Fences' value is unknown, but costs of building and repairing fences in 1879 were, on average, 1% of the total value of land, buildings, and fences.

The effect of barbed wire on this overall measure of land value is estimated using equations (9) and (10). 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.[37] Additive shocks would have a larger percentage effect in areas with low initial levels, however, so it may be more important to control for differences in initial levels. For example, given similar large increases in settlement across all counties from 1870–1880, there would tend to be larger percentage increases in land value in low-woodland counties with low initial land values.

Table 7, columns 1–2, presents the basic results from estimating equation (9) for the natural log of land value per county acre. In contrast to previous results, the estimated relative changes are largest from 1870–1880. These estimated relative increases then decline over time and indicate a steady pattern of convergence at both low and medium woodland levels.

Table 7, columns 3–4, presents analogous results when controlling for initial outcome differences. While this approach is subject to the same concerns as before, it adjusts for a tendency toward convergence that appears to underlie the results in columns 1–2. Land value per county acre is now estimated to have decreased relatively from 1870–1880 in counties with low- and medium-woodland. There were large relative increases in low-woodland counties from 1880–1900, though only the change from 1880–1890 was statistically greater than relative changes between medium- and high-woodland counties. This increase of 0.365 log points from 1880–1890 represents a relative increase of 44% above 1880 levels. By comparison, in 1880, the value of all agriculture products averaged 26% of the total land value in low-woodland counties.[38]

These estimates largely corroborate earlier findings, but it is difficult to quantify the overall value of barbed wire to farmers for two main reasons. First, an unknown amount of these increases in measured land value would be paid in construction costs. Second, the empirical methodology is fundamentally ill-suited to determining the total effect of barbed wire; rather, it focuses on identifying relative effects.

[37] Running the analysis in levels yields imprecise and unstable estimates, particularly in later periods.

[38] An analysis of land value per farm acre is complicated by potentially important changes in the composition of farmland, though the results are similar to those for land value per county acre. Without controlling for initial differences, the relative increases are largest from 1870–1880. When controlling for initial differences, land value per farm acre increased 14% more in low-woodland counties from 1880–1890, after decreasing relatively from 1870–1880.

If the first concern is set aside and barbed wire is assumed to have had no effect on counties with some amount of woodland, it is possible to calculate an approximate overall effect of barbed wire on the sample counties. Sixty-three counties had between 0% and 1% woodland, with an average of 0.42% woodland and \$1.7 million of land value in 1880. From 1880–1890, the estimated change in total land value for a county with 0.42% woodland relative to one with 6% woodland was 0.32 log points or 38%, when controlling for initial outcome differences. Thus, if it is assumed that barbed wire had no effect on counties with 6% woodland, the estimated overall effect on land value within this group of counties is estimated at approximately \$41 million ($63 \times$ \$1.7m $\times$ 38%). Adding these estimated amounts for counties in other woodland groups (1–2%, 2–3%, 3–4%, 4–5%, 5–6%) yields an estimate of \$91 million with a standard error of \$30 million. Similarly, if it were assumed that barbed wire had no effect on counties with 12% woodland, the estimated total effect is \$128 million with a standard error of \$51 million. As a comparison, the United States' GDP in 1880 was approximately \$10 billion [Johnston and Williamson 2005].

VI Analysis of Potential Confounding Factors

VI.A Other Shocks Correlated with Woodland Levels

These empirical estimates would not identify the effects of barbed wire if there were other reasons for counties with little woodland to have trended differently from 1880–1900 than counties in the same State with more woodland. It is impossible for any historical account, empirical methodology, or statistical test to rule out this possibility. Yet, as a complement to the previous statistical techniques, this section provides additional evidence on some potential reasons for these counties to have trended differently.

An initial concern might be that some shock to the timber market might differentially affect farmers' decisions in these counties. Indeed, barbed wire may have lowered the value of local timber by replacing wooden fences.[39] These counties had such little woodland, however, that shifts in the timber market would have had limited effects on land-use. In contrast to the Eastern United States, land improvement in the Midwest did not generally involve clearing woodland because there was already so much open land. Also, the timber market was only a very small sector of the economy: in 1870, the average value of all forest products was only 0.7% of all farm products.

[39] It is even possible that barbed wire raised the overall demand for local timber, by greatly increasing the amount of settlement. Farmers would still have required some wood for buildings and fence posts.

Two other potential sources of differential shocks 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]. There were a number of subsequent land acts, but they were uniformly ill-suited to the region, poorly enforced, and played little role in the successful settlement of the Great Plains [Webb, pp.424–431].[40] It might be a concern if railroads were just expanding into low-woodland counties around 1880, but most railroad construction had been completed by 1873, at which point the railroad industry faced a panic due to excessive construction and little usage on the Great Plains. Webb summarizes:

> 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]

There were a number of technological improvements in the post-Civil War period and mechanization began to increase in the 1900s, but the rise of barbed wire from 1880–1900 appears to coincide with a notable lack of other major advances [Rasmussen 1962, Primack 1977]. 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. This leads Webb to conclude 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]. Also, for the regions analyzed here, conflict with Native Americans had ended by this time.

VI.B Theory and Evidence on Additional Effects of Barbed Wire

Valid estimates of barbed wire's effects need not represent the effects of increased property rights if barbed wire affected the analyzed outcomes through any additional channels. Property rights are of no concern in a single-agent economy, so these other effects can be seen in a stylized economy with one agent, fixed prices, and two production goods: cattle and crops. A simple model captures what appear to be the two main additional effects of barbed wire: first, the encouragement of cattle production and, second, the encouragement of joint production of cattle and crops. Barbed wire is estimated to have had small or negative effects on cattle production and to have decreased joint production, however, indicating that the primary effect of barbed wire was to lower the cost of protecting property rights.

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

Assume that an economy is endowed with land that varies in quality q from 0–1. Land produces either one unit of cattle or $\max(0, q - \alpha)$ units of crops ($0 < \alpha < 1$). That is, crops require higher quality land and their production is more sensitive to differences in land quality. "Fences" can be constructed at some cost. The first effect of fencing is to increase the number of cattle produced per unit of land, reflecting an increase in control over feeding and breeding. The second effect of fencing is to allow a combination of cattle and crops to be produced, by preventing the cattle from trampling all crops. For non-extreme price ratios, heterogeneity in land quality implies that the total value of production would increase when joint production becomes possible.

In this model, a decrease in the cost of fencing would encourage its construction and, thus, encourage both the production of cattle and the less prevalent good. These effects could either reinforce or mitigate each other, so the final predictions for observed land-use and productivity depend on very specific assumptions about the land, production technology, and data collection. Therefore, the empirical analysis will focus on the two clear intermediate effects that are more easily tested: the predicted increases in cattle production and/or joint production. Of course, changes in the availability of property rights would also affect these outcomes, but this exercise is designed to address whether non-property right effects could be driving the earlier results. If so, it seems reasonable to expect that non-property right effects should also dominate along these dimensions.

Data on the number of cattle per county are available beginning in 1880, so county regions are held constant at their 1880 boundaries. The effect of barbed wire on cattle production is estimated using the same methodology as in equation (9). The dependent variable is the number of cattle per five county acres. Five acres is a very rough approximate per cow average acreage requirement, so the estimated magnitudes can be compared somewhat to previously estimated changes in land-use.

