Private Gains from Public University Research: The Case of Productivity Spillovers from Agricultural Experiment Stations

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March 2012

For presentation at the All-UC Conference on Science, Intellectual Property, and Innovation

VERY PRELIMARY AND INCOMPLETE

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Abstract

This paper investigates the effects of university research on regional economic development in American agriculture. We study whether the establishment of agricultural experiment stations at the end of the 19th century led to persistent impacts on local economic development. The opening of the stations at predetermined locations provides the rare chance to examine whether university research has persistent effects -- many decades later -- on local economic development. Our analysis of county-level agricultural census data from 1870 to 1930 reveals that university research does indeed increase local productivity, and the effects persist and even grow over time. We find crop reallocation response to university research, but little evidence for an investment response, suggesting that reallocation is necessary for the full spillovers effect to manifest. We also find that the national agricultural extension program begun in 1914 was effective in spreading university research and agricultural development far from universities and throughout the nation.

We thank Chris Abrescy, Aly Anderson, Michael Wall, and Marko Zivanovic for excellent research assistance. We thank Caroline Hoxby, Paul Rhode, Romain Wacziarg, and Bruce Weinberg for helpful conversations.

I. Introduction

The discovery and adoption of new, more productive ideas is central to long-term economic development. It is less clear if the location of discoveries matters for where they are adopted. On the one hand, much recent evidence points to the role of social learning and other frictions in technology adoption, thus suggesting that personal interaction and geographic distance is central to technology adoption.[1] On the other hand, these frictions may not persist as the technology adoption process takes substantial time.[2] Thus, longer-term differences in technology choices may simply reflect the fact that different technologies are optimal in different environments.[3]

In this paper we seek to measure the extent and magnitude of local spillovers from a formal institution whose sole mission is the creation and dissemination of knowledge – the research university.[4] In other words, since research universities exist and are heavily subsidized to "spill knowledge," it seems natural to look here first to understand the importance of local knowledge production for local economic development in general.[5]

Despite the prominence of high-profile university-industry partnerships in Silicon Valley and along the Route 128 corridor, there is a relatively small but growing body of empirical

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[1] For recent examples see Wacziarg and Spolaore (2009), Conley and Urdy (2010), Duflo et al. (2011), Bloom et al. (2011).

[2] See Comin and Hobjin (2010) for cross country evidence the diffusion often takes multiple decades.

[3] Suri (2011) makes this point in the context of agriculture.

[4] Of course, more recently research universities have been engaged in the commercialization of their knowledge creation.

[5] The public subsidy to higher education in the U.S. to create and disseminate knowledge is significant. In FY 2008 public universities received $85 billion from state and local governments for their wide-ranging activities from teaching, research, to outreach (SHEEO 2009, Table 6). The federal government, in FY 2007, contributed $30.4 billion to the research and development activities of colleges and universities (NSF 2009). In addition, many individuals, foundations and firms donate large sums to universities, often to enhance the performance of institutions they support or to sponsor specific research endeavors. In FY 2008 universities received $31.6 billion in voluntary support from non-governmental sources (CAE 2009).

research that has attempted to measure the role that universities play in contributing to economic growth at the local level. Following Jaffe (1989; see also Acs, Audretsch, and Feldman 1991) much of the research has explored the spillover effects of academic research on such outcomes as patents, innovations, business start-ups, or employment changes.[6] While recent research has shown that the of productivity gains from academic research tend to be highly localized over a relatively short time horizon (Kantor and Whalley, 2010), we still have little understanding of the extent to which research university activities contribute to regional economic development over a longer time horizon. Our study aims to fill this gap.

This paper seeks to address this question directly. The main challenge we face is that university research does not occur randomly. The endogeneity arises because the activities of universities themselves may be directly affected by the presence of highly productive and innovative producers in a region. Highly productive farms may provide the capital needed for a university research to be successful. Thus, naively examining the cross-sectional correlation between university activity productivity of farmers in the neighboring area may lead one to conclude that universities generate spillovers, when in fact the causal link is unclear. Our estimation strategy seeks to isolate the spillover effects of research universities' activities on their local economies. Recent research has argued that biological innovation was central to agricultural productivity at this time, and at least some of the innovations were discovered in the agricultural experiment stations (Olmstead and Rhode, 2008).

To address the endogeneity concern we utilize simple differences in differences strategy based on the fact that university locations were fixed before the Hatch Act was passed in 1887 to establish the agricultural experiment stations. Because the policy change was driven by national

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[6] See Kantor and Whalley (2010) for a literature review.

concerns to improve agricultural productivity there is little reason to expect that agricultural productivity near stations would increase disproportionately faster, except because of the local spread of more productive farming practices discovered through university research. Using this method we can estimate the causal effect of university research on the productivity of local farmers, which is the parameter of interest.

