The Impact of Broadband on U.S. Agriculture: An Evaluation of the USDA Broadband Loan Program

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1. Introduction

Increasing the availability of broadband in rural communities has been an important U.S. rural development policy goal over the past decade.[1] Since 2000, federal broadband loan programs authorized under consecutive Farm Bills have directed more than $1.8 billion to private telecommunications providers in 40 states with the explicit goal of making high-speed data transmission capacity available to rural residents and businesses. Most recently, the American Recovery and Reinvestment Act of 2009 authorized $2.5 billion in new federal funding for these same purposes (Kruger 2009).

Arguments in favor of these programs are supported by research projecting large economic benefits from widespread broadband deployment (Crandall and Jackson 2001; Crandall et al. 2007). However, these projections obscure the fact that the distribution of these benefits is not likely to be uniform, either spatially or across industries. For example, a recent study comparing economic outcomes in communities that did or did not receive broadband loans found evidence that the loan program created a range of impacts – some positive, some negative – that varied across industries and across county types (Kandilov and Renkow 2010).

One particularly interesting finding in the Kandilov and Renkow (2010) study is that agriculture is one of the industries that experienced positive outcomes (in terms of payroll and number of establishments) in counties receiving broadband loans *vis-à-vis* non-recipient counties. In this paper, we further explore the impact of broadband loans on the agricultural industry. We employ a variety of program evaluation econometric techniques to ascertain whether or not various indicators of economic performance in the agricultural sector – commodity sales, production expenses, farm income, and farm size – have been positively affected by the broadband loan program. The analysis is conducted using county-level data from

the U.S. Census of Agriculture (Ag. Census), the county being the smallest level of geographic disaggregation for which we have data on both the receipt of broadband loans and performance indicators for agriculture.[2]

1.1   Why Should Acess to High-speed Internet Matter for Farmers?

There are several reasons why the availability of (high-speed) internet might boost farm profitability. The internet can substantially reduce the costs of interaction between spatially dispersed market participants and provide real-time access to information relevant for both production and marketing decisions of farmers (see Just and Just 2001). It can greatly facilitate access to current weather and pricing information for inputs and output; it can also speed technology adoption and improve management practices. All of these improvements can result in a reduction in farmers' costs and an increase in their revenue, ultimately leading to higher profits.

In particular, consider the farmer's profit maximization problem, equation (1) below:

$$(1) \qquad \max_{Q,L} \pi = TR(P^Q, Q) - TC(P^L, L) = P^Q Q - P^L L,$$

where π is farm profit; Q and L are the quantities of output produced and inputs purchased, respectively; P^Q and P^L are the market prices of output and inputs, and fixed costs are suppressed for simplicity. Access to (high-speed) internet can increase total revenue (TR) in two ways. First, it allows farmers to search for new customers for their output, which may lead to an increase in output produced, Q. Second, farmers might be able to find buyers willing to pay a higher price than what they currently receive, which leads to a higher output price, P^Q. On the other hand, having access to high-speed internet may reveal less costly sources inputs such as

seeds, fertilizers, and farm equipment, thereby lowering the price of inputs farmers face, P^L.

Finally, access to (high-speed) internet can increase the diffusion of better management practices

that can help farmers produce the same amount of output with fewer inputs.[3] All of these factors

can lead to higher revenue or lower costs or both, resulting in higher profits for farmers with

access to (high-speed) internet.

1.2   Empirical Findings

To our knowledge, we are the first to systematically evaluate the impact of increased

access to high-speed internet (via the USDA low-cost broadband loan programs) on the U.S.

agricultural sector nationwide. To estimate the impact of receiving a broadband loan and hence

increased access to high-speed internet on farm sales, costs, and other economic outcomes, we

employ a panel difference-in-differences (DID) fixed effects model as well as a DID propensity

score matching method. We use nationwide county-level data from the Ag. Census in 1997,

2002, and 2007, coupled with data on broadband loan receipt from the USDA. The pilot

broadband loan program was a nationwide program that was introduced in 2000; while the

current broadband loan program started after the 2002 Farm Bill took effect. The goal of the two

programs has been to supply low-cost broadband loans to small U.S. communities.

Our results are consistent with expectations. First, we show that the USDA broadband

loans have a positive effect on high-speed internet use among U.S. farmers – we find that

counties which have received a loan have a higher number of farms that use high-speed internet.

Then, we demonstrate that access to high-speed internet via the USDA broadband loans boosts

farm revenue by about 6 percent. In particular, our baseline estimates suggest that in counties

which received either a pilot broadband loan, administered before 2003, or a current broadband

loan, administered following the Farm Bill of 2002, total commodity sales increased by 6.6 and

6.1 percent, respectively, after the loan receipt. Further, the results suggest that total farm

expenditure rose about 3.2 (3.4) percent in counties which received a pilot (current) broadband

loan. Given that we find an increase in farm expenditure following the receipt of the broadband

loans, these estimates imply that farm output in counties receiving the broadband loans must

have increased as a result of increased access to high-speed internet. Overall, our estimates

imply that farm profits have risen about 3 percent as a result of the broadband loans.

Further, we provide evidence that the increase in total commodity sales in counties that

received either of the broadband loans is primarily driven by an increase in crop sales. Sales of

livestock and animal products appear less sensitive to broadband internet access. The current

broadband loan program does not seem to affect total farm acreage, but the earlier pilot loan

program appears to have increased acreage by about 3.6 percent, possibly due to lags in acreage

adjustment. Also, both types of broadband loans are associated with an increase in the number

of farms with positive crop sales in the recipient county. The number of farms with positive

livestock and animal products sales is unaffected by either of the broadband loans.

1.3   Related Literature

There is a large empirical literature on farmers' computer use that generally focuses on the farm

and farmer characteristics that lead to computer adoption. Examples include Huffman and

Mercier (1991); Hoag et al. (1999); as well as Smith et al. (2004), the last two of which analyze a

sample of Great Plains farmers. Also, Putler and Zilberman (1988) study computer adoption

patterns of farmers in Tulare County, California; and Batte et al. (1990) examine a sample of

Ohio commercial farmers, while Amponsah (1995) studies commercial farmers in North

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Carolina. Most of these studies provide evidence that the farmer's age and education and the size of the farm operation affect computer adoption. Another related strand of the literature analyzes farmer and farm characteristics affecting both internet adoption and use. Examples include Smith et al. (2004); Mishra and Park (2005); and Briggeman and Whitacre (2010). These studies also indicate that farm operator's age and education play a role in the internet adoption decision and the intensity of use.

While there is substantial literature on farmers' computer and internet adoption and use, there is little previous research on the impact of internet access on agricultural performance. When it comes to high-speed internet, to our knowledge, there is no previous work done at all, likely because broadband has only become more readily available in the last 10 to 15 years. The only relevant work that we were able to locate is an Agricultural and Resource Economics Newsletter from the Giannini Foundation of Agricultural Economics at the University of California-Davis by Smith and Paul (2005). Using self-reported survey data obtained from farmers from the Great Plains in 2000, Smith and Paul (2005) compute that 27 percent of the Great Plains farmers reported financial gains of about $3,800 (farmers' estimates of returns) from using the internet and 42 percent of farmers reported cost savings of an average of 14 percent. The farmers in the survey reported the most beneficial feature of the internet was finding information on input pricing or agricultural commodity markets. These estimates of the financial benefits of access to the internet, however, may be difficult to generalize to farmers in other regions (for example, as Smith and Paul (2005) note, internet marketing may not be as much of an option for Midwestern grain and livestock farmers as for operators in other parts of the country). Also, using more objective economic measures, instead of farmers' estimated

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financial returns and benefits, may be more appropriate when evaluating the overall economic impact of the internet on the U.S. agricultural sector.