Table 8 presents the results, evaluated at the same woodland levels as before. The number of cattle was nearly unchanged in counties with 0% woodland from 1880–1890, relative to counties with 6% woodland. The estimated coefficient can be roughly interpreted as implying that 0.46% less of the county became devoted to cattle production. This change was statistically lower than the relative change at higher woodland levels. The relative number of cattle did increase somewhat from 1880–1890, though not only for low-woodland counties. These increases also continued through 1920, suggesting a general trend towards increased cattle production. In all, there is little indication that barbed wire specifically led to relative increases in cattle production and, especially, not of a magnitude that could account for the estimated changes in land-use.

To estimate the effect of barbed wire on the joint production of cattle and crops, it is necessary to create a dependent variable that captures the geographic distribution of both. It is very difficult, however, to estimate the percentage of land devoted to cattle in each county.[41] It is straightforward, however, to compute the percentage of farmland allocated to the production of all measured crops in each county and decade, M_{ct}. The remaining portions of farmland are then assumed to be used for cattle, or other purposes that are not systematically changing over time within States.

This assumption allows the definition of two "county specialization" indexes. The first index is defined as the squared difference between the percentage of county farmland devoted to crops and the average over all counties in that decade: $I^1_{ct} = (M_{ct} - \overline{M_t})^2$. To account for differences across States in the proportion of other land used for cattle, a second index is defined similarly as the squared difference from the average in that decade and State: $I^2_{ct} = (M_{ct} - \overline{M_{st}})^2$.[42] These indexes increase when counties with an above-average percentage of farmland devoted to crops then increase that proportion, and vice versa. Applying the methodology from equation (9) controls for average county deviations from the mean and any State-wide shocks. Columns 3–6 of Table 8 report the estimation results, along with the mean and standard deviation for each specialization index in 1880.

Counter to the prediction of the model with no role for property rights, counties with 0% woodland became increasingly specialized from 1880–1890, relative to counties with 6% woodland. The estimated magnitudes are difficult to interpret, but are large relative to the indexes' mean and standard deviation. The increases continued from 1890–1900 for one index and were always larger than the relative changes at higher woodland levels. After 1900, the relative degree of specialization declined moderately or stayed constant.

Thus, it does not seem that the previously estimated effects of barbed wire were due to the encouragement of joint production. Indeed, one might expect the advantages to joint production to have been minimal, given that it was two distinct groups of people that raised crops and managed large cattle herds. Even if barbed wire had meaningfully encouraged joint production, land quality would have had to vary an unreasonable amount within these Midwestern counties for this to explain increases in land settlement and improvement on par with the total amount of land previously used by cattle.

[41] The problem is not only that per cow acreage requirements vary with the environment, as this would be somewhat observable, but that the amount of land used per cow would also vary depending on the farmer's production methods, desired cattle quality, and the desired sustainability.

[42] If acres of cropland are restricted to include only those crops measured in each period, the specialization indexes and estimation results are nearly identical.

VII Evidence on States' Legal Reforms

Legal reforms to the "lawful fence" requirement had the potential to lower the costs of establishing exclusive land-use rights in the Great Plains. State legislatures could pass a "herd law," which made cattle owners formally responsible for all damages to others' crops, whether or not those fields were fenced. If these herd laws were enforced, they would have reduced the need for fencing and, thus, lowered farmers' costs of establishing exclusive land-use rights. Davis [1973] argues that these laws provided many of the benefits that were subsequently reinforced by the introduction of barbed wire, though there is little evidence on the laws' effectiveness.

Table 9 reports the results from estimating equation (9) in each State to implement some version of these reforms, as discussed by Kawashima and Davis. The analysis is less stable within individual States, but the bulk of the evidence indicates that these legal reforms were not successful along the same dimensions that barbed wire was found to have had large effects. The following two paragraphs describe the two types of reforms and the main results (boxed in Table 9).

Nebraska adopted a State-wide herd law in 1871, which would have mostly benefited farmers in counties with the least woodland and highest fencing costs. By 1880, however, land improvement in counties with 0% woodland declined substantially relative to counties with 6% woodland. Not until 1890, after the introduction of barbed wire, did low-woodland counties show substantial increases in land improvement. The coefficients are not estimated reliably at higher woodland levels because 90% of the counties had less than 6% woodland.

Kansas gave counties the option of adopting a herd law in 1872. While I do not know which specific counties adopted the herd law, it was generally implemented in counties with more woodland, likely because farmers were a larger and more powerful political force [Webb, p.500; Sanchez and Nugent; Kawashima]. In contrast to the case of Nebraska, it was farmers in counties with more woodland that would have most benefited. Settlement increased more in low-woodland counties from 1870–1880, however, and there was little relative change in land improvement. It was not until 1880–1890, after the introduction of barbed wire, that low-woodland counties gained in improved land. As the number of farmers increased, the entire State adopted a herd law in 1889. In theory, this would have mostly benefited farmers in low-woodland counties, yet these counties subsequently experienced small declines or no changes in land improvement. Texas also adopted a county-option policy in 1870 and, again, it was generally implemented in counties with more woodland. There are few systematic patterns in the data, though, either after these laws or the introduction of barbed wire.

Most evidence on the effectiveness of herd laws comes from advocacies in newspapers, yet there is little evidence on the laws' enforceability. As one would expect, cattle owners resisted making compensating payments. 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 kept building fences at considerable expense both before the legal reforms, after the legal reforms, and after the introduction of barbed wire. These laws likely had some influence or they would not have been so hotly debated, but their passage was more a reflection of changing local political power than an influence on production decisions. In the absence of physical barriers, formal laws appear to have provided farmers little refuge from roaming cattle.

VIII Conclusion

Barbed wire fencing is argued to have encouraged property rights protection due to the combination of timber shortages and the role of fences in establishing exclusive land-use rights in the 19$^{\text{th}}$ century American Midwest. Barbed wire would likely not have similar effects in other contexts, but it is natural to consider whether these estimates may be informative about the effects of increased property rights protection in other places and times. Property rights lack a natural unit of measurement, so it is rarely possible to estimate magnitudes that are directly interpretable in other contexts. By analyzing a shock to the entire frontier of American farmland, though, these results do not merely reflect local composition and substitution effects.

Decreased costs of enforcing property rights, due to the introduction of barbed wire fencing, are found to have encouraged the development of timber-scarce regions in the Midwest United States. Substantial increases in farming were estimated along both the extensive and intensive margins, though increases on the intensive margin were found to be dominant. Farmland became more intensely improved and cropland more efficiently managed. The estimated magnitudes remain substantial throughout several robustness checks.

The transformation of farming in the Great Plains suggests a potential for similar success on a grand scale in other regions with current difficulties in protecting land rights. In contrast to the typical policy reform, these results reflect the potential gains from improvements in property rights protection that largely fall outside formal institutional channels. Indeed, the apparent ineffectiveness of contemporaneous legal reforms may indicate a difficulty in depending on purely *de jure* actions. For any mechanism that might improve the security of property rights, however, the potential gains appear to be large.

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]. The conversion process is designed to obtain data for each initial county when the data are subsequently reported for different county definitions. The required map files are available at the beginning of each decade, so data from 1925 are not included. A few counties in the data, between 3 and 9 in each period, are dropped because they do not match to the map files.

