Local Effects of Land Grant Colleges on Agricultural Innovation and Output *

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Abstract

To estimate the local effect of establishing land grant colleges, I compare locations that receive a land grant college to "runner-up" counties that were in contention to receive the land grant but did not for as-good-as-random reasons. I find that establishing a land grant college causes an increase in local innovation in college counties relative to the runner-up counties. In particular, locations that receive a land grant see increases in agricultural innovation as measured by both patents in agriculture-related technology classes and the introduction of new wheat varieties. But land grant college counties see only small and imprecisely estimated improvements in agricultural performance, measured by yield and output, relative to runner-up counties. I discuss several alternative interpretations of these findings. By comparing the establishment of land grant colleges to the establishment of non-land grant colleges, I show that local invention, population, and agricultural output increase by less following the establishment of a land grant college relative to other types of colleges, but agricultural yields and new crop varieties increase by more. The effect of land grant colleges on local innovations is largest, even relative to non-land grant colleges, following the passage of legislation that increases funding to agricultural research.

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I Introduction

The U.S. land grant college system is frequently hailed as a major success of agricultural innovation policy (Wright, 2012). To be sure, agriculture in both the U.S. and around the world has become massively more productive over the last 150 years. Moreover, many land grant college towns are now innovation hubs (Harrington and Sauter, 2018) and frequently top lists of best places to live (Im, 2019). But to what extent are these facts *caused* by the presence of a land grant college, and how much is due to innate location fundamentals?

This question is typically difficult to answer. Simply comparing places with land grant colleges to places without is unlikely to give the true causal effect of a college. Even more frustrating is that it is not clear in which direction this naive comparison is biased. On one hand, land grant colleges were likely established in up-and-coming regions with access to natural amenities like rivers to facilitate transportation and the diffusion of new ideas, suggesting that estimates of the effect of colleges is biased upwards. On the other hand, states might choose to locate their land grants close to farmers and far from innovative major cities, implying a downward bias. Indeed, I show that both of these factors were important when states were deciding where to locate their land grant colleges.

To overcome these challenges, I identify cases in which the location of colleges was determined essentially at random. This randomization ensures that estimates of the local effect of land grant colleges represent the true causal effect of the college. More specifically, I use the natural experiments introduced in Andrews (2020b), identifying "runner-up" counties that were strongly considered to become the site of a new college but were ultimately not selected for reasons that are as good as random assignment. As just one example, the location of North Dakota State University was determined by drawing lots, and hence the location of the college site was literally random. The locations of many other land grant colleges, including the University of Maine and the University of Nevada, were decided as the result of particularly close and contentious votes. For still other colleges, such as Iowa State University and the University of Illinois, locations were determined by auction-like processes in which counties submitted bids to receive a new college, and I can compare the bids of the winning and losing finalist sites. While Andrews (2020b) focuses on a broad cross section of different types of colleges, here I narrow the focus to land grant colleges but examine a wide set of agriculture-related outcomes. The first contribution of this paper is to elaborate on the site selection processes for the land grants, providing detailed narrative evidence about the kinds of decisions made and tradeoffs considered when choosing the location for agricultural colleges.

Next, I use the runner-up counties as counterfactuals for locations that received land grant colleges in a differences-in-differences framework and present a number of results. I begin by showing that counties that received a land grant colleges have about 54 log points more patents per year than the runner-up counties after the land grant college is established. I also observe an increase in agriculture-related patents of about nine log points in land grant colleges relative to runner-up counties after establishing the land grant, although this is imprecisely estimated.[1] I find no evidence that land grant college counties increase the share of county patents belonging to these agriculture-related technology classes. While not precisely estimated, land grant colleges also appear to cause an increase in county population,

[1] I use the classification of agricultural patents as defined by Hall, Jaffe, and Trajtenberg (2001). This includes patents that are filed in technology classes related to, for instance, plant and animal husbandry, food, agricultural techniques and processes, and farm machinery like harvesters and combines.

a factor that is likely to positively affect aggregate invention but may dilute the focus on agriculture.

These results follow a sizable body of research on the local effects of colleges that use patents to proxy for innovation (Andrews, 2020b; Hausman, 2017; Jaffe, 1989; Kantor and Whalley, 2014). But patents are less likely to serve as an effective proxy in agriculture than in other sectors because many agricultural improvements are not patentable.[2] I make some progress on this issue by using data on the location of origin of new U.S. wheat varieties from a historical U.S. Department of Agriculture report (Clark, Martin, and Ball, 1922). While the data are much sparser than those for patents, containing information for only 227 new varieties between 1822 and 1922, I find that land grant counties are about five times more likely to introduce a new wheat variety than the runner-up counties after the college is established.

While land grant college counties see sizable increases in local innovations relative to the runner-up counties, they see modest and imprecisely estimated effects on agricultural outcomes, including agricultural yields, total agricultural output, crop output, and livestock production. This overall finding, that land grant college counties have large increases in local agricultural innovation but little increase in local agricultural output, could be interpreted either as evidence that innovations developed at land grant colleges are diffusing to the areas that will use them, or that the innovations developed at land grant colleges are irrelevant for agriculture within the state.

While more study is needed to conclusively distinguish between these interpretations and

[2]While asexually reproduced plants became eligible for protection under a plant patent in 1930, and both asexually and sexually reproduced plants became utility patent-eligible in the late 1980s, none of these methods were available at the time land grant colleges were established. See Moser and Rhode (2012) and Moscona (2019) for studies on the effects of patent protection laws for plants.

rule out alternative explanations, the data on wheat varieties (Clark et al., 1922) can again be helpful here. The most commonly planted wheat variety in 1919 was Turkey wheat. Accounting for almost 30% of all wheat acreage nationwide, it was likely brought to the U.S. from Russia in the 1870s by immigrants who settled in rural Kansas. The most commonly planted variety that came from a land grant experiment station was Poole wheat, accounting for about 3.5% of national acreage in 1919 after first being documented at the Ohio State University in 1884. On average, in 1919 wheat varieties developed at land grant colleges and their experiment stations tend to be less widely grown than varieties developed elsewhere. This provides some suggestive evidence that land grant innovations may not have been particularly relevant or impactful, although I stress that much more evidence is needed to substantiate this conclusion and to see if it holds for years after 1922.

Are these results on agricultural innovation and performance unique to land grant institutions, or would establishing a college of any type produce similar outcomes? To answer this, I compare my sample of land grant colleges to a sample of non-land grant colleges for which I am also able to identify runner-up locations. These non-land grant colleges do not have the same mandated focus on agricultural research that the land grants do. While measured imprecisely, the estimated increase in local patenting and population is smaller following the establishment of land grant colleges than following the establishment of other types of colleges. In terms of agricultural outcomes, the story is less clear: land grant colleges are associated with a larger increase in local agricultural yield relative to other types of colleges, but smaller increases in local agricultural output, and in most cases the magnitudes are small. In short, it is difficult to definitively conclude that land grant colleges play a unique role in promoting local agricultural innovation or output.

Finally, I attempt to get a sense of what drives the observed local effectiveness of land grant colleges. Several pieces of legislation have been passed since the land grant college system was first established in 1862, each of which has affected land grant colleges and their role in agricultural innovation in different ways. One piece of legislation that was particularly important was the Hatch Act of 1887, which established state agricultural experiment stations as well as providing direct federal funding for agricultural research. The post-World War II era also represented a watershed moment in the federal government's relationship to agricultural research, as exemplified by the Research and Marketing Act of 1946 that reorganized the administration of federal research support and greatly increased the level of federal spending going to land grant colleges. I show that the difference in innovation between college and runner-up counties increases following the passage of these pieces of legislation. This is suggestive evidence that these laws had their intended effect: as funding for agricultural research at land grant colleges increases, these counties indeed produce more innovations. The increase following the passage of these pieces of legislation is larger for land grant colleges than for non-land grants, so the effect does not appear to be driven by, for instance, college life-cycle effects.

In sum, all of these results paint a picture in which explicit funding of agricultural research had large positive effects on the amount of measured agricultural innovation, but there is less clarity regarding how useful these innovations were or how widely they diffused.

This paper is organized as follows. Section II provides a rich description of the land grant college site selection experiments and describes the sample of colleges used in this paper. Section III presents the results and Section IV concludes.

II Land Grant College Site Selection Experiments

The main difficulty with attempting to estimate the causal effect of establishing an institution of higher education, including a land grant college, is that these institutions are not located at random. For instance, colleges were often located in up-and-coming areas that were more productive and innovative than other areas in the same state, and so comparing places that get colleges to these other locations will overstate the effect of a college. At the same time, many land grant colleges were located away from productive population centers with the belief that proximity to urban areas would distract students' from their learning. On a similar note, state officials frequently wanted to locate public universities close to the geographic center of the state so that they could be equally accessible to all; these concerns often trumped desires to locate colleges in more productive areas. Indeed, many land grant colleges appear to have been located so as to be, as one university president put it, "equally inaccessible from all parts" of the state (Dunaway, 1946, p. 14-15). Hence, it is ex ante unclear whether college location decisions are likely to bias estimates of the effects of colleges upwards or downwards.

To overcome this challenge, I use the data and estimation strategy from Andrews (2020b). More specifically, I examine the historical record to find locations that were finalists to become the site of a new college, similar to the technique used to identify counterfactual locations for large manufacturing plants in Greenstone, Hornbeck, and Moretti (2010). I further restrict attention to cases in which the choice of the winning finalist site is as good as random assignment. I refer to the losing finalists as "runner-up" sites. Andrews (2020b) examines colleges of various types, while in this paper my primary goal is understanding the role of land grant colleges.[3]

Andrews (2020b) provides a detailed overview of these natural experiments, including showing that college and runner-up sites are observationally similar prior to establishing the college; showing that college and runner-up sites evolve along parallel trends prior to establishing the college; conducting numerous placebo tests; and describing qualitatively the site selection process, arguing that these decisions were fraught with randomness and unpredictability (see especially the Historical Appendix, Andrews (2020a)). I therefore take the opportunity here to describe several of these college site selection experiments in more detail than is possible in this other work, providing a deeper understanding of the kinds of historical contingencies at work while referring the reader to Andrews (2020b) for technical details.

