Assessing the Value of Broadband Connectivity for Big Data and Telematics: Technical Efficiency

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association’s 2015 Annual Meeting, Atlanta, Georgia, January 31-February 3, 2015

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ABSTRACT

Researchers and practitioners of precision agricultural technology have worked to overcome adoption, cost, and environmental obstacles since its introduction. The next gap in the adoption continuum of profitable precision agricultural technologies is data and data use, the so-called Big Data. Broadband connectivity could be the next hurdle affecting the precision agricultural technology chain and the employment of ‘big data’ and telematics services. Without adequate connectivity the transferring of ‘big data’ from machine-to-machine or to the cloud, inefficiencies are created. These inefficiencies come in the forms of machine downtime, increased human error, and lack of real-time information. We have addressed this issue in a conceptual framework by proposing a non-parametric data envelopment analysis. Simulation and Data Envelopment Analysis (DEA) are utilized to evaluate differing levels of data utilization made possible by broadband internet connectivity. The DEA methodology is useful to estimate the foregone societal value and farm-level profitability due to lack of broadband connectivity. In addition to constraining the profitability of agricultural firms; lack of broadband connectivity limits the adoption of precision agricultural technologies that make use of or relies upon near real time connectivity. The expected results are that producers that have adequate connectivity to employ ‘big data’ and telematics will be more efficient than producers without. Thus, the importance of adequate connectivity can be evaluated.

Keywords: broadband, big data, telematics, data transfer, wireless

JEL codes: Q10 D85
INTRODUCTION

The introduction of precision agricultural technologies in the early 1990’s was made possible through the advent of global positioning system (GPS). However, unlike GPS which has worldwide satellite coverage allowing field-level precision agricultural activities to occur, collecting spatial and machinery data into a repository efficiently is not currently feasible in real-time due to lack of broadband and wireless connectivity in many rural areas even in developed counties. Cellular connectivity has potential but limitations as well. Lack of broadband access in these rural areas is not a new problem but it has become a hurdle to increasing the efficiency of American agriculture.

In order to feed predicted population levels, American agriculture will have to increase the efficiency with which we produce food or increase the acreage allocated to food production. Increasing acreage may not be feasible, given the inelastic supply of farmland and demand for acreage to produce other crops. However, there is the potential to continue to increase the efficiency of American farms. Schimmelpfennig and Ebel (2011) show that producers are making gains in yields and in some cases may reduce costs if they choose to adopt precision agriculture technologies, such as yield monitors.

Currently, a critical mass of cash grain farmers in the US employs at least one form of precision agricultural technology and the majority employs multiple precision agricultural technologies (Schimmelpfennig and Ebel, 2011). The next big leap in efficiency gain for precision agricultural technologies could be the ability for the various forms to be able to communicate seamlessly with one another wirelessly – and in real-time. The more formal term for this would be telematics. Through telematics, farmers have the potential to remotely track equipment, send information to machines, and receive information from machines in real-time. Fulton and Brooke (2012) describe telematics as a technology capable of connecting wirelessly through either a computer or cellular phone and capture near real-time data on a wide variety of equipment operations.

Historically, farmers utilized the internet for discussion forums, social media, staying current with commodity prices, assessing likelihood of weather events via forecasts, and shopping for parts. Recent advancements in wireless capabilities have allowed farmers to wirelessly evaluate irrigation systems, weather stations, and field equipment and employees. Farmers who are making the most of their broadband connectivity are transferring data between their machinery and cloud-based storage, pushing prescriptions to applicators, and monitoring real-time alert systems for immediate pest threats.
Farmers, the agricultural industry, and the public sector recognize the value in data connectivity even without the notion of traditional voice, text, and other human communication purposes. In several agricultural production areas around the world, high accuracy GPS-enabled guidance systems were desired but the investment costs for base-station real time kinematic (RTK) GPS was prohibitive in many scenarios. An alternative was to extend the range that existing base stations could be used by incorporating a continuously operating reference station (CORS) or virtual reference station (VRS) concepts that pass packets of data via cellular connectivity. Without adequate broadband connectivity, however, some aspects of telematics will not be feasible. Although it is possible to physically move data from field machinery to a storage device, it can be difficult and time consuming to transfer that data manually. Additionally, human error is much more likely in these non-real time interactions. Thus, farmers are at best doing *ex post* analysis of the data and may not be doing any analysis at all especially in years where time is at a premium. A perfect example of this would be the start to the 2014 year. In an article written by Winsor (2014), Ben Gramig states that the planting window for corn and soybeans has shrunk by about a half a day per week. This puts additional pressure on farmers to increase critical tasks such as field work and spend less time conducting tasks perceived as noncritical such as uploading, downloading, and analyzing data. With increased access to broadband this issue could be resolved. Gaps in the precision agricultural continuum, such as broadband access, impede adoption because the true benefits and power of the technology is essentially impossible to capture without real time access to field data and subsequent analytics. In order for a precision agriculture system to be fully effective, a series of agricultural and non-agricultural technologies must exist in a collaborative manner. Additionally, lack of broadband connectivity negatively impacts the efficiency of the entire agricultural sector and has negative impacts on society as a whole.