Finally, our work is also related to the nascent empirical literature analyzing the impact of broadband on economic performance at the macro level or at the industry level. No work in this literature has studied the agricultural sector specifically, although as was mentioned earlier Kandilov and Renkow (2010) found evidence that the USDA broadband loan programs have had a positive effect on the agricultural sector's payroll and number of establishments. Other work in this literature includes Stenberg et al. (2009) who use county-level data to provide evidence that rural counties with greater broadband access also had greater economic growth. Gillett et al. (2006) use data on broadband availability between 1998 and 2002 and find that high-speed internet had a significant positive impact on local employment and the number of businesses establishments, especially in IT-intensive sectors, but not on wages.[4] Shideler et al. (2007) employ county-level broadband availability data in Kentucky and also uncover a positive impact of broadband on employment growth in certain sectors. The last two studies indicate that the positive effects of high-speed internet are smaller in rural counties. In contrast, we present evidence below that for the agricultural sector, the impacts of high-speed internet are uniformly positive across urban and rural counties; that is, we find no evidence that a rural-urban divide exists when it comes to the impacts of broadband on U.S. agriculture.

The rest of the paper is organized as follows. The next section provides details on the USDA broadband loan programs. Section 3 describes our data and presents summary statistics. Section 4 outlines the econometric model that we use to identify the impact of increased access to high-speed internet on farm sales, expenditure, and farm acreage. We discuss our results in section 5, which also presents a number of robustness checks. Section 6 concludes.

2.   USDA Broadband Loan Program

In December 2000, Congress authorized a pilot broadband loan program to help expand

broadband access in underserved rural communities. Program eligibility criteria included having

a population of 20,000 or less, having no prior access to broadband, and providing a minimum

matching contribution of 15 percent by recipients of the loan. Loans were extended mainly to

small telecommunications services firms at varying (subsidized) interest rates; most participating

communities qualified for a "hardship rate" of 4 percent (Cowan 2008).

Administered by the USDA's Rural Utilities Service (RUS), loans worth $180 million

were made in 2002 and 2003 to broadband providers serving 98 communities located in 13

states. Beginning with the 2002 Farm Bill, funding for the current (post-pilot) broadband loan

program was expanded. Program operations were modified due to problems with repayment:

more than one-quarter of the loans extended via the pilot broadband loan program were defaulted

(USDA 2007). As a result, RUS imposed tighter equity and loan security requirements. Another

concern with both the pilot and current programs relates to an overly broad definition of what

constitutes a "rural" community. For example, a 2005 audit by the USDA's Inspector General

chided RUS for having extended nearly 12 percent of total loan funding to suburban

communities located near large cities (USDA, Office of Inspector General 2005). A follow-up

audit found that this situation was not remedied, noting that between 2005 and 2008 broadband

loans were extended to 148 communities within 30 miles of cities with populations greater than

200,000 – including Chicago and Las Vegas (USDA, Office of Inspector General 2009).

3.   Data

Information on which counties obtained loans under the pilot broadband loan program and the

current broadband loan program was obtained from the USDA's Rural Development broadband program website for all the counties in the U.S.[5] As previously discussed, the pilot broadband loan program was introduced in 2000, while the current broadband loan program started after the 2002 Farm Bill took effect. Therefore, no counties had received any loans by 1997, and by 2002, only the pilot loans had been administered. By 2007, loans from the current broadband loan program were administered as well. For each county, we construct four treatment variables that show if a given county has received at least one of either the pilot or the current broadband loans. The first two variables, $Pilot\_BBLP_{ct}$ and $BBLP_{ct}$ are indicator variables equal to one in year t and afterwards if county c has at least one community which has received a pilot or a current broadband loan in year t, respectively.[6] The other two variables, $N\_Pilot\_BBLP_{ct}$ and N_BBLP_{ct}, show the exact number of communities in county c that have received a pilot or a current broadband loan, respectively.

To estimate the impact of a broadband loan receipt, and hence increased access to high-speed internet, on farming activities, we use county-level data from the Ag. Census. The county is the smallest level of geographic disaggregation for which we have information on receipt of the broadband loans as well as performance indicators for farms. While, with some exceptions, the USDA does provide data on the actual communities that received broadband loans, nationwide, comprehensive agricultural performance data is only available at the county level. Data on farm sales, expenditure, other income, crops and livestock sales, farm acreage and the number of farms with positive sales were all taken from the Ag. Censuses of 1997, 2002, and 2007. For a number of our robustness checks, we also used data on county population and income per capita from the U.S. Census of Population.

Table 1 presents summary statistics for two sets of counties in the U.S. – those who received at least one broadband loan, and those who did not. As of 2007, approximately 14 percent of all counties contained at least one community which had received a USDA broadband loan.

Panel A of Table 1 provides means and standard deviations for a set of key outcome variables for 1997, the last Ag. Census year prior to the authorization of the pilot broadband loan program, as well as for 2007, the most recent Ag. Census for which we have data on whether or not a county had received a broadband loan. Counties that have received broadband loans tend to be smaller in population. This is unsurprising, given the stated intent of the program is to target smaller, rural communities. Interestingly, though, there are no significant differences in mean income per capita between recipient and non-recipient counties. Likewise, there is little difference between the two types of counties in terms of the other indicators of agricultural performance, with the exception of livestock sales, which are somewhat higher in non-recipient counties.

Panel B of Table 1 indicates that many counties contained more than one community receiving a broadband loan. On average, 2.6 communities received broadband loans in each county for which any loan was received. Likewise, 3.8 pilot broadband loans were received per recipient county. Thus, broadband loans tended to be spatially clustered to some extent.

4.　　　Econometric Strategy

To identify the impacts of the USDA's promotional broadband loan programs (i.e. the effect of access to high-speed internet) on farm sales, expenditure, other farm-related income, farm

acreage, as well as crop and animal sales, we specify the following reduced-form panel DID

fixed effects model:

(2) $$ln(\Psi_{ct}) = \mu_c + \tau_t + \beta_1 Pilot\_BBLP_{ct} + \beta_2 BBLP_{ct} + X_{ct}\boldsymbol{\beta}_3 + \varepsilon_{ct},$$

where $ln(\Psi_{ct})$ is the natural logarithm of the respective dependent variable in county c and in

Ag. Census year t, $t = 1997, 2002, 2007$. The county fixed effects, μ_c, capture county-specific

characteristics that are time-invariant. The year dummies, τ_t, capture economy-wide shocks that

affect all farms. The coefficients of interest are β_1 and β_2 – the coefficients measuring the

impact of the two broadband loan programs, the pilot ($Pilot\_BBLP_{ct}$) and the current program

($BBLP_{ct}$). In our baseline specification, $Pilot\_BBLP_{ct}$ and $BBLP_{ct}$ are indicator variables equal

to one if a county c has received at least one pilot broadband loan ($Pilot\_BBLP_{ct} = 1$) or at least

one loan from the current broadband loan program ($BBLP_{ct} = 1$) by year t. In alternative

specification, we also use the number of pilot ($N\_Pilot\_BBLP_{ct}$) or the number of current

broadband loans (N_BBLP_{ct}) that a county has received by year t. We also show that the

estimates of the impact of the broadband loans are robust to inclusion of time-varying county-

specific covariates, such as county population and income per capita, that may affect the

dependent variable and may potentially be correlated with broadband loan receipt. These

variables are included in the matrix X_{ct}. Finally, ε_{ct}, is a classical error term.