I begin with a description of the college site selection process in North Dakota, where the state legislature literally randomly assigned the location of its land grant college, North Dakota State University (NDSU).[4] In an effort to get northern towns to support the move of the Dakota Territory's capital to the south, Territorial Governor Nehemiah Ordway promised other state institutions, including the agricultural college and the state university, to towns in the north. (This push to move the capital would eventually result in the Dakotas splitting into North and South in 1889.) Representatives from the towns of Fargo, Grand Forks, Jamestown, and Bismarck all wanted one of the educational institutions, and despite furious negotiations, they could not be made to agree. Finally, in 1883, with a legislative

[3]For the purposes of this paper, I do not consider historically black colleges and universities (HBCUs) funded under the Second Morrill Act of 1890 as land grants. Reclassifying them as land grant colleges does not qualitatively alter the results.

[4]The location of the University of North Dakota was also assigned randomly at the same time and in the same manner; see Section II.A below.

deadline approaching, the representatives agreed in exasperation to draw lots to allocate the institutions. Fargo won the agricultural college. Seven years later, the school was formally established as the state land grant university (Geiger, 1958, p. 13-27). In the empirical analysis below, I compare Fargo to Jamestown and Bismarck, the runner-up sites, to estimate the effect of the college.[5] One point worth emphasizing is that Jamestown and Bismarck looked very similar to Fargo prior to the establishment of NDSU and, as far as one can ascertain from the historical data, all had the climate, infrastructure, and temperament to successfully support a school. The point is not that the location of NDSU was random, but rather that it was random *among the set of finalist locations.* Thus, comparing Fargo to only the runner-up sites ensures that the comparison locations are good counterfactuals for Fargo.

Of course, literal random assignment of college sites is rather rare. More common are cases in which states set out a number of criteria that any prospective site must meet, and then painstakingly surveyed areas for their suitability. Many "wannabe" locations were eliminated at this stage. Among the remaining candidate locations, a board of trustees or site selection committee would typically meet and debate. Finally, the decision would then come to a vote. These votes were often quite contentious. I consider a candidate location to be as good as randomly assigned if, following this process in which less suitable sites are eliminated, the vote between the winner and the loser is very close. This occurred, for instance, in the cases of the University of Maine (Smith, 1979), the University of Nevada (Doten, 1924), Clemson University (Reel, 2011), and the University of Tennessee (Montgomery, Folmsbee,

[5] I do not consider Grand Forks as a runner-up site because it received an institution of higher education of its own. Including the few cases in which the "losing" sites receive a college does not meaningfully alter any results.

and Greene, 1984).

The University of California Davis provides an example of a typical site selection process. Berkeley was originally the location of California's only land grant college, but from the very beginning critics complained that Berkeley was not climatically representative of the rest of the state and so was a poor site for agricultural research.[6] In 1905, the California state legislature voted to establish a model farm operated independently of the Berkeley campus. The site selection commission was overwhelmed by more 70 offers from around the state. When narrowing down the sites, the commission set the following criteria:

> The farm site should lie within the central portion of the state, in close proximity to a main railroad line, with easy access to good service; its soils should consist largely of medium loam not subject to flooding or under a level; an irrigation system should already be in place; and the proposed property should be situated within the vicinity of a clean and progressive town. Additionally, [the commission] thought the site ought optimally to represent the state's "typical" rainfall and general agriculture (i.e., irrigated crops) and avoid extreme heat or other insalubrious conditions. (Scheuring, 2001, p. 18)

As this quote demonstrates, representative climatic conditions and infrastructure to support farming were often explicit criteria when deciding land grant locations, providing confidence that winning and runner-up sites are likely similar in terms of their suitability for agriculture. Given the parameters of this refined search, the California commission was left with four finalist locations in Davis, Walnut Creek, Suisun, and Woodland. Although final votes

[6]The original location of California's land grant college was selected because it was close to San Francisco but far enough away to avoid distractions. The trustees settled on Berkeley only after planned land purchases in neighboring counties fell through (Ferrier, 1930, p. 157-214).

among these finalists are not known, the final meeting to select among these sites dragged on for hours, highlighting just how contentious the decision was. Davis was selected only after speculators tripled the price of land at the commission's first choice. The farm was officially established in 1906 and would become an full-fledged agricultural college in 1921.

The other way in which land grant college sites were often selected was through an auction-like process. Based on the prevailing interpretation of the 1862 Morrill Act, states could use their land grant endowment to fund the operating expenses of agricultural colleges, but could not use them for purchasing land or erecting buildings. If a state wanted to create a new agricultural college from scratch, they often solicited bids from localities in the state. I consider the college site to be as-good-as-randomly assigned if candidates' bids are known and the winning bid is very similar to that of losing candidates. These close bidding processes are typically also followed by a contentious vote among a site selection committee. These auction-type processes occur for schools such as the University of Arkansas (Reynolds and Thomas, 1910), the University of Illinois at Urbana-Champaign (Turner (1932), Solberg (1968)), Iowa State University (Ross, 1958), the Missouri University of Science & Technology (Roberts, 1946), and the University of Missouri (Rees and Walsworth (1989), Burnes (2014)).

In many cases, the decision of where to locate a college was not only contentious among a site selection committee, but among the residents of the state as well. The University of Florida provides such an example. In 1905, the state of Florida had eight small institutions of higher education scattered across the state. In an effort to consolidate, the legislature passed the Buckman Act, which closed the existing institutions, re-evaluated the best locations, and then re-established the college at a potentially new site. Gainesville and Lake City quickly emerged as the clear frontrunners to become the new site of the college. Lake City had the added distinction of being the site of the previous Florida Agricultural College. Both Gainesville and Lake City submitted bids of similar amounts, and when it came time for the Board of Control of the university system to vote on the matter, Gainesville won over Lake City, six to four, following a contentious debate. But as acrimonious as the vote was, it paled in comparison to the views of the citizens of Lake City: as materials from the former agricultural college were being packed to move to their new home in Gainesville, they were done so under an armed guard for fear of rioting (Proctor and Langley, 1986, 18-26).

In still other cases, unusual “fluky” events proved decisive in determining the location of land grant colleges. The establishment of Cornell University (New York’s land grant college and the only private land grant institution) provides such an example. What would become Cornell University was originally intended to be located at the People’s College in Havana, New York, but the state senator sponsoring the bill suffered an ill-timed stroke, delaying the decision. Later, the legislature was strongly considering placing the college in Ovid when a well-known advocate for the compassionate treatment of the insane died mid-speech before the state assembly in Albany. State senators Andrew White and Ezra Cornell were able to use the death to convince the legislature that Ovid should receive an insane asylum instead of a college. Satisfied with the arrangement, Ovid’s representatives then decided to support whatever location White and Cornell decided to endorse, creating a dominant legislative coalition (Bishop (1962), Kammen (2003)). Even then, the decision was not settled: White and Cornell each wanted to place the college in their hometowns, with White being from Syracuse and Cornell from Ithaca. But Cornell adamantly refused to allow the college to be located in Syracuse, because as a young man he had been “robbed [there] not once but twice” (Kammen, 2003, p. 2003); White and Cornell settled on Ithaca instead.

Other colleges provide further examples of serendipity determining a school's location. Louisiana State University moved to Baton Rouge after its prior location burned down, and only a few sites in the state had the infrastructure to take on the school on short notice (Fleming, 1936). There are even accounts (possibly apocryphal) that the location of Texas Agricultural and Mechanical University was decided by a poker game (Dethloff, 1975, p. 18)!

Even acts of God intervened to determine college location. In 1885, Arizona's famous (or infamous) "Thieving Thirteenth" legislature met to divvy up the territory's state institutions. The citizens of Tucson had their hearts set on obtaining the state insane asylum when they set off for the legislative assembly in Prescott. But flooding on the Salt River delayed the Tucson delegates, and when they arrived in Prescott the insane asylum had already been spoken for. The people of Tucson were stuck with the state's land grant college, which became the University of Arizona (Martin (1960, p. 21-25), Wagoner (1970, p. 194-222), Cline (1983, p. 2-4)).

As these examples illustrate, the narrative historical record contains rich details about both the locations that received land grant colleges and those that were strongly considered but ultimately did not. Some of these details suggest variation that may be useful for additional analysis. For example, in the case of North Dakota State and the University of Arizona, the "losing towns" that did not receive the land grant college received another type of institution instead. Likewise, in the case of Cornell University, Ovid received an insane asylum in lieu of the land grant college. Syracuse, another runner-up for Cornell University, did not receive any other institution at the time Cornell was established, but did receive a university of its own within a few decades. In this paper, I abstract from these issues, but I discuss them in some detail in Andrews (2020b). Analysis of other types of heterogeneity, such as exploring more finely differences across types of institutions, geography, or other local conditions, may be of interest for future work. All of this is possible using the details available in the narrative record.

II.A Non-Land Grant Colleges

Similar strategies can be used to determine runner-up locations for non-land grant colleges as well. As mentioned above, North Dakota drew lots to determine the location of its flagship public university, the University of North Dakota, as well as its land grant college. In the case of the Georgia Institute of Technology, 24 rounds of balloting were required before Atlanta was selected over Macon (McMath Jr., Bayor, Brittain, Foster, Giebelhaus, and Reed, 1985, p. 24-32). For Southern Arkansas University, eight rounds of balloting were required (Willis, 2009, p. 21-43), and the University of Mississippi took seven (Sansing, 1999, p. 1-24).[7] Auction-like processes and other "fluky" events are likewise common for the non-land grant colleges.