This conversion process is now described for the case of converting 1930 data into the county definitions in 1870, as seen in Figure 1. The 1870 map is intersected with the 1930 map and each 1930 county is assigned the identification number of its 1870 county origin. When the 1930 county falls within more than one 1870 county, each piece of the 1930 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 1930 piece are found by multiplying the original 1930 Census value by that piece's relative size. Finally, the 1930 data for each 1870 county region are found by summing across all 1930 pieces that make up the region. The summed measure is considered to be missing when data for any piece is missing. Final values equal to zero are included, though the results are very similar when these are considered to be missing.

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 electronic 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 standard deviation of the number of acres is greater than 50,000 are dropped (3% of the final sample). The cutoff was chosen at a point where the standard deviations then began to increase very rapidly. The effect on the results is minimal, but the coefficients' magnitude and precision generally increase slightly.

References

Acemoglu, Daron and Johnson, Simon. 2005. "Unbundling Institutions." *Journal of Political Economy*. Vol. 113, No. 5, pp. 949-995.

Anderson, Terry L. and Hill, Peter J. 1975. "The Evolution of Property Rights: A Study of the American West." *Journal of Law and Economics*. Vol. 18, No. 1, pp. 163-179.

Anderson, Terry L. and Hill, Peter J., eds. 2001. The Technology of Property Rights. The Political Economy Forum Series: Oxford.

Anderson, Terry L. and Leal, Donald R. 2001. Free Market Environmentalism. Palgrave: NY.

Banerjee, Abhijit V.; Gertler, Paul J.; Ghatak, Maitreesh. 2002. "Empowerment and Efficiency: Tenancy Reform in West Bengal." *Journal of Political Economy*. Vol. 110, No. 2, pp. 239-280.

Besley, Timothy. 1995. "Property Rights and Investment Incentives: Theory and Evidence from Ghana." *Journal of Political Economy*. Vol. 103, No. 5, pp. 903-937.

Bogue, Allan G. 1963. "Farming in the Prairie Peninsula, 1830-1890." *Journal of Economic History*. Vol. 23, No. 1, pp. 3-29.

Brasselle, Anne-Sophie; Gaspart, Frederic; Platteau, Jean-Philippe. 2002. "Land Tenure Security and Investment Incentives: Puzzling Evidence from Burkina Faso." *Journal of Development Economics*. Vol. 67, No. 2, pp. 373-418.

Carville, Earle; Heppen, John; Otterstrom, Samuel. 1999. HUSCO 1790-1999: historical United States county boundary files [electronic resource]. Louisiana State University (Baton Rouge, LA): Geoscience. http://www.ga.lsu.edu/husco.html

Cheung, Steven N.S. 1970. "The Structure of a Contract and the Theory of a Non-Exclusive Resource." *Journal of Law and Economics*. Vol. 13, No. 1, pp. 49-70.

Coase, Ronald H. 1960. "The Problem of Social Cost." *Journal of Law and Economics*. Vol. 3, No. 1, pp. 1-44.

Cooke, Alistair. 1973. America. Alfred A. Knopf: New York. 1976 printing.

Davis, Rodney O. 1973. "Before Barbed Wire: Herd Law Agitations in Early Kansas and Nebraska," in Essays in American History in Honor of James C. Malin, ed. Burton J. Williams. Coronado Press.

Demsetz, Harold. 1967. "Toward a Theory of Property Rights." *American Economic Review: Papers and Proceedings*. Vol. 57, No. 2, pp. 347-359.

Encyclopedia Britannica, eleventh edition. 1911. "Barbed Wire." http://1911encyclopedia.org/B/BA/BARBED_WIRE.htm

Gates, Paul W. 1973. "The Role of the Land Speculator in Western Development," in Landlords and Tenants on the Prairie Frontier, pp. 48-71. Cornell University Press.

Goldstein, Markus and Udry, Christopher. 2005. "The Profits of Power: Land Rights and Agricultural Investment in Ghana." Mimeo, Yale University, November.

Gutmann, Myron P. 2005. "Great Plains Population and Environment Data: Agricultural Data [Computer file]." Ann Arbor, MI: University of Michigan / Ann Arbor, MI: ICPSR.

Hayter, Earl W. 1939. "Barbed Wire Fencing – A Prairie Invention." *Agricultural History*. Vol. 13, pp. 189-207.

Haines, Michael R., and the Inter-university Consortium for Political and Social Research. 2005. Historical, Demographic, Economic, and Social Data: The United States, 1790-2000 [Computer file]. ICPSR02896-v2. Hamilton, NY: Colgate University / Ann Arbor, MI: ICPSR.

Jacoby, Hanan G.; Li, Guo; Rozelle, Scott. 2002. "Hazards of Expropriation: Tenure Insecurity and Investment in Rural China." *American Economic Review*. Vo. 92, No. 5, pp. 1420-1447.

Johnston, Louis D. and Williamson, Samuel H. 2005. "The Annual Real and Nominal GDP for the United States, 1790 - Present." Economic History Services, http://www.eh.net/hmit/gdp/

Kawashima, Yasuhide. 1994. "Fence Laws on the Great Plains, 1865-1900," in Essays on English Law and the American Experience, eds. Elizabeth A. Cawthorn and David E. Narrett. Walter Prescott Webb Memorial Lectures, No. 27, pp. 100-119. Texas A&M University Press.

Kraenzel, Carl Frederick. 1955. The Great Plains in Transition. University of Oklahoma Press.

Libecap, Gary D. 2006. "The Assignment of Property Rights on the Western Frontier: Lessons for Contemporary Environmental and Resource Policy." NBER Working Paper 12598.

McCallum, Henry D. and McCallum, Frances T. 1965. The Wire that Fenced the West. University of Oklahoma Press: Norman. 1972 printing.

Miceli, Thomas J.; Sirmans, C.F.; Kieyah, Joseph. 2001. "The Demand for Land Title Registration: Theory with Evidence from Kenya." *American Law and Economics Review*. Vol. 3, No. 2, pp. 275-287.

North, Douglass C. 1981. Structure and Change in Economic History. W.W. Norton & Company.

Primack, Martin L. 1966. "Farm Capital Formation as a Use of Farm Labor in the United States, 1850-1910." *Journal of Economic History*. Vol. 26, No. 3, pp. 348-362.

Primack, Martin L. 1969. "Farm Fencing in the Nineteenth Century." *Journal of Economic History*. Vol. 29, No. 2, pp. 287-291.

Primack, Martin L. 1977. Farm Formed Capital in American Agriculture 1850-1910. 1962 Dissertation. Arno Press: New York.

Rasmussen, Wayne D. 1962. "The Impact of Technological Change on American Agriculture, 1862-1962." *Journal of Economic History*. Vol. 22, No. 4, pp. 578-591.

Sanchez Nicolas and Nugent, Jeffrey B. 2000. "Fence Laws vs. Herd Laws: A Nineteenth-Century Kansas Paradox." *Land Economics*. Vol. 76, No. 4, pp. 518-533.

Smith, S. Ray; Benson, Brinkley; Thomason, Wade. 2004. "Growing Small Grains for Forage in Virginia." Virginia Cooperative Extension, Publication No. 424-006.

U.S. House of Representatives, 42nd Congress, 2nd session. 1872. "Statistics of fences in the United States." *House Executive Documents*. Vol. 17, No. 327 (Report of the Commissioner of Agriculture), pp. 497-512. Washington: Government Printing Office. (US Congressional Serial Set Vol. 1522).