Our empirical analysis reveals that university research activity results in statistically significant and persistent spillovers. Our preferred estimates indicate that a one standard deviation increase in distance to the university research reduces crop productivity by 2.5 percent. We also find that these effects are persistent, with the effects of distance increasing by 25% to 50% from 1890, shortly after the opening of the stations, to 1910. We also look at how the federal extension program begun in 1914 with agents in most counties attempting to spread university research though out the country affected the localization of agricultural productivity. This analysis reveals that the extension program largely undid the localization effects of university research, suggesting that the policies to spread university knowledge through demonstration were effective.

We further investigate whether the local effects of universities are more likely to reflect social learning based frictions in technology adoption or other factors. To do so we construct other measures of the distance between the university county and each other county that may well be correlated with distance. We examine three other distance measures. First, we construct a measure of population relatedness between the university and other nearby counties based on genetic distance (Wacziarg and Spolaore, 2009). If social groups are geographically concentrated our results may reflect this fact rather than geographic localization. Interestingly, our results echo Wacziarg and Spolaore (2009) in that genetic distance to the population in the experiment station county also reduces crop productivity. They differ in that genetic distance does not fully mitigate the importance of geographic distance.

We next create measures of climate and soil similarity between the experiment station county and other nearby counties. As biological innovation can result in new seed varieties or techniques that are very specific to a micro climate, then limited geographic diffusion could indicate that the university-based research is not applicable for farther-away climates. The results of this analysis reveal that geographic distance to university research continues to reduce crop productivity.

For our last set of results we utilize the highly detailed data in the agricultural census to uncover what mechanisms are at play in generating larger long-term than short-term effects. We consider two potential possibilities. First, the lower cost access to research that local producers have could stimulate investment in land improvement, equipment or fertilizer. As this investment takes time to affect output we would expect longer-term effects to be larger. Second, research may not affect the productivity of all crops equally and it could take time for producers to adjust and reallocate land towards the most productive crops. We test for both of these possibilities. We find little evidence of an investment response, but significant adjustment and reallocation in planting decisions. As reallocation may be necessary for the full spillover effects to manifest, our results may suggest that differences in the costs of reallocation could account for the mixed nature of recent estimates of spillover effects from scientific discoveries (see Azoulay, Graff Zivin and Wang (2010), Waldinger (2011) and Borjas and (2012)).

II. Experiment Station Background

The Morrill Act of 1862 granted each state 30,000 acres for each senator and representative in Congress. The land grants were designed to provide for:

> the endowment, support, and maintenance of at least one college where the leading object shall be, without excluding other scientific and classical studies and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts, in such manner as the legislatures of the States may respectively prescribe, in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life. (7 U.S.C. § 304)

While the Morrill Act provided for the initial establishment of the land grant colleges in each state, the colleges struggled financially for at least two decades, no doubt because nothing in the Act compelled state governments to participate as a partner in accomplishing the stated goals of the Act. As a result of the states' apparent struggles in maintaining support for their new land grant institutions, the Second Morrill Act of 1890 provided each state with a $15,000 appropriation in that year, with an annual increase of $1,000 for 10 more years. By 1900, then, the states' nominal budgets for their land grant institutions would have increased by $25,000 relative to the 1890 baseline. Again, in 1907, the federal government further enhanced land grant funding. Known as the Nelson Amendment, the new law appropriated each state an additional $5,000 in 1908, with marginal annual increases of $5,000 more over the next four years. Thus, by 1912 each state received an additional $25,000 – on top of the $25,000 from the Second Morrill Act – to support the operation and maintenance of their land grant institutions.[7] In 32 states the Nelson appropriation enhanced the public universities' budgets by over 5

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[7] This brief history of land grant funding is drawn from Covert (1938).

percent, and in many cases where the institutions were fairly small to begin with, the percentage increase was substantial.

A second set of significant federal laws further bolstered the mission and funding of the land grant colleges. The Hatch Act of 1887 provided each state with $15,000 to establish an agricultural experiment station "under direction of the college or colleges or agricultural department of colleges in each State," as established under the Morrill Act of 1862. Prior to the Hatch Act, 12 states had already established their own experiment station and a number of others reported such work without having a formal structure governing such work (Carstensen 1960, 13). The objective of the Hatch Act was "to aid in acquiring and diffusing among the people of the United States useful and practical information on subjects connected with agriculture, and to promote scientific investigation and experiment respecting the principles and applications of agricultural science." The U.S. Department of Agriculture established the Office of Experiment Stations (OES) in 1888 to carry out the Secretary's authority "to secure, as far as practicable, uniformity of methods and results in the work of said stations . . . [and] to furnish such advice and assistance as will best promote the purpose of this act." Six years later Congress authorized the USDA to monitor station expenditures to ensure that federal funds were spent in accordance with the objectives of the Hatch Act.