Another robustness check we perform employs a propensity score matching (PSM)

method. This method was developed by Heckman, Ichimura, and Todd (1997), extending the

original work of Rosenbaum and Rubin (1983) for cross-sectional data. Because we have panel

data, we use the DID version of the PSM method developed by Heckman, Ichimura, Smith, and

Todd (1998) specifically for panel data setting. Different from the PSM method for cross-sectional data, the DID version accommodates for selection on time-invariant (county-level) unobservables.[7]

To evaluate the impact of the USDA broadband loans, this method matches (and then compares) counties that received a broadband loan with counties that did not receive a loan based on their observable characteristics before any of the counties received a loan (pre-treatment characteristics).[8] We use what is known as the radius matching protocol with a bandwidth of 0.001 to carry out the DID version of PSM method in our context. Specifically, we implement this method in two stages. In the first stage, we estimate the probability of broadband loan receipt using a set of pre-treatment conditional variables and a logistic regression. We include all variables that affect both the incidence of the broadband loans and the outcomes of interest, such as farm sales and total expenditure, as conditional variables in the logistic regression. In the second stage, we compare the outcome variables between the two groups of counties – the group that received the broadband loans and a group of appropriately matched counties that did not. The second group consists of counties whose predicted probabilities from the first stage logistic regressions (propensity scores) fall within 0.001 (radius) of the propensity scores of the counties that received broadband loans. We then calculate the impact of the broadband loans on those counties which received them (i.e. the average treatment effect on the treated) by taking the difference in the differences (post-broadband loan program minus pre-broadband loan program) of the outcomes between the group of counties that received broadband loans and the matched group that did not.[9] The Appendix provides further details on the matching procedure.

Finally, to investigate the impact of access to high-speed internet (i.e. the effect of the low-cost USDA broadband loans) on the number of farms with positive sales and other income, as well as the number of farms with positive crop and animal sales, instead of the linear DID fixed effects model (2), we use a fixed-effects Poisson model for count data (see, e.g., Cameron and Trivedi, 1998, pp. 280-282).

5.   Results

5.1   The Impact of the USDA Broadband Loans on High-speed Internet Use among U.S. Farmers

We start by providing direct evidence of the impact of the USDA broadband loan programs on internet use – in particular, high-speed internet use – among U.S. farmers. Farm-related information on access to (high-speed) internet was not collected in the 1997 Ag. Census, as this was prior to the initiation of the pilot broadband loan program (and there was little, if any, broadband available in rural communities). In the 2002 and 2007 Ag. Censuses, information was collected on the number of farms with an internet connection. Only in 2007 was specific information on the number of farms with high-speed internet connection recorded. We take advantage of this limited data on access to high-speed internet in 2007 to show that counties that have received a loan through the pilot or the current broadband loan programs by 2007 do in fact have a higher number of farms with access to high-speed internet vis-a-vis non-recipient counties. This provides evidence that the broadband loans succeeded in increasing the penetration and use of broadband in recipient counties.

Panels A and B of Table 2 present the results of cross-sectional Poisson count models estimated using data from 2007. The dependent variable is the number of farms with access to high-speed internet. In Panel A, we employ the indicator variable for broadband loan receipt as

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the treatment variable, whereas in Panel B, we use the actual number of loans received. We

further check the robustness of the results by estimating a baseline model with all counties

(columns 1, 3, 4, and 6), and only counties with a population smaller then 20,000 (columns 2 and

5).

The estimates in Table 2 supports the hypothesis that counties which received at least one

of either the pilot or the current broadband loan also have a larger number of farms with access

to both internet in general and high-speed internet in particular More specifically, the estimates

in column 4 of Panel A indicate that 11.7 percent, or 28 more farms, at the mean (of 239 farms

with high-speed internet access), had access to high-speed internet in counties that received at

least one of the current broadband loans, while 32.8 percent more farms had access to high-speed

internet in counties that received a pilot broadband loan. The latter impact declines to 17.9

percent when county population and income per capita are included in the Poisson regression.

Similar positive and statistically significant estimates are obtained when the number of

broadband loans received, instead of the incidence of the loans, is used as the treatment variable

in Panel B of Table 2. Overall, the results provide a strong indication of a positive effect of the

USDA broadband loans on high-speed internet use among U.S. farmers.

*5.2   The Impact of the USDA Broadband Loans on Farm Sales, Expenditure, and Profits:
         Baseline Results*

In this section, we continue by estimating equation (2) which relates an outcome of interest, for

example farm sales, to receipt of the USDA broadband loans. The first specification we present

in Panel A of Table 3 contains no covariates and uses total commodity sales as a dependent

variable. The estimates imply that farms in counties which received at least one current USDA

broadband loan experienced about 6.1 percent increase in total commodity sales following the

receipt of the loan.[10] This impact is both economically and statistically significant. Also, the results suggest that counties that received at least one of the pilot broadband loans experienced a 6.6 percent increase in total commodity sales. This impact is also economically and statistically significant, and it is of similar magnitude to that of the current broadband loan program. This is not surprising since the two broadband loan programs are quite similar, although some of the differences, as we already outlined earlier, would lead us to expect the pilot program to have a somewhat larger effect than the current program.

While we have documented an increase in total commodity sales as a result of increased (high-speed) internet penetration, it is difficult to assess if this is due to higher prices that farmers can obtain (from higher information efficiency brought about by access to high-speed internet) or due to increased output (from a larger customer base that they can now locate). Because there is no information available on average prices that farmers obtain or production quantities (and the latter would be meaningless if multiple commodities are produced), we next consider farmers' total expenditures before and after increased availability of high-speed internet. To produce the same quantity after they gain increased access to (high-speed) internet, farmers would at most face the same level of expenditure and likely experience lower production costs. Hence, if farm expenditures rise following the receipt of broadband loans in the county of operation, it must be the case that inputs and therefore production quantity have increased.

The second column in Panel A of Table 3 reveals that farms' total expenditure in counties that have received at least one of the current broadband loans also increased by about 3.4 percent. The impact is statistically significant, but economically, it is only about half the size of the impact of the current broadband loans on the total commodity sales. This increase in expenditures signals an increase in production quantity. Overall, farms profits increased by about

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2.7 percent (= 6.1 - 3.4) as a result of increased access to (high-speed) internet.

The third column in Panel A of Table 3 shows that other farm income (i.e. income from farm-related sources, such as agricultural services, cash rent and share payments, sales of forest products, recreational services, patronage dividends, and refunds from cooperatives) has also increased by about 5 percent in counties that received at least one of either the current or the pilot broadband loans. Note, however, that while economically significant, these effects are not estimated precisely enough to be statistically significant.

The fourth column of Panel A of Table 3 presents the impact of the broadband loans on farm acreage in counties that received at least one of the broadband loans. The estimates reveal that farm acreage did not change as a result of the current broadband loans, but it rose by about 3.6 percent in counties that received at least one of the pilot broadband loans.[11] Similar results obtain using harvested cropland acreage instead of overall farm acreage as a dependent variable.