In Sections III.A and III.B, I use non-land grant colleges as a set of "control institutions" to gain a sense of whether or not the effects I observe from establishing land grant colleges are caused by policies specifically related to land grants or whether they are common to all institutions of higher education. The Appendix lists more details about the sample of non-land grant colleges used in this paper.

[7] Southern Arkansas University actually began as an agricultural school, although it was not a land grant college. The results in this paper are insensitive to dropping schools like Southern Arkansas or reclassifying them as "land grants."

II.B The Sample of Colleges

In total, there are 29 cases in which the site selection decision for a land grant college was as-good-as random, representing 55% of the 53 non-HBCU U.S. land grant institutions. As in Andrews (2020b), all results in this paper are robust to dropping individual colleges or types of site selection decisions. Table 1 list each of these 29 colleges, the winning county of each, the runner-up counties, and the year in which the college is established.

Table 2 presents summary statistics of the land grant college site selection experiments. The median land grant college had one runner-up county, with the mean having about 1.5 runner-up counties. The median runner-up site is about 110 km from the college site, although there is considerable heterogeneity, with the mean runner-up 150 km away, the farthest runner-up 550 km away, and the closest runner-up being only 30 km away.

Throughout this paper, I define the year in which a college is established to be the year in which the college site is selected as described in the college site selection experiments above. In some cases, this date is not the same as the date in which an institution was formally founded, nor need it coincide with the date at which the college opened its doors. Results are unchanged when using the first year when students attended or the first year students graduated as the establishment year. In Section III.B, I investigate the importance of other dates in a college's life, such as the year colleges began receiving reliable federal research funding. Most of the sample colleges selected their sites and opened their doors in the first decade and a half after the Morrill Land Grant Act was passed. Two schools were established before the act and obtained land grant status later. Western states typically established their land grant colleges around the same time they obtained statehood, with several states doing so in the 1880s and 1890s. Southern states could not take advantage of the Morrill Act while in rebellion against the U.S. government during the Civil War, so all southern schools in the sample established their colleges in 1869 or later. There is thus substantial temporal variation in the establishment of land grant colleges.

III Results

Figure 1 plots four different outcome variables for the land grant and runner-up counties over time. Year 0 is normalized to be the year in which each land grant college is established. In Panel (a), I plot logged patenting, in Panel (b) logged county population, Panel (c) logged agricultural yield (that is, $\log(\frac{ValueAgr.Output}{FarmAcres})$), and Panel (d) the logged value of all agricultural output. Throughout, all U.S. patenting data come from the dataset assembled in Berkes (2018); population data come from the National Historical Geographic Information System (Manson, Schroeder, Riper, and Ruggles, 2018); and all agricultural data comes from agricultural censuses, cleaned and compiled by Haines, Fishback, and Rhode (2018). For the population and agricultural data that comes from federal census data, I linearly interpolate values for all between-census years; unless otherwise noted, results are not sensitive to alternative interpolation approaches or to only using data from census years.

These four pictures tell the main story of this chapter: counties that receive a land grant college see a measurable increase in local invention, especially after about five decades. There is weak and noisy evidence that land grant colleges also cause increases in population, a major driver of local invention for the larger sample of colleges considered in Andrews (2020b). But the counties that receive land grant colleges see no clear increase in agricultural yield or output relative to the runners-up; while the agricultural measures fluctuate over time, these fluctuations are typically common to both the college and runner-up counties.

Table 3 confirms these results in a regression framework. I estimate the simple differences-in-differences model:

$$
\begin{aligned}
Y_{it} =& \beta_1 LandGrantCounty_i \times PostLandGrant_{it} + \beta_2 PostLandGrant_{it} \\
&+ County_i + Year_t + \epsilon_{it}. \qquad (1)
\end{aligned}
$$

$LandGrantCounty_i$ is an indicator variable equal to one for the counties that receive land grant colleges. $PostLandGrant_{it}$ is an indicator variable equal to one in years t after the establishment of the college for which county i was either the winner or runner-up. $County_i$ is a county fixed effect, $Year_t$ is a year effect, and ϵ_{it} an idiosyncratic error term. The estimation sample is made up of the college and runner-up counties for all years for which data is available; not all variables are available for all years. In all regressions that follow, I cluster standard errors at the county level.

I estimate effects of establishing a land grant college for a larger battery of outcome variables than I present in Figure 1. Panel (a) of Table 3 shows results for innovation and population outcomes. Column 1 confirms the results from Panel (a) of Figure 1: establishing a land grant college causes about 54 log points more patents per year relative to the runner-up counties. Column 2 specifically examines patents classified as agricultural according to the NBER patent classification system (Hall et al., 2001).[8] While the estimated coefficient is

[8]These correspond to the following U.S. Patent Classification classes: 8, 19, 71, 127, 442, 504, 43, 47, 56, 99, 111, 119, 131, 426, 449, 452, 460. The results are robust to using alternative definitions of what constitutes an agricultural patent.

positive, it is imprecisely estimated and much smaller in magnitude than overall patenting, at a roughly nine log point increase in agricultural patents per year. Column 3 shows that there is no significant change in the fraction of agricultural patents in land grant college counties after establishing a new college.[9]

One challenge with measuring agricultural innovation is that many important breakthroughs, particularly the development of new and improved crop varieties, are not patented (Olmstead and Rhode, 2008).[10] To provide some insight into the location of non-patented agricultural invention, I consult a USDA technical report (Clark et al., 1922) that attempts to classify every variety of wheat grown in the United States as of 1920. Crucially, and exceedingly rare among agricultural studies, the authors also provide histories of each wheat variety, including how, when, and where each variety was developed and/or introduced to the United States. This allows me to investigate the extent to which land grant colleges directly contributed to innovation in the wheat sector. Because individual counties are extremely unlikely to develop more than one variety in a given year, in Column 4 I present estimates from a regression in which the outcome variable is an indicator that is equal to one if a county develops a new variety in that year and zero otherwise.[11] Establishing a land grant college has a statistically significant increase in the likelihood of introducing a new

[9] This variable is constructed as the number of agricultural patents divided by the number of patents with a known patent class (Marco, Carley, Jackson, and Myers, 2015). Patent class information is still missing for some patents, particularly older patents. This measure is undefined when a county has no patents in a given year and when the class is unknown for all patents in a county in a given year.

[10] This is not to say that patent data is irrelevant to an understanding of agricultural innovation, only that patent data alone paints an incomplete picture. Improvements in farm implements and mechanized equipment, often highlighted as vital contributors to American agricultural development (Cochrane (1979), Hayami and Ruttan (1985)) were patentable.

[11] Note that, in contrast to the data on patenting, the wheat varieties data from this report is unavailable after 1922. In ongoing work, I attempt to transcribe more recent USDA reports that contain histories of crop varieties developed in later years, as well as to gather data on yields or other measures of quality for the different varieties. I thank Paul Heisey for pointing out the existence of these later reports and discussing their potential usefulness for research on the geography of invention.

variety, on the order of 2%. Given that the baseline probability of introducing a new wheat variety in a given year for this sample of counties is about 0.4%, counties that receive a land grant college are about five times more likely to introduce a new variety after the college is established.

Consistent with Panel (b) of Figure 1, Column 5 shows that establishing a land grant college is associated with a positive but statistically insignificant increase in total population of about ten log points. The fraction of the county population living in urban areas, shown in Column 6, is also positive but statistically insignificant, and is close to zero in magnitude.

In Panel (b) of Table 3, I show results for various agricultural outcomes. In Column 1, I show that establishing a new college has no statistically significant effect on agricultural yields, although the coefficient is positive and non-trivial in magnitude, equal to a roughly ten log point increase in agricultural yield relative to the runner-up counties. One issue with yields as an outcome variable is that it is defined as the value of agricultural output divided by agricultural land, and establishing a new college may affect both the numerator and the denominator. In particular, a successful land grant college may induce more marginal land to come into agricultural production, decreasing yields while increasing output. In columns 2-4, I estimate the effect of establishing a land grant college on several output measures: the total value of agricultural output, the value of crop output, and the value of livestock produced. In all cases, establishing a land grant college has statistically insignificant effects, although in the effect is positive and sizable in magnitude for agricultural output and crop output.[12] This suggests that the land grant counties are increasing the amount of agricultural

[12]The agricultural results here present one case in which interpolation meaningfully alters point estimates. When using only data from agricultural census years, the coefficients for agricultural yield, agricultural output, and crop output are all smaller in magnitude, and the coefficient on agricultural output becomes negative. These results are available upon request.

land relative to the runner-up counties, consistent with untabulated results on the amount of improved farm acreage.

In a related paper, Kantor and Whalley (2019) conclude that land grant colleges cause an increase in the value of agricultural output in the areas closest to the college. It is worth exploring why the conclusions in Panel (b) of Table 3 differ from those in Kantor and Whalley (2019). First of all, the two studies use different samples of colleges. My sample consists of all land grant colleges for which I can identify a runner-up location, while Kantor and Whalley (2019) focus on land grant colleges in the Northeast, Midwest, and Texas. However even when restricting attention to the land grant colleges in the states studied by Kantor and Whalley (2019), I find results similar to those in Table 3, and if anything the coefficient on agricultural output is even closer to zero in magnitude; these results are available upon request. The most important difference is that the two studies ask subtly different questions. The independent variable in Kantor and Whalley (2019) is the distance from each county (not just the runners-up) to the land grant college interacted with a year fixed effect, whereas I compare the land grant college counties only to the runner-up counties. While Kantor and Whalley (2019) ask how agricultural output decreases with distance from a land grant college, I compare locations that would have been equally suitable sites to conduct agricultural research and see how agricultural outcomes change when one of these locations gets a land grant college. If land grant colleges are indeed located in the areas most suitable for agriculture as the discussion in Section II suggests, with surrounding areas less suitable for agriculture and likely less able to take advantage of agricultural innovations, then we should expect to see a negative gradient of agricultural output with distance, as documented in Kantor and Whalley (2019).[13] It should also be noted that I find similar dynamics to Kantor and Whalley (2019): as shown in Panel (d) of Figure 1, the difference between the land grant college counties and the runner-up counties is largest in the earliest decades after a college is established, before shrinking to virtually nothing; in contrast to Kantor and Whalley (2019) however, this difference is small in magnitude and statistically insignificant.[14]

How to interpret the large positive coefficients for local innovation outcomes and small-in-magnitude and statistically insignificant coefficients for agricultural outcomes? One interpretation is that the agricultural innovations documented in Panel (a) of Table 3 successfully diffuse throughout the land grant college's state, so the county from which these innovations originated saw little benefit from them relative to the otherwise similar runner-up counties. Alternatively, the results could be interpreted as evidence that the innovations developed in land grant college counties are irrelevant to agricultural production in the state, or that the agricultural outcome measures are mismeasuring true agricultural productivity.