Lou Ferleger's (1990) analysis of the OES reports of the states' experiment station activities prior to 1900 found that the OES believed that station scientists were not conducting enough original research and that they were being assigned heavy instructional loads that served the land grant colleges well, but not agricultural science. As Rosenberg (1964, 4) argues, "the Office of Experiment Stations had to fight a continuous and dispiriting war against the pilfering of station funds and the misuse of station personnel by college deans and presidents. These administrators saw in the Hatch Act a windfall for undernourished instructional budgets . . . In the dozen years between 1894 and 1906, the Office of Experiment Stations had evolved a persistent and well-articulated policy aimed at converting Hatch appropriation into a research fund exclusively." The main shortcoming of the Hatch Act, according to Rosenberg, was Congress's conflicting charge to the experiment stations: "diffusing . . . useful and practical information . . . [and] conduct[ing] original researches or verify[ing] experiments." Station staff were hard pressed to please their multiple constituents – farmers with immediate questions and concerns, college administrators facing constraints in their instructional budgets, and federal regulators pressing for basic scientific research that would advance agricultural science (see True 1899).

The passage of the 1906 Adams Act was designed to tilt the balance. At the same time doubling the level of federal funding to the state experiment stations, the Adams Act stipulated that the new money was to be appropriated only for "original" scientific research, not dissemination or the so-called verification of experiments as the Hatch Act allowed. Moreover, the use of Adams funds required consultation with the OES, which ensured that projects that were funded focused on basic research (Ferleger 1990, 20). The Adams Act, according to Rosenberg (1964, 8), represented a "new era for the experiment station scientist . . . a necessary first step in the direction of a final emancipation from the duties of teacher and analytical drudge." While there might have been an inadequate number of scientists to effectively conduct the new research that could be sponsored under the Adams Act, the funds served as an endowment of sorts that "permanently strengthened the scientific department of the land-grant colleges" and paved the way for advances in genetics, biochemistry, and bacteriology (Rosenberg 1964, 11). While the agricultural scientists were not completely free from the everyday problems and concerns that farmers faced as they met with farmers in short courses offered at the land grant colleges or on the lecture circuit, the passage of the Smith-Lever Act in 1914 marked a next phase in the specialization of the experiment station researcher. The Smith-Lever Act provided additional funding for extension agents, connected to the land grant colleges, whose specific focus was to disseminate new knowledge and to demonstrate best practices to farmers in their home locations. With a specialized cadre of extension agents who were placed in each county where agriculture had even a modest presence, the localized benefits of being near a land grant university and having the ability to communicate with and observe experiment station staff were presumably reduced. It is the local external benefits of research activity that we empirically examine in the analysis below.

III. Data and Empirical Strategy

Data

The primary data that we use to estimate the impact of university agricultural-related research on local agricultural development comes from the Agricultural Census. We obtain county-level data on agricultural outcomes from 1870 to 1930 from this source. We use county-level data on crop revenue, farm value, farm acreage, fertilizer expenditure, improved acres, and equipment value for the full sample period. For the period from 1880 to 1930 we also have data on acreage planted in wheat, corn, and oats.

We choose our sample of counties in states east of the continental divide so that we are working with counties that are relatively settled in 1870. We further drop southern states as the USDA began early federal extension programs headed by Knapp in the south to combat the Boll Weevil and to establish the rice industry in Louisiana in the early 20th century. Lastly we drop counties that were sparsely settled in 1870 (less than 10% of their land in farms) so that that our analysis measures the impact of agricultural experiment stations on existing farming operations rather then on expanding farming to unsettled regions. We also define counties based on the 1880 definitions and drop those counties with large boundary changes that make this definition problematic. Our final sample contains 862 counties.

We merge into our dataset variables reported at the county level from the decennial Population Census, the Census of Libraries in 1903, the Directory of Agricultural Fairs (Marti, 1986), and the Fishback, Horrace and Kantor (2005, 2006) (FHK) county geography database. We create indices of county soil and climate suitability for agriculture by first regressing farm revenue per farm acre in 1870 on a set of fixed (1) climate or (2) soil measures from the FHK database. We these use the regression coefficients from these specifications with the observed climate or soil measures to predict revenue per acre for each county. This procedure gives us climate and soil based indices of agricultural suitability at the county level.

We can take the difference between each county's index to measure the difference between the experiment station county and each county in the state in terms of soil and climate suitability for agriculture. We view these differences as potentially important in explaining limited diffusion of biological innovation in agriculture as differences in endowments. Given the climate- and soil-specificity of some biological innovations, a slow take-up of new ideas may simply reflect the profit maximizing responses of farmers to differing conditions rather than frictions in technology diffusion.