Finally, in the last two columns of Panel A, we assess if the growth in commodity sales due to the increased access to high-speed internet is a result of increased sales of crops or animal products. The estimates reveal that the positive impact of the broadband loans is larger for crops than it is for animal products. For both the current and for the pilot broadband loan programs, the effects are larger in magnitude for crops, although for the pilot loans the two effects are not significantly different from each other. For the current loans, the impact on crop sales is estimated to be 10 percent – quite a bit larger than the impact on animal products, which is estimated to be only 2.6 percent (and not statistically significant).

In Panel B of Table 3, we investigate if receipt of the broadband loans has had any impact on the number of farms with positive sales and other farm income. The results from the Poisson county fixed effects model demonstrate that indeed the number of farms with positive sales and

other farm income have increased as a result of the better access to high-speed internet brought about by the broadband loans. For example, the estimated impact of $BBLP_{ct}$, the current broadband loan program, implies that in counties which received at least one of the current loans, the number of farms with positive sales has increased by about 7 farms.[12] The last two columns of Panel B show that the number of farms with positive crop sales increased more than the overall number of farms with positive total sales, while the number of farms with positive animal sales declined following improved access to high-speed internet. This is may indicate increased consolidation of animal farms following the increased access to distribution channels and consumer markets.

5.3   Robustness Checks

Next, we present a number of robustness checks that confirm our initial findings from the baseline specification (2). We begin in Panel A of Table 4 by adding two county-level time-varying covariates to our baseline specification – (the natural logarithm of) the county's population and (the natural logarithm of) the county's income per capita – both of which may be correlated with broadband loan receipt and also may affect farm-related outcomes. Excluding these variables from the model could lead to biased estimates of the impact of increased broadband access on farm outcomes. Panel A of Table 4 reports the estimates of the expanded model that includes the two additional covariates. None of the coefficients differ significantly, either economically or statistically, from their counterparts in Table 3. Most of the estimated effects are slightly larger when the two covariates are introduced in Panel A of Table 4. To conserve space, we only report the results for sales, expenditure, other income, acres, sales of crops and animal products (Panel A of Table 4). The expanded model estimates for the number

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of farms with positive sales, other income, as well as crop and animal sales are quite similar to their counterparts in Panel B of Table 3.[13]

For the second of our robustness checks, we estimate our baseline specification (2) using only "small" counties, i.e. counties with population of less than 20,000 people. Note that a community qualified for a broadband loan if its population was less than 20,000. However, a community is a smaller geographic unit than a county – for example, there are counties with more than one community of less than 20,000 people with a broadband loan, resulting in a number of counties with multiple broadband loans.[14] Here, we limit our attention to counties that resemble "small" communities, i.e. counties that themselves have a population of less than 20,000 people. The results are presented in Panel B of Table 4. The estimates of the impact of broadband access on county-level farm sales and profits are similar to those obtained with the full sample of all counties. The only difference is the smaller estimate of the impact of the pilot broadband loan on both farm sales and expenditure – the estimated impact of the pilot loan on farm profits is still positive at 1.0 percent.

Our third robustness check involves estimating a DID propensity score matching method. As before, this method employs DID methodology to estimate the effect of broadband penetration on farm-related outcomes, but here we compare counties that received at least one broadband loan (treated) to a carefully selected group of similar counties that did not receive a loan. The selection rule, as we described earlier, is based on county characteristics prior to the broadband loan programs. The estimates from the propensity score matching procedure are presented in Panel C of Table 4. The impacts on farm revenue and expenditure are a little smaller than the baseline estimates in Panel A of Table 3, but the differences are not statistically significant. The implied increase in profits for farms with increased access to broadband internet

is about 2 percent and 3 percent for the current and the pilot loan programs, respectively, which is consistent with the baseline estimates in Table 3. Another difference between the PSM results and the baseline estimates is that the impact of broadband penetration on crop sales is smaller than what the baseline results indicated. In the case of the current loan program, the PSM estimator suggests that the impacts of the loans on crop sales is positive and is of roughly the same size as the impact on animal product sales; in contrast, the baseline estimates reported in Table 3 indicate that the positive impact of the current broadband loans is more than three times larger for crop sales than for animal product sales.

5.4   Alternative Measure for Increased Broadband Access

As previously discussed, counties could receive more than one broadband loan if multiple communities within the county received a loan. In our fourth robustness check, we incorporate this information into our specification by using the number of broadband loans received in each county (current, N_BBLP_{ct}, and pilot, $N\_Pilot\_BBLP_{ct}$) instead of the broadband loan receipt indicators (current, $BBLP_{ct}$, and pilot, $Pilot\_BBLP_{ct}$) that we employed earlier. These results are presented in Panels A and B of Table 5. The estimates are consistent with our previous findings and indicate that counties that received a larger number of broadband loans, and in which farmers have better and faster internet access, experienced an increase in commodity sales, especially crop sales, and a positive but not statistically significant increase in total expenditure.

The results also imply that the average farm profit in counties which received a larger number of broadband loans increased more than the average farm profit in counties with a smaller number of loans. Given that the average number of loans in counties that received at least one loan is 2.612, the estimates imply that the average farm sales in a county that received

at least one broadband loan increased by about 2.4 percent (2.4=0.9*2.612). On the other hand, average farm expenditures in a county that received at least one loan grew by about 0.5 percent, implying that the average profit in a county that received a broadband loan rose about 2 percent.

Overall, all of the robustness checks indicate that increased access to a broadband internet connection leads to higher farm sales, expenditures, and profits. Farm sales are estimated to have risen between 4 and 6 percent due to receipt of a loan from the current broadband loan program. On the other hand, the impact of a current broadband loan on farm expenditures is estimated to be between 2.5 and 4 percent, implying that increased access to high-speed internet has led to an increase in farm profits of about 2 to 3 percent. Similarly, sales increased between 3 and 7 percent, on average, following the receipt of a broadband loan from the pilot program, and expenditure increased between 2 and 6 percent, leading to an increase in profits between 1 and 3 percent. Most of the evidence suggests that the increase in crop sales, estimated to be between 5 and 10 percent, is higher than the estimated increase in animal product sales, estimated to be between 2.5 and 6 percent. Additionally, the results show that other farm income rose between 2.5 and 6 percent following receipt of a broadband loan from the current program. Finally, there is no evidence that total farm acres are affected by broadband loans from the current program, but they do show a slight increase of about 2 to 3 percent as a result of a loan from the pilot program.

5.5   *Difference in Impact of the USDA Broadband Loans by the Farm's Proximity to an Urban Continuum*

Previous research has found a positive relationship between the economic impacts of broadband and proximity to densely populated urban areas (see, for example, Gillett et al. 2006; Shideler et al. 2007; Mack and Grubesic 2009; Kandilov and Renkow 2010). This may be a result of

economies of density in broadband supply and/or agglomeration economies affecting broadband demand. To check whether a similar spatial gradient of the impacts on farm-related outcomes exists in the case of the broadband loan program, we re-estimated our baseline specification (2) separately for three different sub-samples of counties – metro counties, rural counties adjacent to metro counties, and rural counties that are not adjacent to metro counties. We use the USDA's Rural-Urban Continuum codes to delineate these groupings.[15]

These results are displayed in Panels A, B, and C of Table 6. The impact of increased access to broadband internet on farm sales and costs is quite similar across the three different types of counties. Except in the case of the pilot broadband loan for Metro counties, the positive impact of both the current and the pilot loan on farm profits varies between 2 and 3 percent, which is consistent with the baseline results in Table 3. The estimated positive effect of high-speed internet availability through the pilot broadband loans in Metro counties is about 6.5 percent (0.065 = 0.073 - 0.008), which is nearly twice as high as the baseline estimate of 3.4 percent (3.4 = 6.6 - 3.2) in Table 3. The impacts of the current and the pilot broadband loans on other farm-related outcomes (other farm income, farm acreage, as well as crop and animal (product) sales) are quite similar across the rural-urban continuum. This evidence suggests that proximity to an urban center does not make a difference when it comes to the positive economic impacts of high-speed internet on farm sales and profits -- i.e., that the positive economic impacts of the current and the pilot broadband loan program on U.S. farms found in our baseline results persists across the rural-urban continuum. This contrasts with the findings of Kandilov and Renkow (2010) that the positive impacts of broadband loans on (overall) economic activity are confined to communities located in close proximity to metropolitan centers.