Webb, Walter Prescott. 1931. The Great Plains. Grosset & Dunlap: New York. 1978 printing.

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 Woodland Level

	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	--	--
<u>Land-use outcomes:</u>						
Acres of land in farms, per county acre	0.53	0.42	0.59	0.65	**0.000**	0.257
	(0.26)	(0.26)	(0.28)	(0.26)		
Acres of improved land, per county acre	0.33	0.25	0.45	0.48	**0.000**	0.542
	(0.25)	(0.19)	(0.30)	(0.28)		
Acres of improved land, per acre in farms	0.54	0.55	0.64	0.65	0.032	0.835
	(0.23)	(0.20)	(0.28)	(0.24)		
<u>Other characteristics:</u>						
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, and fences	3,192,401	2,294,290	4,271,744	4,776,354	**0.000**	0.467
	(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 repairing fences	33,514	23,267	41,589	40,162	**0.000**	0.782
	(24,120)	(18,173)	(31,547)	(19,616)		
1880 county boundaries						
# counties	498	254	61	44	--	--
Acres of cropland, per acre in farms	0.30	0.28	0.38	0.42	**0.004**	0.415
	(0.20)	(0.20)	(0.25)	(0.19)		
Acres of cropland	70,288	52,638	102,594	114,472	**0.000**	0.448
	(65,139)	(54,572)	(85,283)	(73,867)		
<u>% acreage for each crop:</u>						
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)		
Cotton (in Texas only)	30.2	7.3	13.8	31.6	0.079	**0.000**
	(17.3)	(10.6)	(12.4)	(10.3)		

Notes: In the top panel, the sample is the same as in columns 1 and 2 of Tables 3 and 4: 377 counties in a balanced panel. In the bottom panel, the sample is the same as in Table 6 (columns 1 and 2) and Table 8 (columns 3 – 6). Missing data for crops is treated as a zero. Cotton production is always equal to zero or missing outside of Texas, so the sample for cotton is restricted to include only Texas counties. P-values are calculated based on standard errors that are adjusted for heteroskedasticity.

Table 3. Estimated Changes in Land-Use, Evaluated at Representative Woodland Levels

	Acres of Land in Farms, per county acre		Acres of Improved Land, per county acre		Acres of Improved Land, per acre in farms	
Woodland levels:	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12
	(1)	(2)	(3)	(4)	(5)	(6)
Decade:						
1870 - 1880	0.044	0.030**	– 0.092**	– 0.000	0.015	0.023
	(0.026)	(0.010)	(0.019)	(0.008)	(0.040)	(0.013)
		[0.54]		[4.97]		[0.22]
1880 - 1890	0.123**	0.046**	0.146**	0.026**	0.100**	– 0.004
	(0.023)	(0.009)	(0.022)	(0.008)	(0.030)	(0.012)
		[3.65]		[6.21]		[4.09]
1890 - 1900	0.141**	0.061**	0.156**	0.048**	0.086**	0.020*
	(0.023)	(0.009)	(0.023)	(0.008)	(0.020)	(0.010)
		[3.83]		[5.39]		[3.38]
1900 - 1910	– 0.021	– 0.013	– 0.019*	– 0.005	– 0.019	0.004
	(0.024)	(0.009)	(0.009)	(0.004)	(0.011)	(0.006)
		[0.33]		[1.47]		[2.23]
1910 - 1920	0.021	– 0.005	0.019*	0.007*	0.003	0.006
	(0.016)	(0.007)	(0.008)	(0.004)	(0.010)	(0.005)
		[1.50]		[1.29]		[0.31]
1920 - 1930	0.025	0.025**				
	(0.015)	(0.006)				
		[0.01]				
R^2	0.6270		0.6886		0.5161	
Observations	2262		1885		1885	

Notes: For the indicated outcome variable, this table reports estimates from equation 9 in the text. The estimated polynomial function of woodland is evaluated at three woodland levels (0, 0.06, 0.12) 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 estimates comparing different woodland levels.

Table 4. Estimated Changes in Land-Use, Controlling for Initial Outcome Differences

	Acres of Land in Farms, per county acre		Acres of Improved Land, per county acre		Acres of Improved Land, per acre in farms	
Woodland levels:	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12
	(1)	(2)	(3)	(4)	(5)	(6)
Decade:						
1870 - 1880	– 0.081**	– 0.030**	– 0.027	0.012	– 0.098**	– 0.003
	(0.030)	(0.011)	(0.023)	(0.010)	(0.034)	(0.013)
		[2.01]		[2.14]		[3.42]
1880 - 1890	0.021	– 0.001	0.060**	– 0.009	0.065*	– 0.015
	(0.028)	(0.012)	(0.023)	(0.010)	(0.033)	(0.013)
		[1.01]		[3.66]		[2.88]
1890 - 1900	0.082*	0.041**	0.102**	0.024**	0.076**	0.017
	(0.035)	(0.013)	(0.023)	(0.008)	(0.022)	(0.010)
		[1.55]		[4.01]		[2.92]
1900 - 1910	– 0.044	– 0.026	– 0.032**	– 0.008	– 0.026*	0.002
	(0.038)	(0.016)	(0.012)	(0.005)	(0.012)	(0.006)
		[0.61]		[2.26]		[2.60]
1910 - 1920	0.006	– 0.011	– 0.005	– 0.001	– 0.005	0.004
	(0.022)	(0.010)	(0.011)	(0.004)	(0.012)	(0.005)
		[0.86]		[0.43]		[0.71]
1920 - 1930	0.049	0.036**				
	(0.024)	(0.010)				
		[0.74]				
R^2	0.6696		0.7372		0.6294	
Observations	2262		1885		1885	

Notes: For the indicated outcome variable, this table reports estimates from equation 10 in the text. Estimated effects are presented in the same form as in Table 3. 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 estimates comparing different woodland levels. Data on land improvement is not available for 1930.

Table 5. Estimated Changes in Crop Productivity

	All Crops		More At-Risk Crops: Corn, Wheat, Oats, Barley, Rye		Less At-Risk Crops: Hay		Cotton	
Woodland levels:	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Decade:								
1880 - 1890	0.193**	0.025	0.273**	0.041	– 0.008	– 0.042	– 0.415	0.045
	(0.061)	(0.028)	(0.073)	(0.031)	(0.066)	(0.038)	(0.220)	(0.069)
		[2.36]		[2.86]		[0.44]		[1.91]
1890 - 1900	– 0.018	– 0.015	– 0.032	– 0.020	– 0.002	0.034	0.088	– 0.124*
	(0.041)	(0.019)	(0.050)	(0.023)	(0.042)	(0.023)	(0.146)	(0.048)
		[0.07]		[0.20]		[0.71]		[1.40]
1900 - 1910	0.056	– 0.013	0.057	– 0.024	0.049	0.005	0.199	0.086*
	(0.035)	(0.018)	(0.042)	(0.020)	(0.043)	(0.030)	(0.110)	(0.035)
		[1.63]		[1.62]		[0.76]		[1.06]
1910 - 1920	0.004	0.032	0.068	0.049	– 0.229**	– 0.080**	0.260	0.199*
	(0.045)	(0.025)	(0.052)	(0.030)	(0.041)	(0.024)	(0.256)	(0.081)
		[0.49]		[0.30]		[3.10]		[0.27]
1920 - 1930	0.189**	– 0.013	0.189**	– 0.018	0.242**	0.037	– 0.318	– 0.192
	(0.051)	(0.024)	(0.052)	(0.026)	(0.052)	(0.026)	(0.349)	(0.102)
		[3.95]		[3.71]		[3.96]		[0.44]
R^2	0.3999		0.4003		0.4739		0.3862	
Observations	10835		8195		2220		420	

Notes: For the indicated outcome variable, this table reports estimates from equation 11 in the text. Estimated effects are presented in the same form as in Table 3. 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 estimates comparing different woodland levels. Production data is not available for 1870.