We create one last distance measure. Recent work by Wacziarg and Spolaore (2009) has shown that the relatedness of populations affects the diffusion of innovation from the frontier to other countries. They use a genetic distance measure to quantify the degree of relatedness of two populations. This simple measure captures how far back in time the populations of two countries spilt off from the same initial population, so that the population of China would be more genetically distant from England than from Japan, for example. We utilize a similar approach here based on the nationality of the population of each county in 1880. We use the 100% sample of the 1880 census to construct a measure of a county of interest's genetic distance to the experiment station county in a state. To do so we first create a measure of the modal country of origin in each county as well as the experiment station county. We then use the data from Wacziarg and Spolaore (2009) to create a measure of the genetic distance between the modal country of origin in the experiment station county and all other counties. We then have a measure of the relatedness or social connections in place between the experiment station county and each other county in the state. This measure allows us to assess whether social network ties that are potentially correlated with distance could explain any geographic localization effects.

Table 1 provides a first look at summary statistics of relevant measures. We report the 1880 summary statistics for the full sample and then stratify the counties based on whether their geographic distance to the experiment station was below- or above-median. As shown in Panel A, agricultural outcomes in below-median distance counties were quite different from their counterparts in counties that were further away. The comparisons indicate many differences exist with the closer counties having higher levels of output, land value, inputs and investment. So this cursory glance suggests that universities focused on agriculture may well have led to local agricultural development, even before the research enterprise was well established. Of course, the results could equally reflect the idea that the land grant universities were placed in highly productive areas. A first glance at the summary statistics is at best only suggestive of a local development effect.

The results in Panel B help us to better understand whether other differences between close and far counties could explain the results. There is little difference in the genetic distance between the groups of counties suggesting that the localization of specific populations may not be correlated with the location of the experiment stations. There are strong correlations between climate and soil quality distance and geographic distance, however. Panel C also provides further evidence that near and far counties differ on a range of observable measures that could affect agricultural productivity.

Finally, Panel D shows that distance from the experiment station is correlated with other population and institutional characteristics. The percentage of the population literate, the presence of a large agricultural fair and the presence of a library all decline with distance from the experiment station. As population demographics and agricultural institutions are also likely to be related to technology adoption, this patterns could explain why closer counties might be more productive.

Methodology

Our empirical approach uses the time series variation in federal policy interacted with distance to the experiment station to estimate the effect of university research on local economic development. Consider a very simple model of the effect of local university research on local economic development,

$$Y_i = \beta \text{Research}_i + \varepsilon_i, \quad (1)$$

where Y_i is local agricultural output, Research_i is local university research activity, and ε_i, is the error term. Counties in our analysis are indexed by the subscript i. The coefficient (β) describes the relationship between local university research and local economic development. If there is a significant local development effect, then we would expect $\beta > 0$. As noted above the central questions we are interested in are whether there is an indeed a positive local development response, whether it persists over a long time horizon, and what explains any persistence. Empirically these questions boil down to different tests of β with different time horizons and with different outcomes.

A central challenge in estimating the casual effect of expansions of university research on development, as represented in equation (1), is that many determinants of Y_i are unobserved. More importantly, university research does not occur at random. The size of the research university sector sector is likely to be correlated with unobserved determinants of the size of the agricultural output. For example, agricultural interest groups such as breeders associations likely have significant resources in highly productive areas. If these groups contribute to funding university research then research will occur in areas that were productive anyway. In this case we would obtain an estimate of β which is biased upwards, perhaps significantly. Alternatively, voters may push for higher levels of government spending on research in response to poor performance in local agriculture. In this case we would obtain an estimate of β which is biased downwards. In any case, the endogenous nature of university research is likely to bias estimates of β in a simple cross-sectional OLS regression.

To address these potentially important sources of bias, we utilize variation in university research that is plausibly exogenous to the performance of local farmers. As noted above, the passage of the Hatch Act in 1887 provides variation in university agricultural research. As the experiment stations were opened in already chosen locations (the land grant colleges) the combination of timing and location of the Hatch Act spending provides a compelling source of exogenous variation in the location of university research. Our central identifying assumption is that changes in university research at land grant colleges are unrelated to changes in unobserved determinants of local agricultural development.

Formally, we estimate the equation,

$$Y_{it} = \beta_1(\text{Distance}_i \times \text{Station}_t) + \beta_2(\text{Distance}_i \times \text{Extension}_t) + \delta_i + \gamma_t + u_{it} \qquad (2).$$

Y_{it} is the agricultural development outcome of interest in county i in year t, Distance_i measures the distance from county i to the land grant county, where the experiment station is located, Station_t is an indicator variable that takes a value of one for all years after the Hatch Act (in 1887) to establish experiment stations at the land grant colleges, Extension_t is an indicator variable that takes a value of one for all years after the Smith-Lever Act (in 1914) to establish agricultural extension in every county, γ_t is a set of year fixed effects, δ_i is a set of county fixed effects, and u_{it} is the error term. Our central parameters of interest are β_1 and β_2. If university research causes an increase in local development we would expect β_1 to be positive. In addition, if the establishment of the extension program effectively spreads university research throughout the state, then localization effects of university will be undone and β_2 will be positive. Fitting equation (2) forms the heart of our analysis.