6.   Conclusion

In this paper we provide an empirical estimate of the impact of the USDA broadband internet loan programs on U.S. agriculture. High-speed internet can reduce the costs of interaction between (remote) market participants and provide real-time access to information relevant for both production and marketing decisions. It can speed access to current weather and pricing information for inputs and outputs, and it can facilitate technology adoption as well as management practices. All of these improvements can reduce farmers' production costs and raise revenue, ultimately leading to higher profits.

In our empirical analysis, we use nationwide county-level data from the Ag. Census in 1997, 2002, and 2007, coupled with data on broadband loan receipt from the USDA. We estimate separately the effects of each of the two low-cost broadband loan programs – the pilot and the current loan program. The pilot broadband loan program is a nationwide program that was introduced in 2000; while the current broadband loan program started after the 2002 Farm Bill took effect. The goal of the two programs was to supply low-cost broadband loans to small U.S. communities.

First, we show that USDA broadband loan receipt is positively associated with high-speed internet use among U.S. farmers. Then, we employ a variety of program evaluation econometric techniques, including a panel DID fixed effects model as well as a DID propensity score matching method, to show that farm sales and expenses, as well as other farm income rose in counties that received a broadband loan. The estimates indicate that increased access to high-speed internet leads to about 6 percent growth in farm revenue and about 3 percent growth in production expenditure, which results in about 3 percent growth in farm profits. Given the documented increase in farm expenditure following the receipt of the broadband loans, the

estimates would imply that farm output in counties receiving the broadband loans must have increased as a result of increased access to high-speed internet.

We further show evidence that the increase in total commodity sales in counties that received either one of the broadband loans is primarily driven by an increase in crop sales, and not sales of livestock and animal products, which appear to be less affected by access to broadband internet. The current USDA broadband loan program does not seem to affect total farm acreage, but the earlier pilot loan program appears to have increased farm acreage by about 3.6 percent. Also, receipt of either type of the broadband loans is associated with an increase in the number of farms with positive total sales and positive crop sales in the recipient county.

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Table 1. Summary Statistics

Panel A: Summary Statistics for Outcome Variables and Covariates

| | Pre-Broadband Loans, 1997 | | | | Post-Broadband Loans, 2007 | | | |
| | Counties with Either Loan | | Counties with No Loan | | Counties with Either Loan | | Counties with No Loan | |
Variable	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Total Commodity Sales	80,741	91,935	85,415	163,599	97,495	119,117	98,322	189,951
Total Production Expenditure	63,103	69,986	66,785	124,339	79,340	96,588	78,520	148,884
Other Farm Income	1,595	1,299	1,502	2,059	4,037	4,008	3,388	4,509
Total Farm Acres	303	261	310	408	294	247	299	393
Crop Sales	41,501	57,270	42,877	113,153	48,954	67,994	47,403	116,370
Livestock and Animal Products Sales	39,526	61,611	43,279	84,195	49,344	85,131	51,724	109,449
Population	59,866	188,385	91,176	295,044	69,490	242,439	100,506	320,284
Income per Capita	26,669	5,369	26,176	6,033	29,525	6,170	30,350	8,227
No Obs.	373		2,699		373		2,699	

Note: All figures are in 1,000's 2007 U.S. dollars, except those for acres (in 1,000 acres), population, and income per capita.

Panel B: Summary Statistics for Broadband Loan Treatment Variables

| | Pre-Broadband Loans, 1997 | | Post-Pilot Broadband Loan, 2002 | | Post-Broadband Loans, 2007 | |
Variable	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Broadband Loan Receipt	0	0	0	0	0.095 (289 counties)	0.293
Number of Broadband Loans (for counties with at least one loan)	0	0	0	0	2.612 (755 loans)	2.509
Pilot Broadband Loan Receipt	0	0	0.032 (98 counties)	0.177	0.032 (98 counties)	0.177
Number of Pilot Broadband Loans (for counties with at least one pilot loan)	0	0	3.847 (377 loans)	3.124	3.847 (377 loans)	3.124
No Obs.	3,072		3,072		3,072	

Table 2. The Impact of the Broadband Loan Program (*BBLP$_{ct}$*) and the Pilot Broadband Loan Program (*Pilot_ BBLP$_{ct}$*) on High-speed Internet Use among U.S. Farmers, 2007. Poisson County Fixed Effects Models.

Panel A. Using an Indicator for a Broadband Loan Receipt in a County as the Treatment Variable.

Variable	Number of Farms with Internet			Number of Farms with High-speed Internet		
BBLP$_{ct}$	0.165***	0.236***	0.140***	0.111***	0.163***	0.010**
	(0.040)	(0.063)	(0.037)	(0.043)	(0.056)	(0.039)
Pilot_ BBLP$_{ct}$	0.215***	0.224***	0.132***	0.284***	0.357***	0.165***
	(0.043)	(0.064)	(0.043)	(0.043)	(0.057)	(0.045)
log(Population)	-	-	0.295***	-	-	0.298***
			(0.012)			(0.013)
log(Income per capita)	-	-	- 0.565***	-	-	- 0.382***
			(0.078)			(0.082)
Pseudo *R^2*	0.25	0.35	0.46	0.25	0.38	0.46
N	3,174	1,348	3,148	3,170	1,346	3,144

Panel B. Using the Number of Loans in a County as the Treatment Variable.

Variable	Number of Farms with Internet			Number of Farms with High-speed Internet		
N_BBLP$_{ct}$	0.042***	0.069***	0.035***	0.039***	0.052**	0.032***
	(0.008)	(0.025)	(0.008)	(0.009)	(0.021)	(0.009)
N_Pilot_ BBLP$_{ct}$	0.032***	0.047***	0.007	0.047***	0.081***	0.012
	(0.007)	(0.011)	(0.010)	(0.007)	(0.009)	(0.011)
log(Population)	-	-	0.295***	-	-	0.298***
			(0.013)			(0.013)
log(Income per capita)	-	-	- 0.556***	-	-	- 0.372***
			(0.078)			(0.081)
Pseudo *R^2*	0.25	0.34	0.45	0.25	0.38	0.45
N	3,174	1,348	3,148	3,170	1,346	3,144

Note: Robust standard errors clustered by county are reported in parentheses. *** indicates significance at 1 percent, ** indicates significance at 5 percent, * indicates significance at 10 percent.

Table 3. The Impact of the Broadband Loan Program (*BBLP*$_{ct}$) and the Pilot Broadband Loan Program (*Pilot_ BBLP*$_{ct}$) on U.S. Farms, 1997, 2002, 2007.

Panel A. The Impact of the Broadband Loan Program (*BBLP*$_{ct}$) and the Pilot Broadband Loan Program (*Pilot_ BBLP*$_{ct}$) on Farm Sales, Expenditure, Other Farm Income, Acres, as well as Crop and Livestock Sales. OLS with County Fixed Effects Models.