As a first pass to addressing this question, I again turn to the data on the introduction

[13]In the Online Appendix to Kantor and Whalley (2019), the authors conduct a robustness test using runner-up counties (see their appendix Section 4 and Tables A2 and A9). As explained in Andrews (2020b), the Kantor and Whalley (2019) runner-up counties include those from low quality site selection experiments. Additionally, in some cases, I am able to identify additional runner-up sites not used in Kantor and Whalley (2019). The sample of runner-up locations in Kantor and Whalley (2019) therefore differ slightly from the sample used in this paper. In their specification, Kantor and Whalley (2019) use the distance from the runner-up counties to each counties interacted with year fixed effects as additional independent variables. They show that while the value of agricultural output decreases with distance to the land grant experiment station, it increases with distance to the runner-up counties. Note that this is different from the analysis I conduct in this paper.

[14]Kantor and Whalley (2019) also find significant declines in the value of agricultural output with distance from the land grant for six decades, whereas in Panel (d) the difference between land grant and runner-up counties closes after about five decades. Other differences between the studies may explain this discrepancy. As noted above, the two studies use a different sample of colleges. Kantor and Whalley (2019) use the passage of the Hatch Act in the 1880s as their date of treatment, whereas I use the establishment of the college (I examine the effects of the Hatch Act in Section III.B below). And Kantor and Whalley (2019) include a number of 1880 county characteristics interacted with year effects as additional control variables.

of new wheat varieties from Clark et al. (1922). In addition to detailed histories of each variety, the report also contains results from a 1919 survey of the total national acreage planted in each wheat variety. By comparing acreage planted in varieties developed at land grant sites to those developed elsewhere, I get a sense of whether land grant varieties tended to diffuse widely by 1919. I restrict attention only to varieties introduced since the passage of the Morrill Land Grant Act in 1862 to avoid counting varieties from before the land grant system could have had any effect.

I present results in Table 4. In Column 1, I count all varieties that Clark et al. (1922) indicate were introduced as a result of research at land grant colleges or state agricultural experiment stations.[15] About 30% of all new varieties introduced between 1862 and 1919 came from land grant research. In Column 2, in addition to the varieties attributed to land grant research in Column 1, I also include any varieties introduced in a county that had a land grant college, even if the land grant site was not explicitly mentioned in the varietal history. Including these additional varieties increases the share of varieties from land grant college counties to about 36% of all new varieties. In Columns 3 and 4, I calculate the national acreage planted in varieties developed at land grant sites. Varieties introduced as a result of land grant research account for only 10% of planted acreage, and all varieties from land grant counties account for 13% of acreage. Comparing the number of varieties introduced to the acreage results suggests that land grant research produced varieties that were, on average, less useful for American farmers. In Row 2, I repeat the exercise but keep

[15] In the calculations, I include wheat varieties developed outside the U.S. as long as Clark et al. (1922) can identify the location within the U.S. at which the variety is first introduced. Many (although not all) of the varieties attributed to land grant research were initially developed outside the U.S., lending support to the claims in Alston (2002) and Maredia, Ward, and Byerlee (1996) that federal support of agricultural innovation generated sizable international spillovers.

only varieties introduced since the passage of the Hatch Act in 1887, which established and provided federal funding for agricultural experiment stations. When restricting attention to this period in which land grant research was on an even firmer financial footing and was conducted in a larger number of geographic locations, land grant colleges account for a slightly larger share of both varieties and acreage (35% and 11%, respectively). This is also true when including all varieties introduced in land grant counties (39% of varieties and 17% of acreage).

From these results, it appears that land grant colleges played an outsized role in discovering and inventing new wheat varieties, although each variety developed at land grant locations was less widely planted on average than varieties grown elsewhere. This suggests that land grant colleges may not cause much of an increase in local agricultural yield and output because the agricultural innovations they produce are of low quality or useful for only a small constituency.

I stress that this conclusion is highly preliminary and suggestive, and several caveats are in order. First, Clark et al. (1922) may have been more likely to uncover information on low quality varieties when they were developed at land grant sites, and so their data may suffer from survivorship bias. Additionally, it is possible land grant colleges played a larger role in the development of different species of crops or in the development of farm machinery, or that their role qualitatively changed in recent decades; additional USDA reports would be particularly useful to address these issues. It is also likely that land grant colleges played a substantial role in promoting the diffusion of wheat varieties developed elsewhere. Indeed, several of the descriptions of varieties indicate that agricultural experiment stations researchers scoured the country to discover varieties developed by obscure farmers.[16] Much more work is needed to conclusively determine why land grants appear to have a large positive local effect on innovation, but little effect on local agricultural output and yield.

III.A Comparing Land Grant Colleges to Other Types of Colleges

Is there something "special" about the land grant college program, or would the observed positive effects on innovation be observed anytime an institution of higher education is established? To answer this question, I use data from all college site selection experiments, not just the land grants.

Figure 2 plots the difference between college and runner-up counties separately for land grant and non-land grant colleges for the same four outcome variables as in Figure 1. Both types of colleges had small and largely constant differences prior to the colleges being established.[17] Both types of colleges exhibit an increase in patenting and population after establishment, although at different rates. In particular, while the non-land grant college counties see almost immediate increases in local population relative to their runner-up counties, the land grant college counties see large increases in population only after about seven decades. The pictures for agricultural yield and output are less clear, with particularly large fluctuations for land grant colleges but no obvious trend.

I next test the difference between the types of colleges more formally in a triple differences

[16] As one example, the Wyandotte variety was discovered by researchers from the Ohio Agricultural Experiment Station at Columbus being grown on a farm in Nevada, OH, although the variety's exact origins remain a mystery. The Indiana agricultural experiment station in Bloomington frequented Everlitt's O.K. Seed Store in Indianapolis to learn about new varieties from across the country.

[17] In all cases, I fail to reject the null hypothesis of parallel pre-trends for both the land grant and non-land grant colleges; results are available upon request. The plotted figures can be misleading in the earliest years since data is not available for all colleges three decades before the college establishment date.

framework. I estimate

$$
\begin{aligned}
Y_{it} =& \beta_1 CollegeCounty_i \times PostCollege_{it} \times LandGrant_i \\
&+ \beta_2 CollegeCounty_i \times PostCollege_{it} \\
&+ \beta_3 LandGrant_i \times PostCollege_{it} \\
&+ \beta_4 PostCollege_{it} + County_i + Year_t + \epsilon_{it}, \qquad (2)
\end{aligned}
$$

where $CollegeCounty_i$ is a dummy equal to one if county i ever receives a college of any type, $PostCollege_{it}$ is a dummy equal to one in years t after the establishment of the college for which county i was either the winner or runner-up, and $LandGrant_i$ is a dummy equal to one if i was either the winner or runner-up for a land grant college.

I present results in Table 5, for the same outcome variables as measured in Table 3.[18] The variable of interest, $CollegeCounty_i \times PostCollege_{it} \times LandGrant_i$, should not be interpreted as causal, since colleges are not randomly assigned to be either land grants or other types of institutions. And the triple interaction term is rarely statistically significant, which is not surprising given the relatively small number of college experiments. Nevertheless, the coefficients suggest an interesting pattern. Local patenting increases by about nine log points less in college counties after establishing a land grant college than after establishing a non-land grant. Agricultural patenting also increases by less after establishing a land grant college, although the coefficient is close to zero in magnitude. But when focusing on non-patent-based agricultural innovations, land grant colleges do have a larger effect than

[18]Results comparing land grant to non-land grant colleges are similar when restricting the sample of non-land grants to include only public colleges (typically flagship state universities that are not also land grant colleges, such as the University of North Dakota), although the smaller sample of colleges results in less precise estimates; these results are available upon request.

the non-land grants: the increase in the likelihood of introducing new wheat varieties is 2% more in college counties after establishing a land grant college than after establishing a non-land grant, an effect statistically significant at the 10% level. Land grant colleges are also associated with less population growth and urbanization than the non-land grant colleges. Agricultural yield appears to increase more in counties that receive a land grant college than in counties that receive other types of colleges, but if anything land grant colleges see worse outcomes in terms of total agricultural output, crop output, and livestock.

The coefficient on $CollegeCounty_i \times PostCollege_{it}$ measures the effect of establishing non-land grant colleges and shows that these other types of institutions also generate sizable increases in local patenting and agricultural patenting, as well as creating positive but statistically insignificant and small in magnitude increases in agricultural output. Unlike the land grant colleges, the non-land grant colleges create large increases in local population and statistically significant increases in urbanization. The coefficient on $LandGrant_i \times PostCollege_{it}$ measures how the land grant runner-up counties perform after establishing a land grant college relative to the non-land grant runners-up after establishing a non-land grant college, and is thus a plausible measure of spillovers from land grants. The coefficient is negative for agricultural yield, agricultural output, and crop output, although it is positive for all measures of innovation. This calls into question whether the land grant colleges were more effective at generating innovations that diffused throughout their states than were other types of colleges. Conclusions about spillovers and diffusion should be made with caution, however, since the non-land grant runner-up counties may be exposed to innovations from a nearby land grant college, and vice versa. A full exploration of these issues is beyond the scope of this paper.