A couple of estimation details are worth noting. First, as we include county and year fixed effects in the model, we control for both time-invariant characteristics of each county and national trends in agricultural outcomes. The identification of our parameter of interest does not use either source of variation. This is a key advantage of our approach as many time-invariant factors such as climate and soil quality have important effects on agricultural productivity and development. Second, to address the possibility of persistent autocorrelation in outcomes within a county, we cluster the standard errors at the county level. Third, we weight counties by their area in 1880 so that our estimates capture the effects for a typical acre of land rather than county.

Our central identification assumption is that absent the passage of the Hatch Act agricultural development in counties close to and far from a land grant institution would have had similar trends in outcomes. While we cannot test this assumption directly, we can probe its validity by examining whether counties far and close to land grant institutions follow similar pre-Hatch trends. It would be cause for concern, for example, if counties close to land grant colleges were already experiencing increasing agricultural development before the passage of the Hatch Act. To examine this issue we estimate the model,

$$Y_{it} = (\mathrm{Distance}_i \times \gamma_t)\beta + \delta_i + \gamma_t + u_{it} \qquad (3),$$

where β is vector of year-by-year interactions with distance to the experiment station county. Equation (3) allows us to examine whether counties close and far from experiment stations were indeed following similar trends before the Hatch Act became law. If the timing of the Hatch Act was driven by trends local to experiment stations then we should observe that β_{1880} would already reflect the post-Hatch trends. If we find this to be the case, then it would undermine our identification strategy and indicate that the timing and structure of the experiment station model was likely endogenously related to trends in agricultural development. We thus regard the timing of any effect as an important validity check for our approach.

Beyond assessing the validity of our approach the full year-by-year effects are also of interest in their own right. They allow us to understand the persistence and dynamics of any local university research effects. For example, if university research generates persistent economic development effects we should see that differences in agricultural outcomes between counties close and far from the university remain decades after the experiment stations open in 1887. On the other hand, as productive farming practices diffuse widely throughout the nation over the long-term, any local productivity effects could be short lived.

A last benefit of examining the year by year effects is that the timing of another key policy is very sharp. The Smith-Lever Act passed in 1914 led to creation of the agricultural extension program in the United States. The sole purpose of the extension program was to get farmers to adopt the best practice methods of farming based on university research. As the program rolled out very quickly (stimulated partly the need to supply food to the allied campaign in WWI) virtually every county in the county had a county agent by 1920. If the extension program was indeed effective, then we should observe agricultural development converging between counties close to and far from universities after 1914.

IV. Empirical Results

We report the results of fitting equation (3) in Table 2. Each column reports the results from one specification. We report results for crop output per farm acre in columns (1) and (2), and for the value of the farm per farm acre in columns (3) and (4). For each outcome we consider two specifications. The first specification in columns (1) and (3) includes no additional controls, however the specification in columns (2) and (4) also includes year × 1870 characteristic interactions as controls. The additional controls may help to pick up national trends in settlement that may be correlated with distance from the experiment station.

The results in column (1) of Table 2 reveals that the distance to the experiment station is related to agricultural productivity after the experiment stations are established in 1887. Moreover, the effects appear to grow over time as the 1900 and 1910 interaction point estimates are indeed larger than those in 1890. This suggests that the full effects of research on local productivity take some time to manifest. The last result to take note of in column (1) is that the effects of distance on agricultural productivity are reduced after the agricultural extension program is established.

One potential concern with the specification in column (1) is that there may be differential trends in agriculture nearby the university before the experiment station is established. The results in column (1) do not show a statistically significant trend before 1890, however one may still be concerned that the pre-experiment station point estimates are rising. To address this potential concern we add additional controls to the model that allow counties with different levels of the fraction of land in farms, population, and crop productivity in 1870 to follow different trends. Including these controls in the specifications reported in column (2) does little to alter the substantive findings of column (1) , but they do lead the 1880 × distance interaction point estimate to be virtually zero. Thus, our results are not sensitive to including these controls in the model. As the pre-trend point estimate being virtually zero is a comforting feature of this specification we include this set of controls in our further models below.

Another finding to note in Table 2 is that the opening of the experiment stations did little to alter the effect of distance on land values in either specification. There are a number of possible explanations for this finding. It could be the case that there is substantial undeveloped land at this time so that more land is brought into production in response to local productivity spillovers leaving the price of land unchanged. It is also possible that the adaption of production required to utilize new farming practices is costly and these costs offset the local productivity benefits. It is difficult to say definitely at this point.