Variable	*log*(Total Commodity Sales)	*log*(Total Expenditure)	*log*(Other Farm Income)	*log*(Total Acres)	*log*(Sales of Crops)	*log*(Sales of Livestock and Animal Products)
BBLP$_{ct}$	0.061***	0.034**	0.050	0.002	0.100***	0.026
	(0.019)	(0.016)	(0.032)	(0.011)	(0.026)	(0.025)
Pilot_ BBLP$_{ct}$	0.066***	0.032	0.048	0.036***	0.093***	0.081**
	(0.022)	(0.023)	(0.052)	(0.007)	(0.026)	(0.034)
Adj. R^2	0.51	0.51	0.48	0.58	0.49	0.48
N	9,140	9,205	9,046	9,153	8,918	8,919

Panel B. The Impact of the Broadband Loan Program (*BBLP*$_{ct}$) and the Pilot Broadband Loan Program (*Pilot_ BBLP*$_{ct}$) on the Number of Farms with Sales, Other Farm Income, as well as Sales of Crops and Livestock. Poisson with County Fixed Effects Models.

Variable	Number of Farms with Sales	Number of Farms with Other Farm Income	Number of Farms with Crop Sales	Number of Farms with Livestock Sales
BBLP$_{ct}$	0.011***	0.035***	0.027***	- 0.013***
	(0.003)	(0.005)	(0.004)	(0.004)
Pilot_ BBLP$_{ct}$	0.023***	0.007	0.055***	- 0.005***
	(0.004)	(0.007)	(0.005)	(0.005)
Pseudo R^2	0.63	0.58	0.61	0.60
N	9,226	9,171	9,208	9,203

Note: All specifications include county and year fixed effects (not reported here). Robust standard errors clustered by county are reported in parentheses.
*** indicates significance at 1 percent, ** indicates significance at 5 percent, * indicates significance at 10 percent.

Table 4. The Impact of the Broadband Loan Program (*BBLP$_{ct}$*) and the Pilot Broadband Loan Program (*Pilot_ BBLP$_{ct}$*) on U.S. Farms, 1997, 2002, 2007. Robustness Checks. OLS with County Fixed Effects Models.

Panel A. The Impact of the Broadband Loan Program (*BBLP$_{ct}$*) and the Pilot Broadband Loan Program (*Pilot_ BBLP$_{ct}$*) on Farm Sales, Expenditure, Other Farm Income, Acres, as well as Crop and Livestock Sales; Including Time-varying Right-hand Side Controls.

Variable	*log*(Total Commodity Sales)	*log*(Total Expenditure)	*log*(Other Farm Income)	*log*(Total Acres)	*log*(Sales of Crops)	*log*(Sales of Livestock and Animal Products)
BBLP$_{ct}$	0.063***	0.035**	0.058*	0.003	0.105***	0.024
	(0.019)	(0.016)	(0.033)	(0.011)	(0.026)	(0.026)
Pilot_ BBLP$_{ct}$	0.071***	0.035	0.063	0.035***	0.108***	0.078**
	(0.022)	(0.023)	(0.051)	(0.007)	(0.026)	(0.034)
log(Population)	- 0.390***	- 0.207***	0.267***	-0.269***	- 0.241***	- 0.438***
	(0.066)	(0.054)	(0.100)	(0.041)	(0.070)	(0.090)
log(Income per capita)	0.358***	0.209***	0.490***	0.032	0.903***	- 0.037
	(0.048)	(0.038)	(0.107)	(0.028)	(0.071)	(0.063)
Adj. R^2	0.52	0.53	0.51	0.60	0.53	0.49
N	9,063	9,127	8,971	9,075	8,845	8,846

Panel B: The Impact of the Broadband Loan Program (*BBLP$_{ct}$*) and the Pilot Broadband Loan Program (*Pilot_ BBLP$_{ct}$*) on Farm Sales, Expenditure, Other Farm Income, Acres, as well as Crop and Livestock Sales; Counties with population of 20,000 or less in 2000.

Variable	*log*(Total Commodity Sales)	*log*(Total Expenditure)	*log*(Other Farm Income)	*log*(Total Acres)	*log*(Sales of Crops)	*log*(Sales of Livestock and Animal Products)
BBLP$_{ct}$	0.061**	0.039*	0.057	- 0.030	0.090**	0.059*
	(0.026)	(0.022)	(0.054)	(0.021)	(0.044)	(0.034)
Pilot_ BBLP$_{ct}$	0.027	0.017	0.021	0.027**	0.098***	0.028
	(0.036)	(0.034)	(0.075)	(0.011)	(0.032)	(0.048)
Adj. R^2	0.62	0.63	0.56	0.68	0.56	0.61
N	3,883	3,907	3,835	3,884	3,752	3,767

Note: All specifications include county and year fixed effects (not reported here). Robust standard errors clustered by county are reported in parentheses.
*** indicates significance at 1 percent, ** indicates significance at 5 percent, * indicates significance at 10 percent.

Table 4 (Cont'd.). The Impact of the Broadband Loan Program (*BBLP*$_{ct}$) and the Pilot Broadband Loan Program (*Pilot_ BBLP*$_{ct}$) on U.S. Farms, 1997, 2002, 2007. Robustness Checks. OLS with County Fixed Effects Models.

Panel C: The Impact of the Broadband Loan Program (*BBLP*$_{ct}$) and the Pilot Broadband Loan Program (*Pilot_ BBLP*$_{ct}$) on Farm Sales, Expenditure, Other Farm Income, Acres, as well as Crop and Livestock Sales; Propensity Score Matching (Radius) method.

Variable	*log*(Total Commodity Sales)	*log*(Total Expenditure)	*log*(Other Farm Income)	*log*(Total Acres)	*log*(Sales of Crops)	*log*(Sales of Livestock and Animal Products)
BBLP$_{ct}$	0.043**	0.024	0.097**	- 0.012	0.045	0.041
	(0.022)	(0.018)	(0.041)	(0.009)	(0.033)	(0.029)
Pilot_ BBLP$_{ct}$	0.052***	0.020	0.044	0.021*	- 0.009	0.060*
	(0.020)	(0.023)	(0.050)	(0.011)	(0.025)	(0.031)

Note: All specifications in Panel C include county and year fixed effects (not reported here). Robust standard errors clustered by county are reported in parentheses. See the text and Appendix II for the details on the propensity score matching procedure. There are 71 counties which obtained a pilot broadband loan and 203 counties which obtained a regular broadband loan used in the matching procedure.
*** indicates significance at 1 percent, ** indicates significance at 5 percent, * indicates significance at 10 percent.

Table 5. The Impact of the Broadband Loan Program (*BBLP$_{ct}$*) and the Pilot Broadband Loan Program (*Pilot_ BBLP$_{ct}$*) on U.S. Farms, 1997, 2002, 2007. Using the Number of Loans in a County as the Treatment Variable.

Panel A.   The Impact of the Broadband Loan Program (*BBLP$_{ct}$*) and the Pilot Broadband Loan Program (*Pilot_ BBLP$_{ct}$*) on Farm Sales, Expenditure, Other Farm Income, Acres, as well as Crop and Livestock Sales. OLS with County Fixed Effects Models.