Table 6. Estimated Changes in Crop Production

	Acres of Cropland, per acre in farms		Acres of More At-Risk Crops, per acre of cropland: Corn, Wheat, Oats, Barley, Rye		Acres of Less At-Risk Crops, per acre of cropland: Hay		Cotton	
Woodland levels:	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Decade:								
1880 - 1890	0.117**	0.013**	0.058*	0.000	– 0.045*	0.007	– 0.056	– 0.016
	(0.014)	(0.005)	(0.023)	(0.007)	(0.022)	(0.006)	(0.030)	(0.008)
		[8.07]		[2.82]		[2.67]		[1.53]
1890 - 1900	– 0.019*	– 0.012**	0.007	– 0.005	– 0.008	– 0.002	0.011	0.018
	(0.009)	(0.004)	(0.015)	(0.006)	(0.015)	(0.006)	(0.030)	(0.010)
		[0.75]		[0.91]		[0.38]		[0.28]
1900 - 1910	0.042**	0.005	0.020	– 0.015	– 0.031*	– 0.006	0.066	0.057**
	(0.009)	(0.004)	(0.019)	(0.009)	(0.012)	(0.004)	(0.044)	(0.017)
		[3.68]		[1.73]		[2.18]		[0.20]
1910 - 1920	0.011	0.001	0.016	0.005	– 0.019*	– 0.012**	0.023	0.008
	(0.007)	(0.004)	(0.015)	(0.009)	(0.009)	(0.004)	(0.050)	(0.019)
		[1.16]		[0.62]		[0.78]		[0.30]
1920 - 1930	0.068**	0.012**	0.018	– 0.006	– 0.056**	– 0.020**	0.170**	0.064**
	(0.008)	(0.004)	(0.016)	(0.008)	(0.010)	(0.004)	(0.037)	(0.013)
		[6.05]		[1.40]		[3.16]		[2.92]
R^2	0.4874		0.3079		0.2744		0.3971	
Observations	2490		2450		2450		745	

Notes: For the indicated outcome variable, this table reports estimates from equation 9 in the text. Estimated effects are presented in the same form as in Table 3. 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 estimates comparing different woodland levels.

Table 7. Estimated Changes in Land Value (Land, Buildings, and Fences)

	Not controlling for land value differences in 1870		Controlling for land value differences in 1870	
Woodland levels:	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12
	(1)	(2)	(3)	(4)
Decade:				
1870 - 1880	1.664**	0.509**	– 0.345*	– 0.217**
	(0.242)	(0.071)	(0.157)	(0.056)
		[5.14]		[0.98]
1880 - 1890	0.700**	0.201**	0.365**	0.060
	(0.084)	(0.029)	(0.102)	(0.036)
		[6.37]		[3.72]
1890 - 1900	0.306**	0.159**	0.235**	0.134**
	(0.054)	(0.019)	(0.073)	(0.027)
		[2.93]		[1.69]
1900 - 1910	0.122*	0.086**	– 0.103	0.013
	(0.049)	(0.018)	(0.078)	(0.028)
		[0.82]		[2.00]
1910 - 1920	0.126**	0.050**	0.080	0.031
	(0.039)	(0.017)	(0.056)	(0.022)
		[1.97]		[1.05]
1920 - 1930	– 0.005	0.012	0.052	0.040
	(0.040)	(0.018)	(0.058)	(0.024)
		[0.42]		[0.25]
R^2	0.7353		0.8862	
Observations	2250		2250	

Notes: Columns 1–2 report estimates from equation 9 in the text. Columns 3–4 report estimates from equation 10 in the text. Estimated effects are presented in the same form as in Table 3. 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 estimates comparing different woodland levels.

Table 8. Estimated Changes in Cattle Production and County Specialization

	Number of Cattle, per five county acres		Degree of Specialization in Crops or Cattle: Index 1		Index 2	
In 1880:						
Mean	0.2027		0.0399		0.0175	
Std. deviation	0.1561		0.0365		0.0248	
Woodland levels:	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12
	(1)	(2)	(3)	(4)	(5)	(6)
Decade:						
1880 - 1890	– 0.0046	0.0258**	0.0265**	0.0117**	0.0102**	– 0.0010
	(0.0139)	(0.0067)	(0.0050)	(0.0015)	(0.0037)	(0.0012)
		[2.11]		[3.14]		[3.26]
1890 - 1900	0.0533**	0.0341**	0.0130**	0.0020	0.0014	– 0.0073**
	(0.0154)	(0.0070)	(0.0040)	(0.0015)	(0.0032)	(0.0020)
		[1.14]		[2.89]		[2.25]
1900 - 1910	0.0427**	– 0.0124*	– 0.0143**	– 0.0075**	– 0.0027	0.0021
	(0.0139)	(0.0063)	(0.0034)	(0.0011)	(0.0024)	(0.0014)
		[3.42]		[2.05]		[1.63]
1910 - 1920	0.0399**	– 0.0049	– 0.0031	– 0.0049**	– 0.0020	– 0.0023
	(0.0105)	(0.0053)	(0.0028)	(0.0012)	(0.0020)	(0.0015)
		[3.56]		[0.67]		[0.12]
1920 - 1930	– 0.0434**	– 0.0032	0.0058*	0.0023	0.0010	0.0040*
	(0.0090)	(0.0057)	(0.0028)	(0.0012)	(0.0026)	(0.0016)
		[3.26]		[1.17]		[0.91]
R^2	0.5768		0.2291		0.1532	
Observations	2480		2490		2490	

Notes: For the indicated outcome variable, this table reports estimates from equation 9 in the text. Estimated effects are presented in the same form as in Table 3. 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 estimates comparing different woodland levels.