In Table 3 we report the results from fitting equation (2) above. Again we examine both crop productivity per acre and land value per acre as outcomes across a range of specifications and samples. The results in columns (1) and (5) echo those in Table 2. In columns (2) and (6) we limit the sample to only those states that do not have a state funded experiment station operating before the Hatch Act. These are the states where the federal intervention may be more exogenous to local trends in agriculture. The results change little. In columns (3) and (4) we include year × climate or year × soil trends in the model to allow for national changes in technology in a flexible way. Again the results change little. The results in Table 3 indicate that our central results are robust to changes in the specification and sample.

We next turn to the question of whether geographic distance to the experiment station county is driving the results or whether other factors are responsible. We consider three other measures of distance between a county and the experiment station county: genetic, climate and soil. We add each distance measure to equation (2) and report the results in Table 4. The results in column (2) reveal that the genetic distance of the population of a county from that in the experiment station county is related to agricultural productivity. This is very similar to what Wacziarg and Spolaore (2009) find using modern cross-country data. Our results differ from Wacziarg and Spolaore (2009) in that geographic distance remains economically and statistically significant with the addition of the genetic distance control. In columns (3) and (4) we examine whether distance from the experiment station in terms of agriculturally important endowments can explain the results. We find that our results are robust to controlling for climate and soil distance.

In Table 5 we examine whether the effects of distance to university research are heterogeneous. This could be the case if the returns to adopting new farming practices depended on the environmental conditions. For example, if experiment stations developed dry farming technology then we would expect that being far from an experiment station would be especially costly for a county with little rainfall. Other heterogeneous effects of interest concern the absorption technologies in place in a county. If a county can absorb written codified knowledge at low cost then distance to research may be less costly. We examine these potential heterogeneous effects in Table 5. In general the results present little evidence that the effects of distance to research are heterogeneous.

The last component of our empirical analysis peers into the mechanisms that could explain the persistence of the impacts. We consider two broad classes of mechanisms: investment and reallocation. We examine whether distance to university research has an effect on investment by farmers in Table 6 by fitting equation (2) with for a range of investment outcomes. We find little evidence of an investment response. We next examine evidence for a reallocation response in Table 7 by fitting equation (2) for a range of land use outcomes. Here we do find some reallocation responses. Distance to research increases the allocation of crop land towards corn and away from oats. Taken together the results in Tables 6 and 7 provide support for a reallocation response, but not for an investment response.

V. Conclusion

This paper investigates the effects of university research on regional economic development in American agriculture. Our analysis of county-level agricultural census data from 1870 to 1930 reveals that university research does indeed increase local productivity, and the effects persist and even grew over time. We find crop reallocation response to university research, but little evidence for an investment response, suggesting that reallocation is necessary for the full spillovers effect to manifest. We also find that the national agricultural extension program begun in 1914 was effective in spreading university research and agricultural development far from universities and throughout the nation. Our results indicate that the location of research does matter for the location of economic development in the short-run, but effective demonstration of more productive modes of production dampen the location effect over time.

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TABLE 1: Descriptive Statistics 1880, By Distance to Experiment Station

		Distance from Station:		
	Full Sample	Below Median	Above Median	t-stat (3)-(2)
	(1)	(2)	(3)	(4)
Panel A: Agricultural Output, Input, Investment and Land Use				
Crop Revenue per Farm Acre	2.64	2.76	2.50	-2.99
	(1.26)	(1.25)	(1.26)	[0.003]
Farm Value per Farm Acre	29.22	31.26	27.05	-2.98
	(20.93)	(22.01)	(19.50)	[0.003]
Fraction of Land in Farms	0.78	0.79	0.77	-1.59
	(0.19)	(0.18)	(0.20)	[0.112]
Fertilizer Expend per Farm Acre	0.04	0.05	0.03	-2.86
	(0.12)	(0.13)	(0.10)	[0.004]
Improved Acres per Farm Acre	0.67	0.69	0.65	-3.76
	(0.16)	(0.15)	(0.18)	[0.000]
Equipment Value per Farm Acre	1.12	1.19	1.04	-3.49
	(0.62)	(0.63)	(0.61)	[0.001]
Percent Crop Wheat	0.29	0.30	0.27	2.99
	(0.19)	(0.19)	(0.19)	[0.003]
Percent Crop Corn	0.46	0.45	0.49	-2.66
	(0.20)	(0.20)	(0.19)	[0.008]
Percent Crop Oats	0.16	0.17	0.16	-1.18
	(0.12)	(0.11)	(0.12)	[0.238]
Crop/Manufacturing Revenue Ratio	0.04	0.03	0.05	0.87
	(0.34)	(0.05)	(0.49)	[0.382]
Panel B: Standardized Distance to Station County				
Geographic Distance	-0.10	-0.79	0.63	41.29
	(0.87)	(0.42)	(0.58)	[0.000]
Genetic Distance	0.12	0.16	0.07	-1.03
	(1.26)	(1.15)	(1.37)	[0.302]
Climate Distance	-0.06	-0.27	0.17	6.52
	(0.99)	(0.82)	(1.11)	[0.000]
Soil Distance	-0.11	-0.32	0.13	8.32
	(0.81)	(0.70)	(0.86)	[0.000]
Panel C: County Climate and Soil Characteristics				
Latitude	40.03	40.68	39.32	-6.27
	(3.23)	(2.87)	(3.45)	[0.000]
Longitude	86.87	86.16	87.64	2.93
	(7.47)	(7.84)	(6.98)	[0.003]