Variable	*log*(Total Commodity Sales)	*log*(Total Expenditure)	*log*(Other Farm Income)	*log*(Total Acres)	*log*(Sales of Crops)	*log*(Sales of Livestock and Animal Products)
N_BBLP$_{ct}$	0.009**	0.002	0.007	- 0.000	0.016***	0.007
	(0.004)	(0.003)	(0.008)	(0.003)	(0.006)	(0.005)
N_Pilot_ BBLP$_{ct}$	0.010**	0.007*	0.008	0.005***	0.016***	0.008
	(0.005)	(0.004)	(0.010)	(0.001)	(0.004)	(0.006)
Adj. R^2	0.51	0.51	0.48	0.58	0.49	0.48
N	9,140	9,205	9,046	9,153	8,918	8,919

Panel B. The Impact of the Broadband Loan Program (*BBLP$_{ct}$*) and the Pilot Broadband Loan Program (*Pilot_ BBLP$_{ct}$*) on the Number of Farms with Sales, Other Farm Income, as well as Sales of Crops and Livestock. Poisson with County Fixed Effects Models.

Variable	Number of Farms with Sales	Number of Farms with Other Farm Income	Number of Farms with Crop Sales	Number of Farms with Livestock Sales
N_BBLP$_{ct}$	0.003***	0.008***	0.005***	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
N_Pilot_ BBLP$_{ct}$	0.005***	0.002	0.008***	- 0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Pseudo R^2	0.63	0.58	0.61	0.60
N	9,226	9,171	9,208	9,203

Note: All specifications include county and year fixed effects (not reported here). Robust standard errors clustered by county are reported in parentheses.
*** indicates significance at 1 percent, ** indicates significance at 5 percent, * indicates significance at 10 percent.

Table 6.   The Impact of the Broadband Loan Program (*BBLP*$_{ct}$) and the Pilot Broadband Loan Program (*Pilot_ BBLP*$_{ct}$) on U.S. Farms, 1997, 2002, 2007. Estimates by the County Position in the Rural-Urban Hierarchy.

Panel A.   Metro Counties.

Variable	*log*(Total Commodity Sales)	*log*(Total Expenditure)	*log*(Other Farm Income)	*log*(Total Acres)	*log*(Sales of Crops)	*log*(Sales of Livestock and Animal Products)
BBLP$_{ct}$	0.049	0.031	0.025	0.027	0.092**	0.010
	(0.036)	(0.032)	(0.060)	(0.022)	(0.043)	(0.056)
Pilot_ BBLP$_{ct}$	0.073**	0.008	0.104	0.050***	0.054	0.104
	(0.029)	(0.041)	(0.085)	(0.013)	(0.062)	(0.074)
Adj. R^2	0.65	0.65	0.61	0.69	0.64	0.61
N	3,133	3,156	3,097	3,136	3,060	3,051

Panel B.   Rural Counties Adjacent to a Metro County.

Variable	*log*(Total Commodity Sales)	*log*(Total Expenditure)	*log*(Other Farm Income)	*log*(Total Acres)	*log*(Sales of Crops)	*log*(Sales of Livestock and Animal Products)
BBLP$_{ct}$	0.054*	0.034	0.015	0.009	0.086*	0.024
	(0.031)	(0.024)	(0.051)	(0.021)	(0.045)	(0.035)
Pilot_ BBLP$_{ct}$	0.056*	0.038	0.150	0.052***	0.157***	0.028
	(0.034)	(0.030)	(0.093)	(0.010)	(0.034)	(0.043)
Adj. R^2	0.61	0.61	0.55	0.63	0.58	0.64
N	3,120	3,145	3,098	3,126	3,050	3,054

Panel C.   Rural Counties Not Adjacent to a Metro County.

Variable	*log*(Total Commodity Sales)	*log*(Total Expenditure)	*log*(Other Farm Income)	*log*(Total Acres)	*log*(Sales of Crops)	*log*(Sales of Livestock and Animal Products)
BBLP$_{ct}$	0.062*	0.025	0.134**	- 0.035***	0.100**	0.024
	(0.033)	(0.026)	(0.055)	(0.010)	(0.042)	(0.043)
Pilot_ BBLP$_{ct}$	0.057	0.036	- 0.067	0.002	0.069*	0.093*
	(0.045)	(0.042)	(0.085)	(0.012)	(0.035)	(0.056)
Adj. R^2	0.68	0.69	0.62	0.74	0.64	0.66
N	2,885	2,901	2,850	2,888	2,808	2,814

Note: All specifications include county and year fixed effects (not reported here). Robust standard errors clustered by county are reported in parentheses.
*** indicates significance at 1 percent, ** indicates significance at 5 percent, * indicates significance at 10 percent.

Appendix
Propensity Score Matching Procedure

The matching version of the difference-in-differences (DID) model controls for selection on time-invariant unobservable factors by allowing for time-invariant differences in the outcome variable between counties that received a broadband loan (program participants) and those that did not received a loan (non-participants). This method is analogous to the standard DID regression but it does not impose a linear functional form restriction in estimating the conditional expectation of the outcome variable. Also, the DID propensity score matching model re-weights the observations according to the weighting functions used by matching estimator.

More formally, define Y_D^T as the outcome of interest for treatment status D, i.e. broadband loan receipt status, in period T. The treatment variable D takes a value of 1 if a county has received a broadband loan and 0 otherwise. T takes on two values: $T = 0$ during the pre-treatment period, i.e. in the years before a broadband loan program was implemented, and $T = 1$ for the post-treatment period, i.e. during the years after the loan program was adopted.

The basic assumption of the DID matching method, the Conditional Mean Independence (CMI) assumption, asserts that the evolution of the unobserved part of the economic performance of the agricultural sector in county that received a broadband loan had it not received such loan is independent of the loan conditional on a set of covariates X_0 measured in the period prior to the loan receipt, i.e. the covariates used to estimate the propensity score are pre-treatment values:

$$E(Y_0^1 - Y_0^0 | P(X_0), D = 1) = E(Y_0^1 - Y_0^0 | P(X_0), D = 0).$$

Control observations (counties that never received a broadband loan) are matched to the treated ones (that received a loan) based on their propensity scores (probability of being treated).

The average treatment effect on the treated is the difference in differences in the pre- and post-treatment outcomes between the treated and their matched control observations:

$$\Delta^{ATT} = E(Y_1^1 - Y_1^0 | P(X_0), D = 1) - E\left(\widetilde{Y_0^1 - Y_0^0} | P(X_0), D = 1\right)$$
$$= E(Y_1^1 - Y_1^0 | P(X_0), D = 1) - E\{E[(Y_0^1 - Y_0^0) | P(X_0), D = 0] | D = 1\}$$

.

As we discussed above, the CMI assumption requires that we choose a set of conditioning variables (covariates) that affect both the county probability of receiving a broadband loan and its agricultural performance (productivity and profitability). The broadband loan programs are available to small and less developed rural communities that previously do not have broadband access. More populous, urban counties are less likely to contain a small, rural community that would qualify for and receive a broadband loan. Hence, to control for the county's likelihood of receiving a loan we use as conditional variables county population, total land area, income per capita, and a dummy indicating the county's place in the Rural-Urban continuum. We also control for potential unobserved agricultural and market conditions related to the geographic region where the county is located by restricting matching to counties within the same geographic region.[xvi] All, of these variables are likely to affect the agricultural performance in a county, as well.

Further, we explicitly control for agricultural performance in the pre-treatment period (before the broadband loan programs were adopted) by including the outcome variables from the beginning of the sample (in 1997) as controls: total commodity sales, total farm acres, number of farms with positive commodity sales, total production expenses, and other farm-related income. We estimate a logistic model for the probability that a county received a broadband loan (either a

pilot loan or a current loan). We then construct the propensity score for each county using the estimated coefficients from the logistic regression.