Having access to broadband internet is going to be one of the key drivers for efficiency of American agriculture. In the near future, farm-level efficiency may be improved not from larger field machinery but instead from better use of underlying farm data. Therefore, increased understanding of this data to control costs will be pivotal (Kester, Griepentrog, Horner, & Tuncer, 2013). The objectives of this paper are twofold. First it is important to develop a conceptual framework that can be used to estimate the loss to farmers of not having internet access. Secondly, the variables needed for this estimation need to be identified. Once these two objectives have been achieved an actual model can be estimated to determine a specific dollar value and the level of inefficiency created at the farm level.
There are many examples of how telematics improve farm-level and agricultural business profitability. Being able to wirelessly transfer yield and the as-applied field experiment data from farm equipment to cloud based analysis services improves turnaround time and reduces chances of human error. Griffin (2010) reported that conducting on-farm experiments was the most common use of yield monitors in cotton and third most common in corn and soybean production. On large acreage commercial farms, especially those with multiple harvesters, the farm decision maker may not be operating the farm equipment. However, the decision maker may prefer to remotely monitor field operations to assess equipment location, equipment operators, and cumulative accomplishment (Griffin et al., 2010). Another example is big data analytics where participating farmers’ data is transferred to a cloud based system, analyzed in conjunction with data from other farmers, and group members receive recommendations based on their individual characteristics.

According to Holland et al. (2013), one of the largest changes between the 2011 and 2013 survey of agricultural service providers is the usage of telematics for field-to-home office communications. In 2011, only 7% of service providers offered the service but 15% did in 2013. There were slightly more dealerships offering telematics in the Midwestern US (17%) than in other states (12%), potentially due to the lack of broadband connectivity outside the Midwest (Whitacre et al., 2014). They also report that two-thirds of service providers stated telematics is perceived to be an emerging technology with 30% suggesting an uncertain future and 37% suggesting a promising future; indicating a lack of understanding of the future of the technology.

There has been considerable interest among different communities to improve rural broadband for agricultural purposes. In the US, Nebraska and Utah have state government committees to address the lack of broadband for agriculture. The US House of Representatives have emphasized needed support of rural broadband initiatives. In many rural areas, public school education and testing services have driven the public sector support for broadband connectivity

**Broadband Access and Economic Importance**

Access to broadband internet has long been an issue and topic of discussion in many political debates, especially in rural areas of the US. Recent studies have demonstrated broadband’s importance for the rural economy in terms of jobs and income (Whitacre et al, 2014a; 2014b). In Johnson et al. (2011) the widening gap between broadband access in rural and urban areas in Missouri has serious implications for the farm sector competitiveness.
This gap may in part be due to the fact that internet providers in the US are for-profit private companies and the profit margins in rural regions given the population base do not warrant the investment required (Fortunato, et al., 2013). Crawford (2013) offers an extreme solution in the form of a rate regulated government sanctioned monopoly. Hahn and Singer (2013) offer some criticism of this solution and determine such tight regulation is not necessary. However, agriculture has become highly information dependent for crop marketing and decision making.