III.B What Pieces of Land Grant Legislation Were Most Effective?

The current land grant college system is the result of several pieces of legislation, from the 1862 Morrill Act to the most recent farm bill, each of which affected the local innovation ecosystem in different ways. To speak of "the effect" of land grant colleges is therefore to obscure many distinctions that may be important for policymakers. As a first pass at understanding which pieces of legislation had the largest local effect, I repeat the basic differences-in-differences analysis from above, but define multiple "post-period" dummy variables that are equal to one during time periods that denote given legislative epochs. I examine the difference between land grant college counties and runner-up counties following the initial establishment of land grant colleges under the Morrill Act of 1862, the establishment of agricultural experiment stations following the Hatch Act of 1887, and the post-World War II era in which the federal government became much more directly involved in research funding, exemplified by the 1946 Research and Marketing Act.[19] Each of these dates marks a commonly-recognized turning point in the funding of higher education, particularly in relation to agricultural research. Numerous studies highlight the pioneering role of the 1862 Morrill Act in establishing institutions dedicated to agricultural education and research, including several full-length histories (Edmond (1978), Cross (1999, p. 77-94), Geiger and

[19]Many other important pieces of legislation could be studied as well, such as the Second Morrill Act of 1890 that established additional land grant colleges, especially for African Americans; the 1906 Adams Act that provided additional federal funding for scientific research; the 1925 Purnell Act that provided federal funding for applied research to aid the local agricultural sector; or the 1935 Bankhead-Jones Act, which introduced formula funding and federal and state matching grants for basic agricultural research. Alston and Pardey (1996) provide a useful summary of major legislation related to agricultural research. In additional untabulated analysis, I consider the effects of these other pieces of legislation as well. Unfortunately, many of the acts occurred within a decade or two of one another, making it extremely difficult to separate the effects of particular laws. I therefore focus on what I consider the most important changes in legislation, with the caveat that more additional research is needed to conclusively determine the effects of each policy.

Sorber (2013), Sorber (2018)). A sizable literature also examines the effects of the 1887 Hatch Act, which established state agricultural experiment stations and provided federal funding to conduct research at those stations, marking the beginning of direct federal funding of agricultural research activities (Kerr (1987), Ferleger (1990), Hillison (1996), Kantor and Whalley (2019)). The 1946 Research and Marketing Act, which dramatically increased federal spending on state agricultural experiment stations and reorganized the administration of federal agricultural research support, has been the least examined by historians of agriculture or education, although it has not been completely ignored (Bowers (1982), Alston and Pardey (1996)). More broadly, the 1946 Act exemplifies the federal government's changing approach in the postwar world, with the end of World War II widely recognized as a watershed moment in the federal government's support for university research (Geiger (1993), Rosenberg and Nelson (1994), Mowery and Rosenberg (1998), Mowery and Sampat (2001)).

I estimate the following model:

$$
\begin{aligned}
Y_{it} = & \beta_1 LandGrantCounty_i \times PostMorrillAct_{it} + \beta_2 LandGrantCounty_i \times PostHatchAct_{it} \\
& + \beta_3 LandGrantCounty_i \times PostWorldWarII_{it} + County_i + Year_t + \epsilon_{it}. \qquad (3)
\end{aligned}
$$

where $PostMorrilAct$ equals one for $1862 \leq t < 1887$, $PostHatchAct$ equals one for $1887 \leq t < 1946$, and $PostWorldWarII$ equals one for $1946 \leq t$.[20] I focus on the first cohort of land grant colleges, established between 1862 and 1870, to see how a constant set of colleges changes over the lifecycle.

[20]Results are similar when replacing the year fixed effects with the much coarser time period dummies for $PostMorrilAct$, $PostHatchAct$, and $PostWorldWarII$.

I present results in Table 6. When splitting up the patenting results into four time periods (the pre-period before 1862 Morrill Act, which is the base time, and the time periods corresponding to each of the three interaction terms), individual coefficients are typically not statistically significant. It appears that the college counties only begin to see larger levels of patenting relative to the runners-up after the passage of the Hatch Act, with an even larger increase observed after World War II. Agricultural patenting, however, exhibits a different pattern, with the increase in the level of agricultural patents increasing in college counties relative to runners-up immediately following the passage of the Morrill Act while falling to almost zero following the Hatch Act and finally rebounding after World War II. The fraction of agricultural patents appears to increase in land grant college counties relative to the runners-up after the Morrill and Hatch Acts, but decreases after World War II, although the post-World War II magnitude is small.[21] Population and urbanization exhibit increases in college counties relative to the runners-up that are large in magnitude following World War II: total population increases by a statistically significant 54 log points, with urbanization increases by nine log points. Total population shows a sizable eleven log point increase following the Hatch Act as well. For agricultural yield, agricultural output, and crop output, the land grant college counties see a decrease relative to the runner-up counties following the Morrill and Hatch Acts before seeing increases after World War II, although most of these coefficients are fairly small in magnitude, with magnitudes between two and thirteen log points. Livestock products actually exhibit the largest increase in college counties relative to the runners-up in the years following the Morrill Act, making it difficult to tell a consistent

[21] Because the data on the introduction of new wheat varieties is from a 1922 report (Clark et al., 1922), no post-World War II observations are available and so I do not examine that outcome variable in Table 6.

story about the role of each piece of legislation on local agricultural outcomes.

While suggestive, interpreting the results in Table 6 is difficult. New colleges began as very small institutions that then grew over time, raising the possibility that larger differences between the college and runner-up counties after 1887 or 1946 are driven by the "natural" growth of these colleges rather than by specific policies. To attempt to account for this, I compare the effect of the 1862-1870 land grant colleges to the effect of other types of colleges that were established between 1860 and 1870.

Figure 4 shows the difference in patenting between college and runner-up counties for this cohort of colleges, where calendar years are plotted on the x-axis and the passage of the Morrill, Hatch, and Research and Marketing Acts are indicated. The land grant college counties see sizable increases in the number of patents relative to the runner-up counties beginning in the early 1900s, while a similar takeoff for the non-land grant college counties does not begin until about 1960.[22] To formalize these findings, I estimate

$$
\begin{aligned}
Y_{it} = & \beta_1 CollegeCounty_i \times PostMorrillAct_{it} \times LandGrant_i \\
& + \beta_2 CollegeCounty_i \times PostHatchAct_{it} \times LandGrant_i \\
& + \beta_3 CollegeCounty_i \times PostWorldWarII_{it} \times LandGrant_i \\
& + \beta_4 CollegeCounty_i \times PostMorrillAct_{it} + \beta_5 CollegeCounty_i \times PostHatchAct_{it} \\
& + \beta_6 CollegeCounty_i \times PostWorldWarII_{it} + \beta_7 LandGrant_i \times PostMorrillAct_{it} \\
& + \beta_8 LandGrant_i \times PostHatchAct_{it} + \beta_9 LandGrant_i \times PostWorldWarII_{it} \\
& + County_i + Year_t + \epsilon_{it}. \qquad (4)
\end{aligned}
$$

The triple interaction terms β_1-β_3 show the effect of establishing a land grant college relative to the effect of establishing other types of colleges in each time period. The interaction terms β_4-β_6 show the average effect of establishing non-land grant colleges in each time period, while the interaction terms β_7-β_9 show the difference between all counties under consideration to receive a land grant college and all counties under consideration for other types of colleges in each time period. The assumption needed to identify the triple interactions terms of interest is that, without the research-related legislation, land grant and non-land grant colleges of the same age would have similar effects on the local economy at every point in time.

Results are presented in Table 7. For readability, I only present coefficient estimates for the triple interactions terms, β_1-β_3; full results are available upon request. All coefficients of interest are, again not surprisingly, not statistically significant, but many are large in

[22]The differences in the relative dynamics of patenting between Figures 4 and 2 is due to the fact that the figures are plotting patenting for a different sample of colleges, with Figure 4 containing only the schools established between 1860 and 1870.

magnitude. After the Morrill Act, land grant colleges have roughly 15 log points less of an increase in local patenting than do the non-land grant colleges. This reverses after the Hatch Act, with land grant colleges increasing local patenting relative to their runner-up counties by 46 log points more than the non-land grant colleges after the Hatch Act and 37 log points more after World War II. Land grant colleges have larger increases in the level of agricultural patenting than do the non-land grant patents for all three periods, although in all periods the land grant colleges see a decline in the share of agricultural patents relative to the non-land grant colleges, with the largest decline in the share of seven log points occurring after the passage of the Hatch Act.

The land grant colleges see less of an increase in population after the Morrill and Hatch Acts than do the non-land grant colleges, although following World War II the land grant colleges have cause a roughly 25 log points larger increase in population than do the non-land grant colleges. In all three periods, the land grant colleges have larger increases in urbanization (or, at least, less of a decrease), although the magnitudes are very small until after World War II. Land grant colleges have a larger increase in agricultural yield only after World War II, although they have an increase in agricultural output and crop output following the Hatch Act as well, and an increase in the value of livestock products sold in all three periods. If anything, land grant colleges see a decline in agricultural yield, agricultural output, and crop output relative to the non-land grant colleges in the initial decades following the passage of the Morrill Act.