Large River	0.16	0.10	0.22	4.55
	(0.37)	(0.30)	(0.43)	[0.000]
Elevation Minimum	558	591	524	-3.12
	(317)	(330)	(298)	[0.002]
Dry	0.16	0.24	0.08	-6.23
	(0.37)	(0.42)	(0.28)	[0.000]
Cold	0.17	0.20	0.14	-2.20
	(0.37)	(0.40)	(0.35)	[0.028]
Agricultural Soil Quality Index	0.08	0.10	0.07	-0.43
	(0.87)	(0.86)	(0.88)	[0.669]
Agricultural Climate Quality Index	-0.09	-0.07	-0.11	-0.72
	(0.98)	(1.00)	(0.95)	[0.471]

Panel D: County Population and Institutional Characteristics

Population	29895	30741	28987	-0.71
	(36056)	(30703)	(41046)	[0.480]
Percent Population Urban	0.15	0.16	0.13	-2.27
	(0.19)	(0.20)	(0.19)	[0.023]
Fraction Literate	0.94	0.95	0.93	-3.87
	(0.07)	(0.07)	(0.08)	[0.000]
Ag Fair	0.08	0.11	0.04	-3.52
	(0.26)	(0.31)	(0.20)	[0.000]
Library	0.38	0.43	0.34	-2.71
	(0.49)	(0.50)	(0.47)	[0.007]
Observations	862	446	416	

Notes: Source authors' calculations. The main entries in columns (1)-(3) report means of the selected variable for the sample indicated. The entries in parentheses are standard deviations. The main entries in the final column report t-statistics and hypothesis tests for the differences in means between the entries in columns (2) and (3) for the variable indicated.

TABLE 2: Geographic Distance to Experiment Station County: Crop Revenue, and Farm Value

	Dependent Variable =	Log(Crop Revenue per Farm Acre)		Log(Farm Value per Farm Acre)	
	Year Interaction:	(1)	(2)	(3)	(4)
Pre-Station	1880 × Geographic Distance	-0.02	0.00	-0.03	-0.02
		(0.02)	(0.01)	(0.02)	(0.02)
Post-Station	1890 × Geographic Distance	-0.04**	-0.03*	0.00	0.01
		(0.02)	(0.01)	(0.03)	(0.02)
	1900 × Geographic Distance	-0.06***	-0.04**	-0.02	-0.02
		(0.02)	(0.02)	(0.03)	(0.02)
	1910 × Geographic Distance	-0.06**	-0.04**	-0.01	-0.01
		(0.02)	(0.02)	(0.03)	(0.03)
Post-Extension	1920 × Geographic Distance	-0.05*	-0.03	0.02	0.02
		(0.03)	(0.02)	(0.04)	(0.03)
	1930 × Geographic Distance	-0.03	-0.02	0.05	0.04
		(0.03)	(0.02)	(0.04)	(0.03)
Additional Controls:					
Year × 1870 Characteristics		No	Yes	No	Yes
R^2		0.96	0.97	0.94	0.94
Observations		5954	5954	6034	6034

Notes: Source authors' calculations. Each column in the table reports the results from fitting equation (3) for the outcome and control set indicated. The main entries in the column are coefficient estimates, standard errors clustered at the county level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10% levels.

TABLE 3: Geographic Distance to Experiment Station County: Crop Revenue and Farm Value, Robustness

Dependent Variable=	Log(Crop Revenue per Farm Acre)				Log(Farm Value per Farm Acre)			
Specification:	Baseline	Hatch States	Climate Trends	Soil Trends	Baseline	Hatch States	Climate Trends	Soil Trends
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station × Geographic Distance	-0.03**	-0.06***	-0.02*	-0.03**	0.00	0.00	0.02	0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.03)	(0.02)	(0.02)
Extension × Geographic Distance	0.01	0.03**	0.01	0.01	0.04**	0.01	0.04***	0.04**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)
Additional Controls:								
Year × 1870 Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year × Climate Characteristics	No	No	Yes	No	No	No	Yes	No
Year × Soil Characteristics	No	No	No	Yes	No	No	No	Yes
Sample	Full	Hatch	Full	Full	Full	Hatch	Full	Full
R^2	0.97	0.96	0.97	0.97	0.95	0.95	0.96	0.95
Observations	5954	4022	5954	5954	6034	4074	6034	6034