We construct the counterfactual for each county that received a broadband loan using the counties that did not receive a loan but have similar estimated propensity scores. We use radius matching and impose a bandwidth of 0.001. Specifically, we construct the counterfactual for a county with a broadband loan using all the counties that do not have a loan and have an estimated propensity score that is within 0.0005 of the propensity score of the treated county. Also, as we already discussed, in order to control any potential bias due to the difference in agricultural production patterns across agricultural regions, we restrict the matching to counties within the same region.

More formally, the constructed counterfactual is

$$E\left(Y_0^{\widehat{1-Y_0^0}}\middle| P(X), D = 1\right) = \left(\sum_{j\in\{D_j=0\}} w(i,j)(Y_0^1 - Y_0^0)|P(X), D_j = 0\right).$$

where j indexes counties that did not receive a broadband loan and i indexes counties that received a loan (with county j being matched to county i based on their estimated propensity scores). The matrix, $w(i,j)$, contains the weights assigned to the jth control county that is matched to the ith treated county. The matching estimator constructs an estimate of the expected unobserved counterfactual for each county that received a broadband loan by taking a weighted average of the difference in pre-treatment and post-treatment outcomes for each matched county without a broadband loan.

To compute the average impact of broadband loan programs on the agricultural outcomes (sales, expenditures, other farm income, acres, etc.) for treated counties, i.e. for counties that received a broadband loan, we use the standard definition of the Average Treatment Effect on the Treated, or the Δ^{ATT} :

$$\Delta^{ATT} = \frac{1}{N} \sum_{i=1}^{N} \left\{ \left[\left(Y_{i1}^1 - Y_{i1}^0 \right) - \left(\widehat{Y_0^1 - Y_0^0} \right) \right] \mid D = 1 \right\}$$

.

In the equation above, N is the number of the counties with a loan, $(Y_{i1}^1 - Y_{i1}^0)$ is the difference in post-treatment and pre-treatment outcomes in a county i with a broadband loan, and $\left(\left(\widehat{Y_0^1 - Y_0^0} \right) \mid D_i = 1 \right)$ is the constructed counterfactual for each county i. The average impact of the broadband loan program is therefore the mean difference in the pre-treatment and post-treatment differences in the outcomes between the counties with a broadband loan and the constructed counterfactual outcomes from the matched counties that did not receive such a loan.

After matching, we check if the treated and control counties (those with a broadband loan and those without one) are balanced on covariates, i.e. if the two groups have similar characteristics in the pre-broadband loan period, in 1997. If unbalanced, the estimated Δ^{ATT} may not reflect solely the impact of the broadband loan programs. Instead, it may be a combination of the impacts of the loan programs and the unbalanced covariates. We rely on t-tests to check if the means for each covariate are statistically the same between the two groups of counties – the treated (those with a loan) and the controls (those without a loan). The balancing criteria are satisfied for all of our covariates, including the dummy variables for agricultural regions as well as the dummy variables for urban/rural status. This indicates that the two groups of counties –

those with a broadband loan and the matched group of counties without a loan – are indeed observationally equivalent, and it also implies that our estimated Δ^{ATT} reflects solely the impact of the broadband loan programs.

[1] Examples of other federally subsidized technological improvements that lower informational barriers and market transaction costs for the rural population and entrepreneurs include the establishment of rural delivery routes for the U.S. Postal Service, as well as the construction of rural roads.

[2] USDA provides data on the actual communities that received broadband loans. However, comprehensive agricultural performance data is only available at the county level.

[3] If output rises as a result of higher demand brought about by access to (high-speed) internet, the amount of inputs will increase, as well.

[4] Also, Forman et al.'s (2009) recent working paper reports that the rise in IT has had little impact on wage growth in rural areas.

[5] The USDA's Rural Development Broadband Program website can be found at the following address: *http://www.usda.gov/rus/telecom/broadband.htm*.

[6] For the pilot broadband loan program, we assign 2002 as the start year for all counties that received such a loan. If a county received a loan from the current broadband loan program before June 1 of a given year, we consider that year as the start year; otherwise, we take the following year as the start year.

[7] The PSM method developed by Rosenbaum and Rubin (1983) accommodates for "selection on observables". Any uncontrolled unobservables that affect counties which received the USDA broadband loan differently from counties that did not would introduce bias in the estimated effects.

[8] Note that a natural candidate control (comparison) group is the group of counties in which potential broadband providers applied for broadband loans but were denied. Unfortunately, the USDA has retained no information on broadband loan applications that were denied.

[9] This DID version of the PSM matching method is analogous to the standard DID fixed effects regression estimator in (2), but it does not impose a functional form in estimating the conditional expectation of the outcome variable, and it re-weights the observations according to the weighting function used by the matching estimator.

[10] More precisely, to calculate the percentage change in total commodity sales resulting from a broadband loan receipt, i.e. increasing $BBLP_{ct}$ from 0 to 1, one needs to raise e ($= 2.718$) to the power of the estimated coefficient β (0.061 here) and then subtract one (the resulting impact is 0.063 here). This procedure is necessary because of the log-linear specification and the fact that $BBLP_{ct}$ is an indicator variable that only changes discontinuously (see Halvorsen and Palmquist, 1980). However, for small β's, the differences between β and $\exp(\beta)$ -1 is trivial.

[11] It is possible that access to broadband internet affects farm acreage with a lag, i.e. the impact of broadband on acreage takes time to emerge. Hence, the estimates may reflect the fact that the Pilot broadband loan program started a number of years earlier than the current broadband loan program.

[12] Given the sample average of 710 farms with positive commodity sales per county, a 1.1 percent increase in the number of farms with positive sales in counties that have received at least one current broadband loan is equivalent to an increase of about 7 farms with positive sales.

[13] Another robustness check that we have done extends the baseline specification (2) by including state-specific time trends which control for state trends potentially correlated with broadband loan receipt – a complication that may possibly confound the estimation. The results

from this expanded specification, which are not reported here to conserve space, are fairly similar to those from our baseline specification presented in Table 2. One more notable difference is that the impact on farm expenditure is estimated to be higher than that in Table 2, which in the case of the current broadband loan implies that the overall impact on farm profits is positive at 1.2 percent.

[14] Also, in a number of instances, broadband loans were given to providers who supplied broadband access to "small" communities, but the same project also included supplying "large" (greater than 20,000 people) communities. In this case, while the loans were specifically granted only for the "small" communities, they were considered to have benefited both the "small" and the "large" communities.

[15] Interested readers can find more details on the USDA Rural-Urban classification at the following address *http://www.ers.usda.gov/briefing/rurality/ruralurbcon*. Note that in metro counties, a large fraction of the workforce commutes to nearby, highly urbanized metro area.

[xvi] We use 12 regions: Appalachian (NC, VA, KY, TN, WV), Corn Belt and Northern Plains (IL, IN, OH, IA, MO, KS, NE, ND, SD), California (CA), Delta and Southeast (AR, LA, MS, AL, GA, SC), Florida (FL), Great Lakes (MI, MN, WI), Mountain I (ID, MT, WY, CO, NV, UT), Mountain II (AZ, NM), Northeast I (CT, ME, MA, NH, NY, RI, VT), Northeast II (DE, MD, NJ, PA), Pacific (OR, WA), Southern Plains (OK, TX).