These results should be interpreted with caution for several reasons. First, every college that received funding through the Hatch Act also received funding through the earlier Morrill Act, thus the coefficients on Hatch Act funding should be interpreted as the effect of Hatch

Act funding conditional on also receiving Morrill Act funding; the coefficients on post-World War II funding should be interpreted similarly. This point is important to the extent that Hatch Act funding complemented rather than substituted Morrill Act funding, building on institutions and programs built under the earlier law. Second and related, because all of the land grant colleges receive funding under all three acts, it is impossible to identify the effects of the Hatch Act from effects of the Morrill Act that take several decades to manifest. This is less of a concern when interpreting the coefficients on the Research and Marketing Act, which went into effect almost six decades after the Hatch Act. Finally, none of the triple interaction terms are statistically different from zero; while not surprising given the sample sizes involved, one should refrain from drawing dramatic conclusions from these results.

In spite of these caveats, facilitating comparisons of different types of institutions over distinct epochs of federal involvement in agricultural research opens the door to many interesting lines of study. Changes that occur in the postwar period are particularly interesting because, while legislation such as the 1946 Research and Marketing Act specifically targeted agricultural research that was largely conducted at land grant colleges, postwar federal involvement in science and research occurred in nearly all sectors, not merely agriculture.[23] The fact that land grant colleges had a long-established history of supporting applied research may have made land grant colleges a particularly attractive destination of federal funding in the postwar era; I leave a deeper exploration of this issue to future work.

[23]One may worry that only a few federal institutions dominated postwar federal funding, and that these institutions are missing from my sample. O'Mara (2005), for example, documents how skewed federal funding was across institutions. While MIT and Stanford are not in my sample, Georgia Tech (which massively increased its share of federal funding in the 1960s and 1970s) is included as a non-land grant college.

IV Conclusion

In this paper, I provide detailed descriptions of the processes through which states decided where to locate their land grant colleges. Serendipity frequently played a role in determining college location, and I exploit this fact to identify runner-up sites that would have received land grant colleges but for as-good-as-random reasons.

Using these runner-up sites as counterfactuals for locations that receive a land grant college, I show that local agricultural innovation, measured both by patents and new crop varieties, increases in college counties relative to the runners-up after establishing a land grant college. While land grant colleges see a sizable increase in innovation, they have small and imprecisely estimated improvements in agricultural performance relative to the runner-up counties. These results lend themselves to several interpretations. One interpretation is that innovations developed at land grant colleges diffuse effectively, but it could also be the case that land grant college innovations have limited relevance to farmers working within the same state. Additional research is needed to determine how the diffusion process for land grant innovations operates. Kantor and Whalley (2019) provide a promising first step in this direction, focusing on the role of geographic proximity and communications technologies in explaining the diffusion from land grant colleges, but much work remains to be done.

More work is also needed to understand exactly what types of policies led to the success of the land grant program, and which of these policies can be replicated in other contexts or with other types of institutions. In this paper I present suggestive evidence that the Hatch Act and post-World War II federal funding, both of which provided direct federal support for agricultural research, were particularly effective in promoting local invention.

Limited variation in the implementation of similar large scale policies makes these types of questions difficult to answer today. While the historical evidence presented in this paper is not conclusive, my hope is that the data and methodology presented here will prove to be of continuing utility in addressing important questions for agricultural innovation policy.

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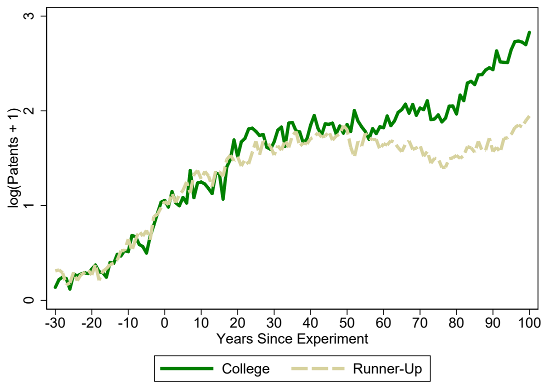
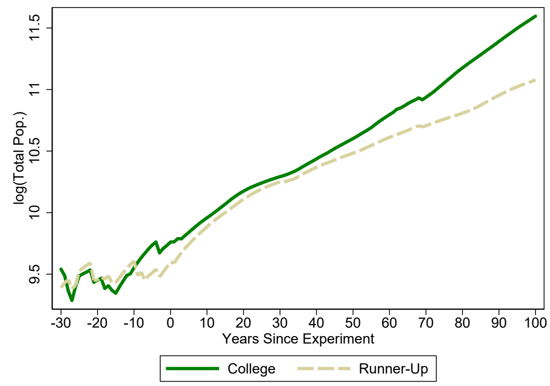
Graphs

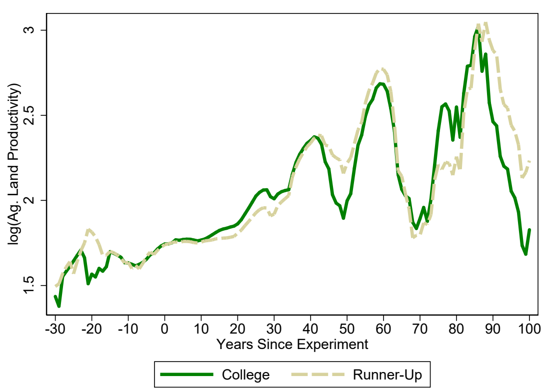
Figure 1: Land Grant College Counties and Runner-Up Counties



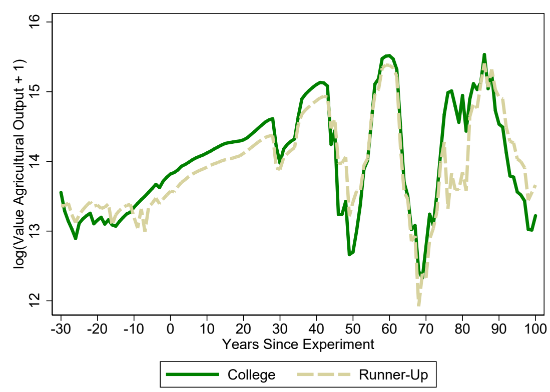
(a) $\log(Patents + 1)$



(b) $\log(Population)$



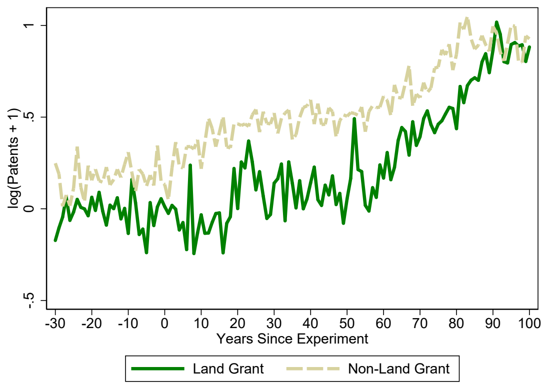
(c) $\log(Ag.Yields)$



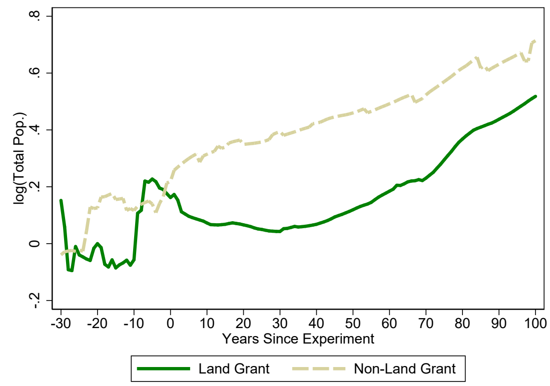
(d) $\log(Ag.Output)$

Notes: Plots of various outcome variables in land grant college (green solid lines) and runner-up (gold dashed lines) counties. The x-axis shows the number of years since the land grant college experiment. The year of the college experiment is normalized to year 0.

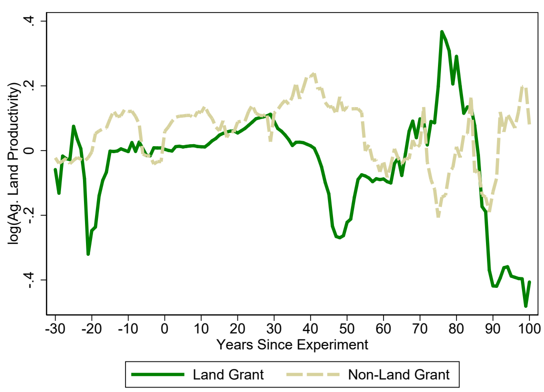
Figure 2: Difference between College and Runner-Up Counties for Land Grant Colleges and Non-Land Grant Colleges



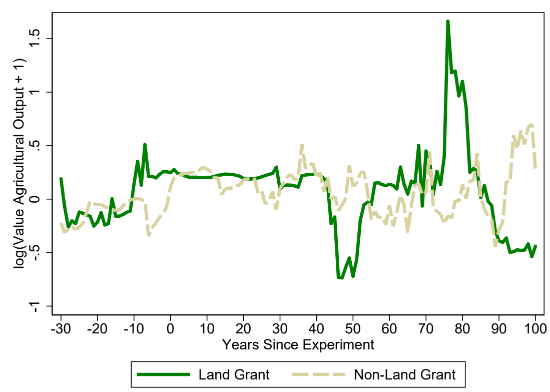
(a) $\log(Patents + 1)$



(b) $\log(Population)$



(c) $\log(Ag.Yields)$



(d) $\log(Ag.Output)$

Notes: Plots of the difference between college and runner-up counties for various outcome variables for land grant colleges (green solid lines) and non-land grant colleges (gold dashed lines). The x-axis shows the number of years since the land grant college experiment. The year of the college experiment is normalized to year 0.