Table 9. Estimated Changes in Land-Use for Nebraska, Kansas, and Texas

	Acres of Land in Farms, per county acre		Acres of Improved Land, per county acre		Acres of Improved Land, per acre in farms	
Woodland levels:	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12	0 vs. 0.06	0.06 vs. 0.12
	(1)	(2)	(3)	(4)	(5)	(6)
Nebraska						
Decade:						
1870 - 1880	0.034	0.640	– 0.239*	0.496	– 0.216*	0.301
	(0.177)	(0.753)	(0.090)	(0.340)	(0.105)	(0.372)
1880 - 1890	0.060	0.206	0.181*	– 0.157	0.294**	– 0.350
	(0.064)	(0.192)	(0.074)	(0.236)	(0.063)	(0.304)
1890 - 1900	0.175**	– 0.120	0.083	0.172	– 0.069	0.335*
	(0.058)	(0.243)	(0.053)	(0.196)	(0.034)	(0.163)
1900 - 1910	– 0.008	0.220	0.046	– 0.111	0.063	– 0.339
	(0.044)	(0.150)	(0.044)	(0.197)	(0.035)	(0.184)
1910 - 1920	0.033	– 0.011	0.028	0.003	– 0.001	0.014
	(0.019)	(0.109)	(0.031)	(0.122)	(0.026)	(0.076)
1920 - 1930	– 0.033	0.039				
	(0.017)	(0.099)				
R^2	0.8499		0.8919		0.8757	
Observations	186		155		155	
Kansas						
Decade:						
1870 - 1880	0.479**	0.045	0.051	– 0.022	– 0.027	0.011
	(0.103)	(0.036)	(0.077)	(0.028)	(0.165)	(0.045)
1880 - 1890	– 0.135*	0.116**	0.137*	0.100**	0.307**	0.053
	(0.066)	(0.030)	(0.039)	(0.026)	(0.060)	(0.027)
1890 - 1900	0.017	0.027	– 0.046	0.021	– 0.091	0.008
	(0.031)	(0.024)	(0.050)	(0.021)	(0.051)	(0.028)
1900 - 1910	0.080*	– 0.023	0.070	– 0.038	0.017	– 0.018
	(0.037)	(0.030)	(0.045)	(0.026)	(0.041)	(0.026)
1910 - 1920	0.037	– 0.029*	0.049	– 0.032	0.028	– 0.018
	(0.019)	(0.013)	(0.030)	(0.017)	(0.031)	(0.015)
1920 - 1930	– 0.007	0.017				
	(0.022)	(0.015)				
R^2	0.8572		0.8325		0.5989	
Observations	306		255		255	
Texas						
Decade:						
1870 - 1880	– 0.110	– 0.026	– 0.045	– 0.018	0.076	0.011
	(0.057)	(0.018)	(0.048)	(0.018)	(0.130)	(0.038)
1880 - 1890	– 0.053	– 0.008	– 0.086*	– 0.054**	– 0.148	– 0.085*
	(0.060)	(0.021)	(0.043)	(0.015)	(0.098)	(0.033)
1890 - 1900	0.212**	0.114**	– 0.009	– 0.007	– 0.029	– 0.035
	(0.074)	(0.021)	(0.025)	(0.009)	(0.060)	(0.022)
1900 - 1910	– 0.196*	– 0.076**	– 0.037	0.006	– 0.001	0.035*
	(0.094)	(0.028)	(0.020)	(0.008)	(0.040)	(0.016)
1910 - 1920	0.014	– 0.011	– 0.000	0.004	– 0.019	– 0.000
	(0.068)	(0.020)	(0.021)	(0.007)	(0.039)	(0.012)
1920 - 1930	0.142*	0.067**				
	(0.067)	(0.021)				
R^2	0.4971		0.3898		0.3529	
Observations	732		610		615	

Notes: This table reports the same coefficients as Table 3, but estimated separately for each State. Robust standard errors clustered by county are reported in parentheses: ** denotes statistical significance at 1% and * at 5%.

Figure 1. Historical County Maps of the United States' Plains Region

1870 **1930**

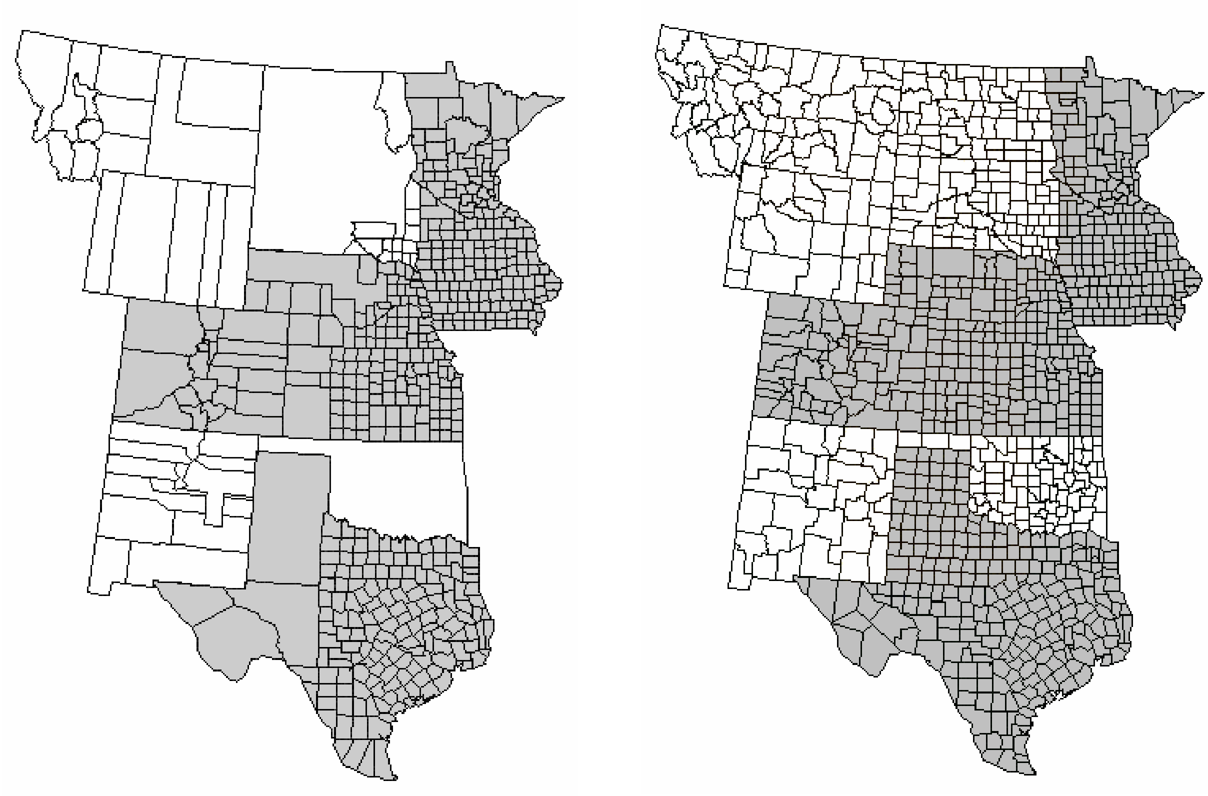

Figure 2. Average Settlement, Land Improvement, and Improvement Intensity by Decade and Woodland Level