Notes: Source authors' calculations. Each column in the table reports the results from fitting equation (2) for the outcome, sample, and control set indicated. The main entries in the column are coefficient estimates, standard errors clustered at the county level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10% levels

TABLE 4: Geographic and Other Distances to Experiment Station County: Crop Revenue

Dependent Variable=	Log(Crop Revenue per Farm Acre)			
	(1)	(2)	(3)	(4)
Station × Geographic Distance	-0.03***	-0.03***	-0.04***	-0.03**
	(0.01)	(0.01)	(0.01)	(0.01)
Extension × Geographic Distance	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
Station × Genetic Distance		-0.06**		
		(0.02)		
Extension × Genetic Distance		0.02		
		(0.02)		
Station × Climate Distance			0.02	
			(0.02)	
Extension × Climate Distance			0.01	
			(0.01)	
Station × Soil Distance				-0.04**
				(0.01)
Extension × Soil Distance				-0.03**
				(0.01)
Additional Controls:				
Year × 1870 Characteristics	Yes	Yes	Yes	Yes
R^2	0.97	0.97	0.97	0.97
Observations	5954	5954	5954	5954

Notes: Source authors' calculations. Each column in the table reports the results from fitting equation (2) with additional control set indicated. The main entries in the column are coefficient estimates, standard errors clustered at the county level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10% levels

TABLE 5: Geographic Distance to Experiment Station County: Crop Revenue and Farm Value, Interactions

Dependent Variable=	Log(Crop Revenue per Farm Acre)					
	(1)	(2)	(3)	(4)	(5)	(6)
Station × Geographic Distance	-0.03***	-0.03**	-0.04**	-0.04**	-0.04**	0.11
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.12)
Extension × Geographic Distance	0.01	0.01	0.01	0.01	0.05**	0.84***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.13)
Station × Geographic Distance × Dry		-0.01				
		(0.04)				
Extension × Geographic Distance × Dry		0.00				
		(0.03)				
Station × Geographic Distance × Cold			0.02			
			(0.02)			
Extension × Geographic Distance × Cold			-0.01			
			(0.03)			
Station × Geographic Distance × Ag Fair				0.04		
				(0.03)		
Extension × Geographic Distance × Ag Fair				-0.01***		
				(0.02)		
Station × Geographic Distance × Library					0.01	
					(0.02)	
Extension × Geographic Distance × Library					-0.08**	
					(0.02)	
Station × Geographic Distance × Literacy						-0.16
						(0.13)
Extension × Geographic Distance × Literacy						-0.90**
						(0.14)
Additional Controls:						
Year × Interaction Variable	Yes	Yes	Yes	Yes	Yes	Yes
Year × 1870 Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.97	0.97	0.97	0.97	0.97	0.97
Observations	5954	5954	5954	5954	5954	5954

Notes: Source authors' calculations. Each column in the table reports the results from fitting equation (2) for the outcome, and interaction set indicated. The main entries in the column are coefficient estimates, standard errors clustered at the county level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10% level.

TABLE 6: Geographic Distance to Experiment Station County: Investment and Input Use Responses

Dependent Variable log of=	Fraction of Land in Farms	Fertilizer per Farm Acre	Improved Acres per Farm Acre	Equipment Value per Farm Acre
	(1)	(2)	(3)	(4)
Station × Geographic Distance	-0.01	-0.01	-0.03	0.00
	(0.01)	(0.05)	(0.03)	(0.02)
Extension × Geographic Distance	-0.01	-0.08**	0.06	0.03
	(0.01)	(0.04)	(0.04)	(0.03)
Additional Controls:				
Year × 1870 Characteristics	Yes	Yes	Yes	Yes
R^2	0.93	0.88	0.83	0.95
Observations	6034	5088	6034	6033

Notes: Source authors' calculations. Each column in the table reports the results from fitting equation (2) for the outcome indicated. The main entries in the column are coefficient estimates, standard errors clustered at the county level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10% level.

TABLE 7: Geographic Distance to Experiment Station County: Land Use Responses

Dependent Variable log of=	Percent Crop Wheat	Percent Crop Corn	Percent Crop Oats	Crop Rev / Man Rev
	(1)	(2)	(3)	(4)
Station × Geographic Distance	0.06	0.05***	-0.06**	-0.04
	(0.04)	(0.01)	(0.02)	(0.04)
Extension × Geographic Distance	0.00	0.00	0.06*	0.08**
	(0.04)	(0.02)	(0.03)	(0.04)
Additional Controls:				
Year × 1870 Characteristics	Yes	Yes	Yes	Yes
R^2	0.90	0.93	0.89	0.87
Observations	5020	5170	5142	5100

Notes: Source authors' calculations. Each column in the table reports the results from fitting equation (2) for the outcome indicated. The main entries in the column are coefficient estimates, standard errors clustered at the county level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10% level.