Figure 3: Difference between College and Runner-Up Counties for Land Grant Colleges and Non-Land Grant Colleges, Calendar Time

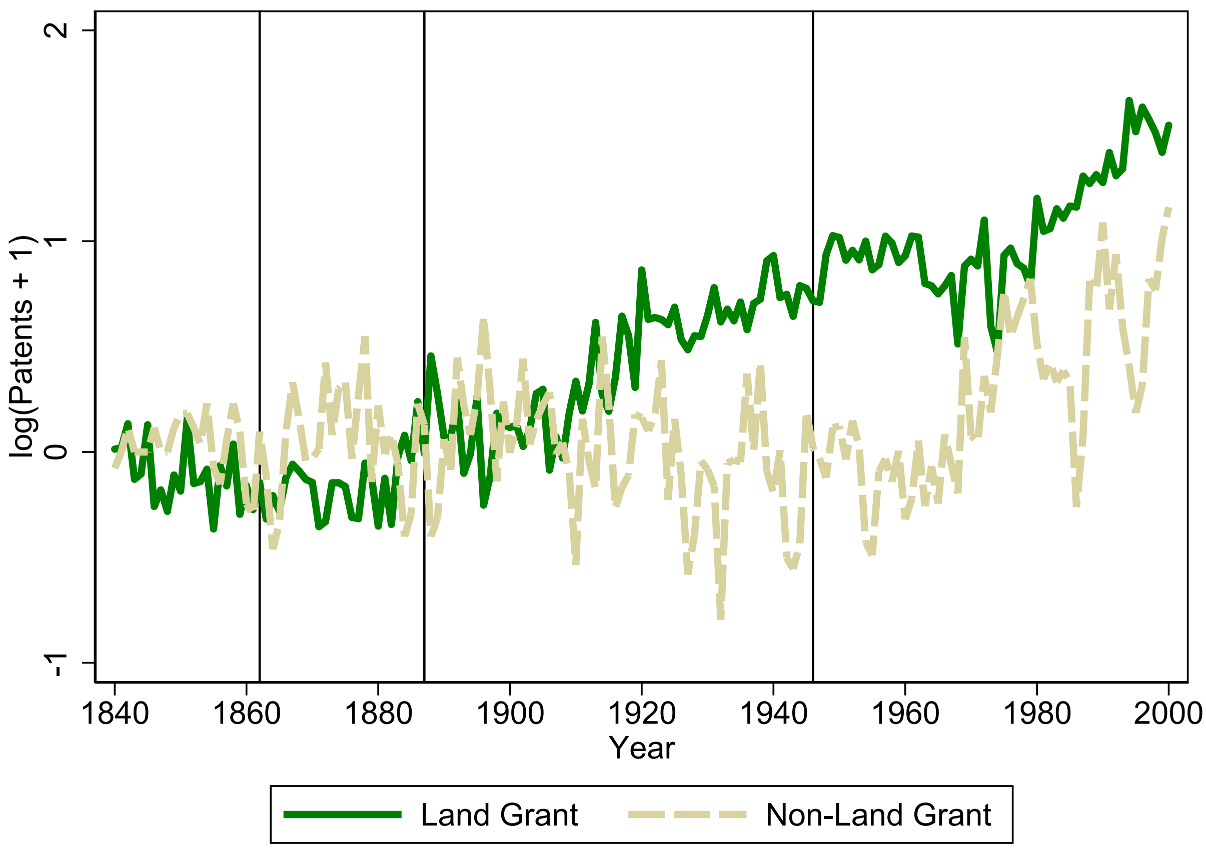


Figure 4: $\log(Patents + 1)$

Notes: Plot of the difference in logged patenting between college and runner-up counties for land grant colleges (green solid lines) and non-land grant colleges (gold dashed lines) established between 1860 and 1870. The x-axis shows calendar years.

Tables

Table 1: List of Land Grant College Experiments

	College	County	State	Runner-Up Counties	Year Established
1	Pennsylvania State University	Centre	Pennsylvania	Blair	1855
2	University of California Berkeley	Alameda	California	Napa; Contra Costa	1857
3	Kansas State University	Riley	Kansas	Shawnee	1863
4	Cornell University	Tompkins	New York	Schuyler; Seneca; Onondaga	1865
5	University of Maine	Penobscot	Maine	Sagadahoc	1866
6	University of Wisconsin	Dane	Wisconsin	Fond du Lac	1866
7	University of Illinois	Champaign	Illinois	McLean; Morgan; Logan	1867
8	West Virginia University	Monongalia	West Virginia	Greenbrier; Kanawha	1867
9	Oregon State University	Benton	Oregon	Marion	1868
10	Purdue University	Tippecanoe	Indiana	Monroe; Marion; Hancock	1869
11	University of Tennessee	Knox	Tennessee	Rutherford	1869
12	Louisiana State University	East Baton Rouge	Louisiana	Bienville; East Feliciana	1870
13	Texas A and M University	Brazos	Texas	Austin; Grimes	1871
14	University of Arkansas	Washington	Arkansas	Independence	1871
15	Auburn University	Lee	Alabama	Tuscaloosa; Lauderdale	1872
16	Virginia Polytechnic Institute	Montgomery	Virginia	Albemarle; Rockbridge	1872
17	North Dakota State University	Cass	North Dakota	Burleigh; Stutsman	1883
18	University of Arizona	Pima	Arizona	Pinal	1885
19	University of Nevada	Washoe	Nevada	Carson City	1885
20	North Carolina State University	Wake	North Carolina	Lenoir; Mecklenburg	1886
21	University of Wyoming	Albany	Wyoming	Uinta; Laramie	1886
22	Utah State University	Cache	Utah	Weber	1888
23	Clemson University	Pickens	South Carolina	Richland	1889
24	New Mexico State University	Dona Ana	New Mexico	San Miguel	1889
25	University of Idaho	Latah	Idaho	Bonneville	1889
26	University of New Hampshire	Strafford	New Hampshire	Belknap	1891
27	Washington State University	Whitman	Washington	Yakima	1891
28	University of Florida	Alachua	Florida	Columbia	1905
29	University of California Davis	Yolo	California	Solano; Contra Costa	1906

Notes: List of land grant college experiments in the sample, along with the winning county and state, the runner-up counties, and the year in which the site selection decision took place.

Table 2: Summary Statistics of Land Grant College Experiments

	N	Mean	S.D.	Min	Median	Max
# Runner-Up Counties	29	1.55	0.69	1.00	1.00	3.00
Distance to College	45	150.38	111.88	30.31	109.28	553.35
Year Established	29	1877.28	13.28	1855.00	1872.00	1906.00

Notes: Number of runner-up counties, average distance from the runner-up counties to the college site, and experiment year for the land grant college experiments in the sample.

Table 3: Differences-in-Differences Results Comparing Land Grant College Counties to Runner-Up Counties

(a) Innovation and Population Outcomes

	log(Patents + 1)	log(Ag. Patents + 1)	Frac. Ag. Patents	New Wheat Variety	log(Total Pop.)	log(Frac. Urban)
CollegeCounty * PostCollege	0.539**	0.0857	0.00246	0.0168**	0.0966	0.00319
	(0.193)	(0.0624)	(0.0196)	(0.00605)	(0.199)	(0.0304)
PostCollege	0.0970	0.105	0.0228	-0.00711*	0.287	0.0264
	(0.172)	(0.0627)	(0.0147)	(0.00282)	(0.157)	(0.0232)
Num. Counties × Years	13141	13141	9745	6639	12449	9477
Adj. r-Sqr.	0.721	0.314	0.0461	0.00778	0.799	0.702

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(b) Agricultural Outcomes

	log(Ag. Yields)	log(Value Agricultural Output + 1)	log(Value Crops + 1)	log(Value Livestock Products + 1)
CollegeCounty * PostCollege	0.0998	0.156	0.127	-0.0419
	(0.118)	(0.286)	(0.331)	(0.385)
PostCollege	-0.177*	0.314	0.189	0.628
	(0.0837)	(0.222)	(0.280)	(0.355)
Num. Counties × Years	11780	12190	12190	12190
Adj. r-Sqr.	0.914	0.923	0.956	0.938

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Differences-in-differences regression results comparing land grant college counties to runner-up counties before and after establishing each college. Panel (a) uses innovation and population outcomes as the dependent variables. Panel (b) uses agricultural yield and output as the dependent variables. All regressions include county and year fixed effects. Standard errors are clustered at the county level.

Table 4: Share of Wheat Varieties from Land Grant Research

	Share Varieties		Share Acres	
	Land Grant Research	Land Grant Counties	Land Grant Research	Land Grant Counties
Post Morrill Act	0.303	0.355	0.097	0.131
Post Hatch Act	0.347	0.389	0.113	0.166

Notes: Columns 1 and 2 list the share of new wheat varieties introduced since the passage of the Morrill Act in 1862 (row 1) and the passage of the Hatch Act in 1887 (row 2). Column 1 shows the share of varieties introduced as a result of land grant college research. Column 2 includes any varieties introduced in land grant college counties, regardless of whether they were the result of programmatic research. Columns 3 and 4 do the same but weight each variety by acreage planted.