Given farmers’ increased data needs and shortened turnaround times, they have to quickly make informed decisions. Data capabilities of new machinery, farmers’ demand for broadband access continues to grow and solutions must be found to fill in the coverage gaps. The current internet service coverage areas in the United States, excluding cellular coverage, are mapped in Figure 1. As one would imagine many of the less densely populated areas have little to no wired broadband coverage. Additionally, in some cases where wired internet is an option the speeds are so slow that it would not be feasible to implement telematics.

When mobile wireless connectivity is added to wired internet, much more of the crop producing areas of the US are included (Figure 2). The addition of mobile access increases significantly the broadband coverage area but there are still areas of the country that have no access. Many new technologies that are coming out in the area of telematics rely on cellular, satellite, or radio technologies as their mode of communication with the home computer (Fulton & Brooke, 2012). Each of these types of communication has advantages and disadvantages and allows the farmer to perform different actions, such as tracking, data transfer, etc., depending upon the manufacturer of the technology.

Having access to broadband internet is important but just because a farmer has access to broadband does not mean that it can be utilized. Just because a farmers’ house or county has wireless connectivity, this does not mean that the production acres in that county have wireless access. Speed of the broadband access is an additional important factor in telematics. If upload and download speeds are too slow then it is the same for the farmer as not having broadband access as all; connections less than 1.5 mbps is not likely sufficient even for the relatively small yield monitor data files. Given the gap between download and upload speeds, it is relatively easier to transfer prescription maps from the cloud to the machine than transferring data from machine to the cloud. Broadband speed requirements are an important area of further research to understand the minimum acceptable speed sufficient so that information can flow unimpeded.
Figure 1. End user access to internet across all platforms except for mobile wireless as of June 13, 2013 (National Telecommunications & Information Administration, 2013)

Figure 2. End user access to internet across all platforms including mobile wireless as of June 13, 2013 (National Telecommunications & Information Administration, 2013)

Figure 3 shows the broadband speeds for the United States by population density. The majority of the country falls into the 1.5 mbps to 25 mbps range. Imagery captured via unmanned aerial system on 92 acre field was 450 MB
(Buschemohle, personal communication). The average yield monitor data file is much smaller at 1.5 MB; but transfer cannot take place until after the whole field has been harvested. Depending upon how integrated the farmer chooses to make the operation and the amount of data they will be moving this may or may not be adequate for the farm needs.

**Figure 3.** Broadband availability across demographics and connection speeds as of June 30, 2013 (National Telecommunications & Information Administration, 2013). Includes mobile wireless.

**Precision Agriculture Adoption**

As farmers continue to integrate spatial technologies into their operations, the amount of data that will be transmitted will continue to increase. Broadband connectivity is expected to increase adoption rates such that geographic regions with improved broadband are likely to have the greatest demand for connectivity. Thus, farmers are looking for simple ways to transmit data from machine to machine or from computer or smart phone to machine, and vice versa. Having to move data manually can be very time consuming and increases the probably of the data being lost or mishandled. Additionally, precision agricultural technologies are becoming standard on some equipment and if producers are already paying for the technology to be on their machine they should at least
evaluate how they can best utilize it to improve farm profitability and efficiency. One example of spatial technology that is on almost every new combine is a yield monitor; just like GPS enabled guidance is almost ubiquitous on tractors.

Schimmelpfennig and Ebel (2011) find that yield monitor adoption has increased to between 35% and 45% of planted acres depending on the crop and year. The primary crops their study explored are corn, soybeans, and winter wheat using data from the Agricultural Resource Management Survey (ARMS). The data were collected for these crops as follows, corn in 2001 and 2005, soybeans in 2002 and 2006, and winter wheat in 2004 and 2009. They also describe a three-stage adoption process that farmers tend to follow, an example of the precision agriculture continuum. Stage one is the collection of yield information via a yield monitor. This technology is almost ubiquitous on all new combines that are currently being produced. Yield monitor data may be stage one because many farmers have concluded that several years of yield data are needed before farm management decisions should be made; and it has a relatively low cost per observation. Stage two is the increased usage of soil mapping technologies. This includes the usage of grid sampling, spectral reflectance sensors, and electrochemical sensors. These typically follow yield monitor adoption due to the increased per acre and per observation costs. Stage three is the adoption of variable-rate technologies. In this stage yield and soil information can be pooled to produce a holistic view of the production process. However, key hurdles that producers must overcome to achieve this level of profitable adoption and actually convert the data generated to production recommendation information are the time commitments required to assimilate the data (including possibly compiling with data from other farms), perform analyses, and the human capital required to interpret the results.