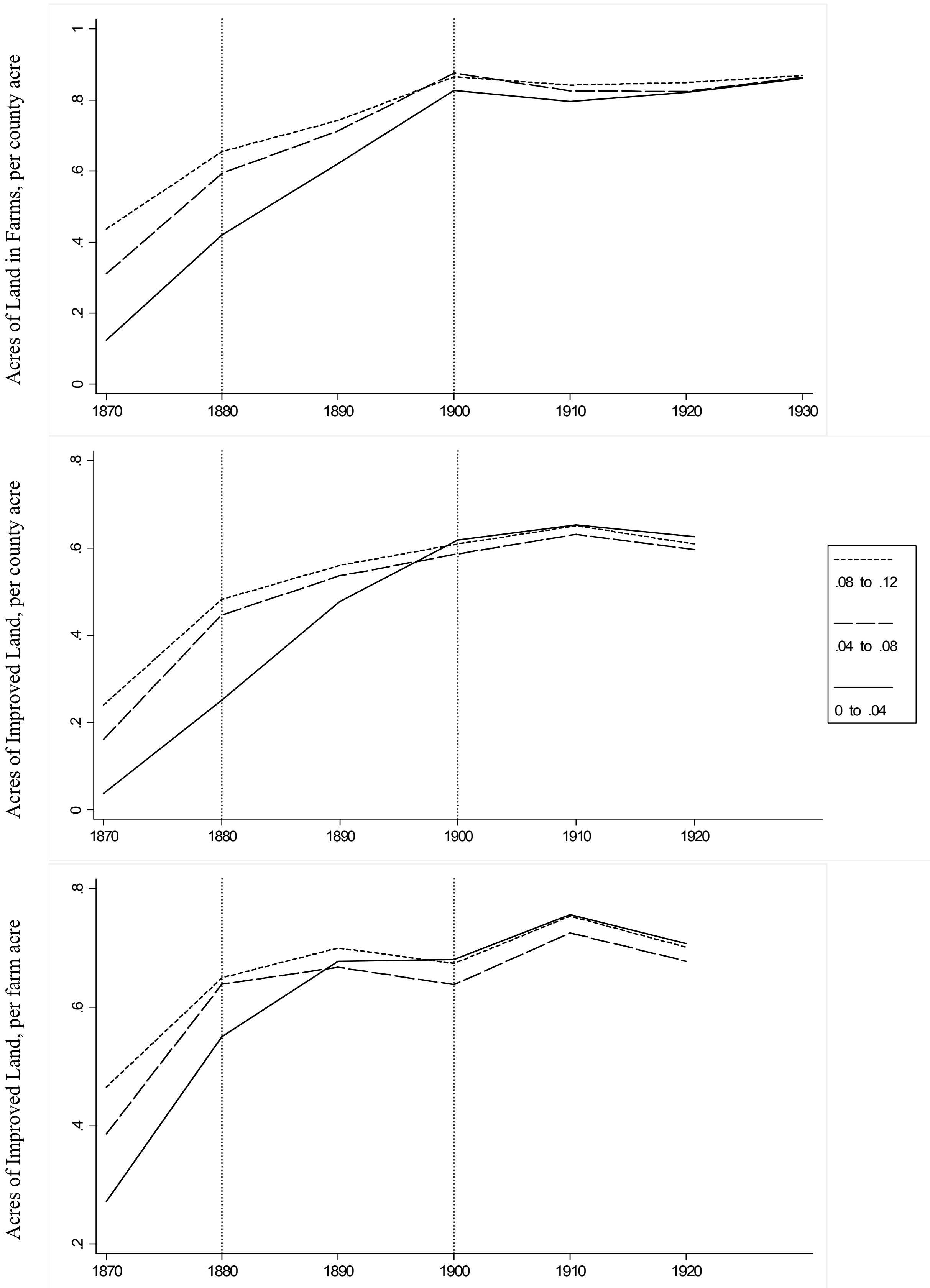

Figure 3. Changes in the Relationship Between Acres of Land in Farms (per county acre) and Woodland, conditional on county fixed effects

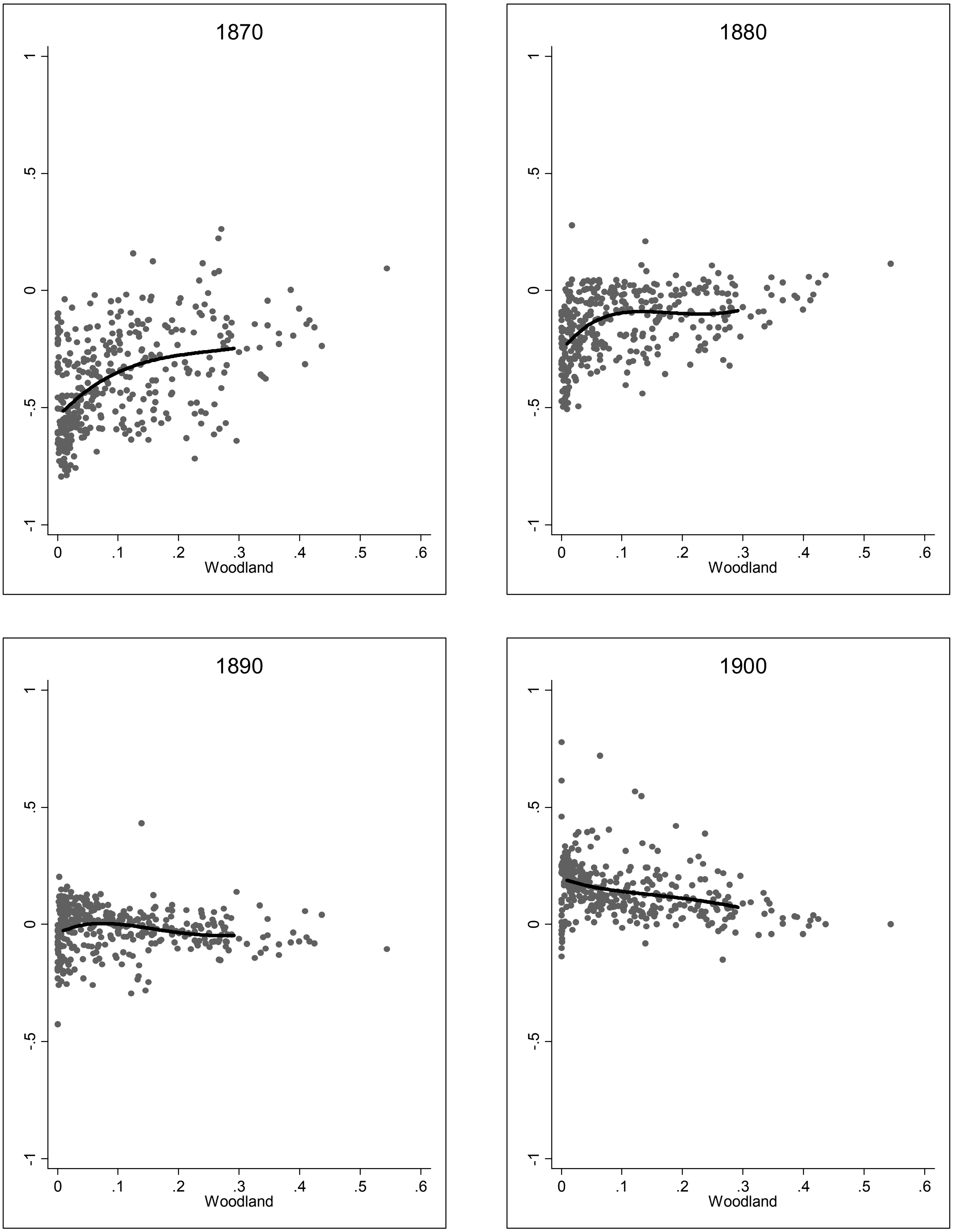

Figure 4. Changes in the Relationship between Acres of Improved Land (per county acre) and Woodland, conditional on county fixed effects