Table 5: Triple Differences Results Comparing the Land Grant to Non-Land Grant Colleges

(a) Innovation and Population Outcomes

	log(Patents + 1)	log(Ag. Patents + 1)	Frac. Ag. Patents	New Wheat Variety	log(Total Pop.)	log(Frac. Urban)
College * Post-College * Land Grant	-0.0934	-0.00639	0.00930	0.0157*	-0.385	-0.0616
	(0.263)	(0.0757)	(0.0257)	(0.00640)	(0.262)	(0.0433)
CollegeCounty * PostCollege	0.634***	0.0926*	-0.00842	0.00118	0.487**	0.0649*
	(0.183)	(0.0426)	(0.0170)	(0.00206)	(0.164)	(0.0310)
Post-College * Land Grant	0.209	0.0798	0.0129	-0.000826	0.216	0.0438
	(0.182)	(0.0570)	(0.0172)	(0.00164)	(0.182)	(0.0267)
PostCollege	-0.126	-0.00841	0.00906	-0.00103	0.00980	-0.00970
	(0.107)	(0.0333)	(0.0116)	(0.00168)	(0.0966)	(0.0164)
Num. Counties × Years	34911	34911	24115	17760	33541	25601
Adj. r-Sqr.	0.724	0.297	0.0527	0.00408	0.803	0.734

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(b) Agricultural Outcomes

	log(Ag. Yields)	log(Value Agricultural Output + 1)	log(Value Crops + 1)	log(Value Livestock Products + 1)
College * Post-College * Land Grant	0.0538	-0.0462	-0.0544	-0.146
	(0.144)	(0.366)	(0.432)	(0.472)
CollegeCounty * PostCollege	0.0337	0.203	0.182	0.123
	(0.0985)	(0.219)	(0.275)	(0.265)
Post-College * Land Grant	-0.177*	-0.0331	-0.0922	0.497
	(0.0751)	(0.199)	(0.245)	(0.265)
PostCollege	0.108	0.227*	0.157	0.0103
	(0.0555)	(0.0953)	(0.121)	(0.119)
Num. Counties × Years	32092	33312	33312	33312
Adj. r-Sqr.	0.918	0.926	0.966	0.947

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Triple differences regression results comparing college counties to runner-up counties before and after establishing each college for land grant and non-land grant colleges. Panel (a) uses innovation and population outcomes as the dependent variables. Panel (b) uses agricultural yield and output as the dependent variables. All regressions include county and year fixed effects. Standard errors are clustered at the county level.

Table 6: Comparing Land Grant College Counties to Runner-Up Counties following Several Pieces of Legislation

(a) Innovation and Population Outcomes

	log(Patents + 1)	log(Ag. Patents + 1)	Frac. Ag. Patents	log(Total Pop.)	log(Frac. Urban)
College * Post-Morrill Act	-0.0165	0.108	0.0643	-0.0151	-0.0202
	(0.255)	(0.152)	(0.0453)	(0.210)	(0.0330)
College * Post-Hatch Act	0.466	0.0238	0.0389	0.112	0.0182
	(0.340)	(0.0914)	(0.0305)	(0.289)	(0.0420)
College * Post-World War II	0.646	0.179	-0.00594	0.538**	0.0911
	(0.332)	(0.0914)	(0.0100)	(0.156)	(0.0587)
Num. Counties × Years	4451	4451	3526	4378	3538
Adj. r-Sqr.	0.747	0.304	0.0582	0.846	0.744

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(b) Agricultural Outcomes

	log(Ag. Yields)	log(Value Agricultural Output + 1)	log(Value Crops + 1)	log(Value Livestock Products + 1)
College * Post-Morrill Act	-0.0765	-0.128	-0.107	0.228
	(0.0810)	(0.302)	(0.264)	(0.423)
College * Post-Hatch Act	-0.0280	-0.0222	-0.0692	-0.161
	(0.137)	(0.357)	(0.376)	(0.324)
College * Post-World War II	0.0459	0.0971	0.106	0.0909
	(0.0800)	(0.261)	(0.426)	(0.238)
Num. Counties × Years	4188	4398	4398	4398
Adj. r-Sqr.	0.951	0.947	0.973	0.950

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Differences-in-differences regression results comparing college counties to runner-up counties before and after several major land grant-related pieces of legislation for the cohort of land grant colleges established between 1860 and 1870. Panel (a) uses innovation and population outcomes as the dependent variables. Panel (b) uses agricultural yield and output as the dependent variables. All regressions include county and year fixed effects. Standard errors are clustered at the county level.

Table 7: Comparing the Land Grant to Non-Land Grant Colleges following Several Pieces of Legislation

(a) Innovation and Population Outcomes

	log(Patents + 1)	log(Ag. Patents + 1)	Frac. Ag. Patents	log(Total Pop.)	log(Frac. Urban)
College * Post-Morrill Act * Land Grant	-0.149	0.149	-0.0372	-0.276	0.00831
	(0.347)	(0.146)	(0.0797)	(0.213)	(0.0398)
College * Post-Hatch Act * Land Grant	0.456	0.0250	-0.0696	-0.148	0.0193
	(0.441)	(0.0932)	(0.0759)	(0.317)	(0.0662)
College * Post-World War II * Land Grant	0.365	0.165	-0.0131	0.246	0.0460
	(0.407)	(0.107)	(0.0524)	(0.218)	(0.0846)
Num. Counties × Years	7248	7248	5253	7227	5817
Adj. r-Sqr.	0.750	0.289	0.0454	0.868	0.771

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(b) Agricultural Outcomes

	log(Ag. Yields)	log(Value Agricultural Output + 1)	log(Value Crops + 1)	log(Value Livestock Products + 1)
College * Post-Morrill Act * Land Grant	-0.0598	-0.0179	-0.152	0.179
	(0.162)	(0.481)	(0.398)	(0.692)
College * Post-Hatch Act * Land Grant	-0.0199	0.153	0.126	0.0783
	(0.144)	(0.480)	(0.505)	(0.462)
College * Post-World War II * Land Grant	0.0941	0.302	0.388	0.145
	(0.0953)	(0.344)	(0.679)	(0.289)
Num. Counties × Years	6947	7267	7267	7267
Adj. r-Sqr.	0.956	0.957	0.976	0.956

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Triple difference regression results comparing land grant college counties to runner-up counties before and after several major land grant-related pieces of legislation for the cohort of land grant and non-land grant colleges established between 1860 and 1870. Panel (a) uses innovation and population outcomes as the dependent variables. Panel (b) uses agricultural yield and output as the dependent variables. All regressions include county and year fixed effects. Standard errors are clustered at the county level.

A Appendix

Table A1: List of Non-Land Grant College Experiments

	College	County	State	Runner-Up Counties	Year Established
1	University of Mississippi	Lafayette	Mississippi	Rankin; Attala; Harrison; Montgomery; Winston; Monroe	1841
2	Eastern Michigan University	Washtenaw	Michigan	Jackson	1849
3	The College of New Jersey	Mercer	New Jersey	Middlesex; Essex; Burlington	1855
4	University of South Dakota	Clay	South Dakota	Bon Homme; Yankton	1862
5	University of Kansas	Douglas	Kansas	Shawnee	1863
6	Lincoln College (IL)	Logan	Illinois	Edgar; Warrick; Macon	1864
7	Southern Illinois University	Jackson	Illinois	Perry; Clinton; Marion; Washington; Jefferson	1869
8	Mercer University	Bibb	Georgia	Spalding	1870
9	Missouri University of Science and Technology	Phelps	Missouri	Iron	1870
10	University of Oregon	Lane	Oregon	Washington; Linn; Polk	1872
11	University of Colorado	Boulder	Colorado	Fremont	1874
12	University of Texas Austin	Travis	Texas	Smith	1881
13	University of Texas Medical Branch	Galveston	Texas	Harris	1881
14	University of North Dakota	Grand Forks	North Dakota	Burleigh; Stutsman	1883
15	Arizona State University	Maricopa	Arizona	Pinal	1885
16	Georgia Institute of Technology	Fulton	Georgia	Clarke; Greene; Baldwin; Bibb	1886
17	Kentucky State University	Franklin	Kentucky	Boyle; Warren; Daviess; Christian; Fayette	1886
18	New Mexico Tech	Socorro	New Mexico	San Miguel	1889
19	University of New Mexico	Bernalillo	New Mexico	San Miguel	1889
20	Alabama Agricultural and Mechanical University	Madison	Alabama	Montgomery	1891
21	North Carolina A and T University	Guilford	North Carolina	Durham; New Hanover; Alamance; Forsyth	1892
22	Northern Illinois University	DeKalb	Illinois	Winnebago	1895
23	Western Illinois University	McDonough	Illinois	Adams; Hancock; Warren; Schuyler; Mercer	1899
24	University of Nebraska at Kearney	Buffalo	Nebraska	Custer; Valley	1903
25	Western Michigan University	Kalamazoo	Michigan	Barry; Allegan	1903
26	Georgia Southern College	Bulloch	Georgia	Tattnall; Emanuel	1906
27	East Carolina University	Pitt	North Carolina	Lenoir; Beaufort; Edgecombe	1907
28	Middle Tennessee State University	Rutherford	Tennessee	Montgomery	1909
29	Western State Colorado University	Gunnison	Colorado	Garfield; Mesa	1909
30	Arkansas Tech University	Pope	Arkansas	Sebastian; Conway; Franklin	1910
31	Bowling Green State University	Wood	Ohio	Henry; Van Wert; Sandusky	1910
32	Kent State University	Portage	Ohio	Trumbull	1910
33	Southern Arkansas University	Columbia	Arkansas	Hempstead; Ouachita; Polk	1910
34	Southern Mississippi University	Forrest	Mississippi	Jones; Hinds	1910
35	Texas Christian University	Tarrant	Texas	Dallas	1910
36	Southern Methodist University	Dallas	Texas	Tarrant	1911
37	High Point University	Guilford	North Carolina	Alamance	1921
38	Texas Tech	Lubbock	Texas	Scurry; Nolan	1923
39	Maine Maritime Academy	Hancock	Maine	Sagadahoc	1941
40	US Merchant Marine Academy	Nassau	New York	Bristol	1941
41	US Air Force Academy	El Paso	Colorado	Walworth; Madison	1954

Notes: List of non-land grant college experiments in the sample, along with the winning county and state, the runner-up counties, and the year in which the site selection decision took place.

Table A2: Summary Statistics of Non-Land Grant College Experiments

	N	Mean	S.D.	Min	Median	Max
# Runner-Up Counties	41	2.12	1.38	1.00	2.00	6.00
Distance to College	87	139.57	202.22	30.61	84.77	1,413.28
Year Established	41	1893.51	24.99	1841.00	1892.00	1954.00

Notes: Number of runner-up counties, average distance from the runner-up counties to the college site, and experiment year for the non-land grant college experiments in the sample.