The presence of broadband internet is one way to reduce the download and transfer time required to achieve stage three of adoption. Broadband access allows communication between transmitters and receivers, data transfer, interaction with automated processes such as data transformation, and send to all parties such as analysts, farmer or others with access rights. The ability to achieve these efficiencies is needed to continue meeting the demand for food of a growing population.

CONCEPTUAL FRAMEWORK

In a perfect world internet access would be everywhere and information would flow seamlessly. This would allow machines that are collecting or needing information to complete various tasks in real-time. Seamless
data transmission would also allow for a central data repository so it can be analyzed and results translated into the next task for the machine. Under this scenario of an operational precision agriculture continuum, farmers could fully utilize precision agriculture and operate at their optimal efficiency. A hurdle that could keep farmers from working at their optimal efficiency when broadband is not accessible is simply the time needed to transfer and move data between the equipment and the home office. It should be noted that currently some farming operations in the United States are wirelessly transferring data for telematics; however, there is significant acreage in the United States where this is not possible. Broadband internet connection speed also plays a role and may make this an impossible task even in areas where broadband is available.

Data envelopment analysis (DEA) will be used to assess the value of big data that broadband connectivity allows via telematics for the farming operation. The DEA framework examines technical efficiency of a farm that fully implements telematics relative to their peer group. Technical efficiency given a production function can be evaluated through the usage of data envelopment analysis (DEA) (Hadad et al., 2013) (Figure 4). In this generic example Y is output and X is input, Y* would have a technical efficiency score of 1 and Y\textsuperscript{1} will be something less. Since farming operations tend to have multiple outputs and multiple inputs, DEA will be used to compare the efficiency of a farm that has fully integrated telematics versus their peers who do not have the technology. This allows for the assessment of the value of broadband internet access.

Two efficiency measures for input-oriented problem are technical efficiency (TE) and allocative efficiency (AE) (Farrell, 1957). Technical efficiency is the proportional reduction in inputs possible for a given level of output in order to obtain the efficient input use while allocative efficiency reflects the ability of the firm to use the inputs in optimal proportions. The two measures can be combined by taking the product to give a measure of total economic efficiency.
Ali and Seifod (1993) set forth an output oriented DEA framework used in our hypothetical example. Specifically, this model considers one output and \( m \) different inputs. A separate linear programming problem is solved for each decision making unit (DMU) in the model – which is the farm in this case. For the variable returns to scale (VRS) DEA model for the \( i \)-th DMU the formulation is as follows:

\[
\max_{\phi_l} \phi_l \\
\text{subject to:} \\
\sum_{j=1}^{n} \lambda_j y_j - \phi_l y_l - s = 0 \\
\sum_{j=1}^{n} \lambda_j x_{kj} + e_k = x_{kl} \quad k = 1, \ldots, m \text{ inputs;} \\
\sum_{j=1}^{n} \lambda_j = 1 \quad j = 1, \ldots, n \text{ DMU} \\
\lambda_j \geq 0 ; s \geq 0 ; e_k \geq 0
\]

where \( \phi_l \) is the proportional increase in output possible for each DMU; \( s \) is the output slack; \( e_k \) is the \( k \)-th input slack; and \( \lambda_j \) is the weight of the \( j \)-th DMU.

The objective of this model is to maximize the proportional increase in output while remaining within the production possibilities set as demonstrated above in Figure 4. When the value of \( \phi \) reaches 1 the \( i \)-th DMU lies on
the frontier and is efficient as \( Y^* \) is in Figure 4. For each DMU the projected frontier production level is denoted by \( \hat{y}_i \), given by

\[
\hat{y}_i = \sum_{j=1}^{n} \lambda_j y_j = \phi_i y_i,
\]

Technical efficiency is measured by \( TE_i \) and it is computed by:

\[
TE_i = \frac{y_i}{\hat{y}_i} = \frac{1}{\phi_i}
\]

From the technical efficiency analysis, it is possible to measure the efficiency gained from having telematics and big data or alternatively efficiency lost from lack of access to broadband. Overall, it is expected that operations that have access to broadband will be more efficient than those operations that do not have access.