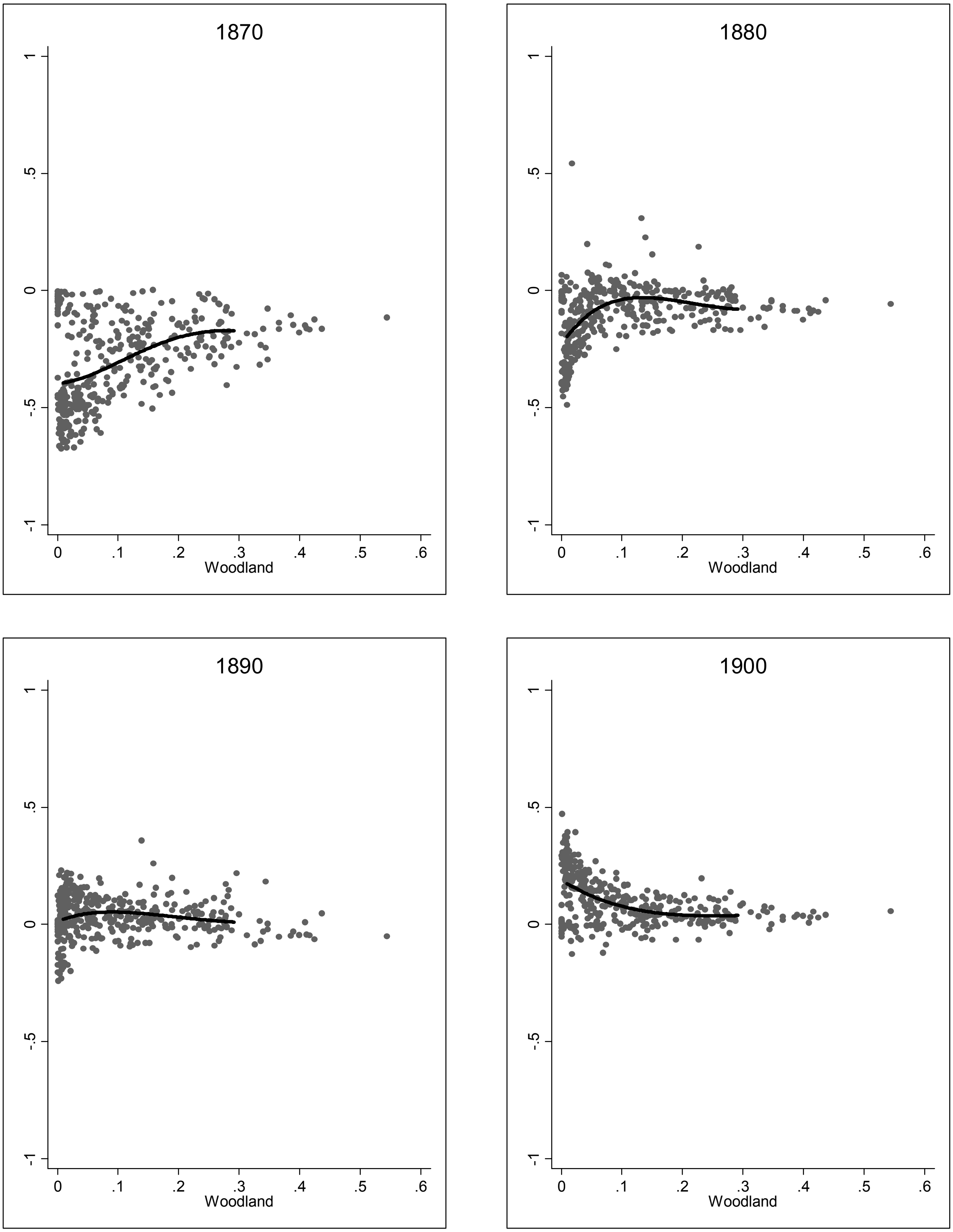

Figure 5. Changes in the Relationship Between Acres of Improved Land (per farm acre) and Woodland, conditional on county fixed effects

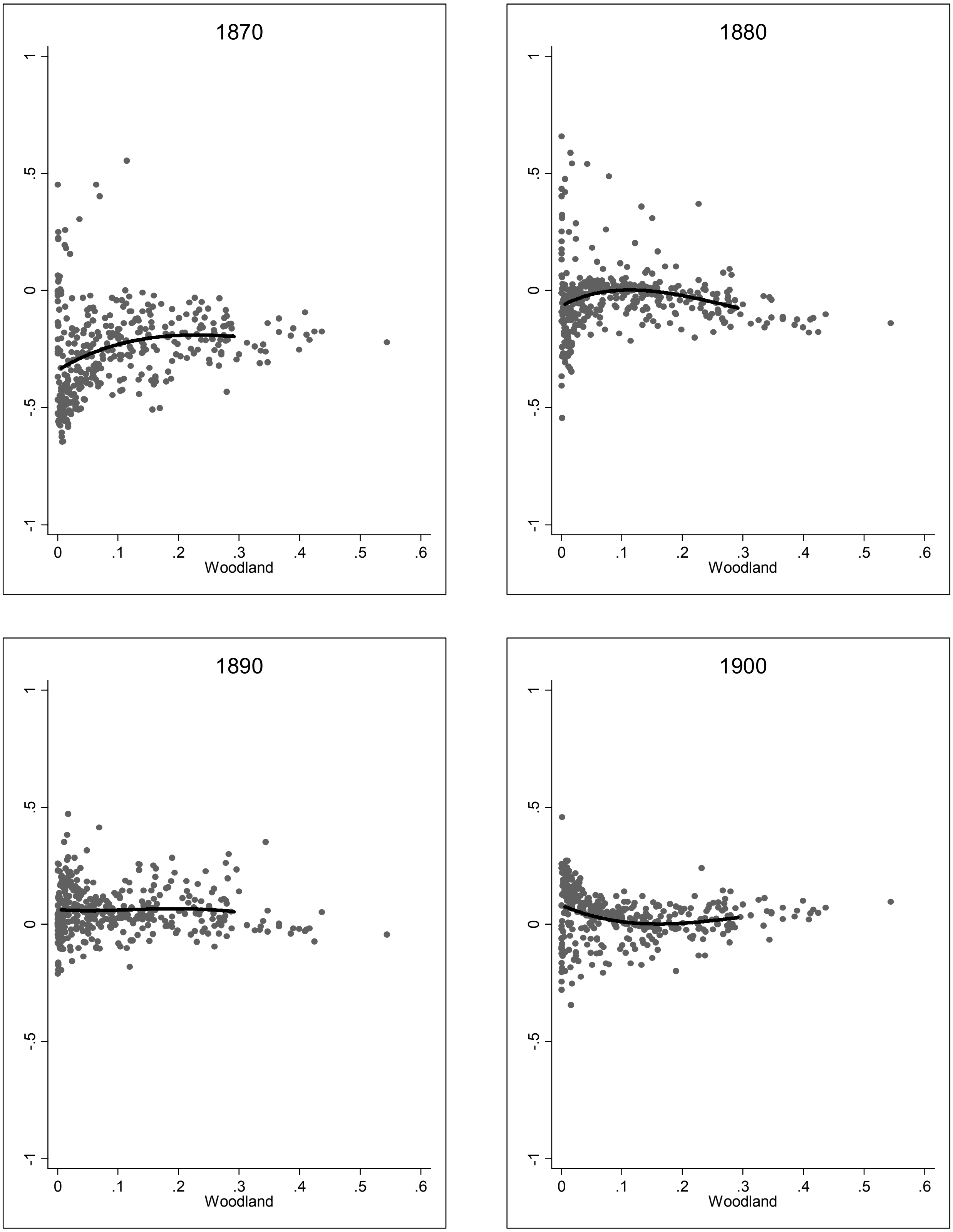

Figure 6. Estimated Cumulative Changes in Land-Use (from Table 3)