A hypothetical example data set were generated via simulation to be analyzed with a DEA model constructed as stated above. The data set was created to meet criteria based on a priori experiences and expectations for operations implementing these technologies. One thousand farm decision making units (DMU) were created across 10 hypothetical regions. Farm sizes ranging from 500 to 7,500 acres were randomly assigned to the 1,000 farms using a gamma distribution. Agronomic intensity was randomly assigned to be between 1 and 10. A yield monitor was randomly added to farms operating more than the 10th percentile of 1,400 acres. Although broadband connectivity allows farmers to improve their operations from activities such as obtaining weather information, reduced costs from online purchasing, and negotiating better prices, broadband without telematics and big data does not impact productivity in this analysis. Broadband connectively were randomly added only to farms in regions 7, 8, 9, and 10. Telematics were randomly added to only those farms with a yield monitor and broadband connectivity. Big Data were randomly added to only those farms with telematics using a binomial distribution with 0.5 probability. Big Data Analytics were randomly added to only those farms with Big Data using a binomial distribution with 0.75 probability. The yield monitor, broadband, and telematics variables were created using a binomial distribution with probability of 0.67. The base net returns (NR) per acre were calculated as a $50 per acre base plus the log of farm size multiplied by 10. A regional premium was assessed from $10 too $100 on increments of $10 for regions 1 through 10. The log of agronomic intensity multiplied by 12 was added to reflect production
ability. The availability of broadband added a random value around $3 per acre, telematics added around $5 per acre, big data added around $10, and big data analytics added around $15 per acre. Net revenue was increased for farms making use of big analytics by adding a random value around $15/acre. The resulting dataset realization included 24 of the 100 farms utilizing big data analytics with a mean of 9.8% increase in net farm income. On average, farms that benefited from big data analytics had $11,485 higher NFI.

$$NR=50+\ln(\text{acres})\cdot 10+\ln(\text{region})\cdot 10+\ln(\text{agron})\cdot 12+\text{BB} \cdot 3+\text{telematics} \cdot 5+\text{BD} \cdot 10 +BDA \cdot 15$$

Given these hypothetical farm decision making units (DMU), results show the relative efficiency of farmers directly compared within a given group (Figure 5) (Bogetoft & Otto, 2011). In this case the given group is those farmers who have access to broadband and could potentially implement telematics. For this example, technical efficiency is expressed as variable returns to scale. Each DMU can be compared to one another with respect to the efficient frontier (Figure 5). Those DMU’s on the frontier are efficient and those below are considered inefficient assuming risk neutrality. These inefficiencies can come from a variety of sources, but one area is the usage of telematics. It is expected that the implementation of telematics increases efficiency, but by how much is the real question. Is the increase in efficiency outweighing the cost of expanding the broadband network? The aim of this framework was to begin answering this question. While the values assigned to the per-acre profitability of various technologies is somewhat arbitrary, the process itself is useful for assessing how the final value of a specific technology (such as broadband) can be quantified.
DISCUSSION

Farmers are continually looking for ways to reduce production costs and increase efficiency. The adoption of precision agriculture technologies has pushed the efficiency frontier but over time agriculture has become increasingly data intensive. Some farmers are pushing the envelope and trying to find ways to utilize the data to increase profits and having access to broadband is a key to seamless data movement. Producers that have to move data manually are less likely to use the data because of time requirements, especially in years when planting or harvesting windows are narrow. However, with the increased push to utilize telematics in agriculture there is an opportunity for producers to capitalize on the data; and the investment they have already made in equipment that is already installed on their farm machinery.

As broadband coverage continues to expand and broadband speed increases there will be efficiency gains at the farm level that will be passed on to society. A growing population mixed with a shrinking agricultural land base requires farmers to continually increase their efficiency to keep up. The concept of how to analyze all this data can be lumped into the notion of Big Data and it will require some advanced statistical analysis. Although big data is not new to agriculture, the recent volume of popular press on the topic leads the uninitiated to believe that the industry has entered a game changing environment; however what has changed is the connectivity of agricultural equipment providing raw data to cloud-based analytics services.
Analytics services themselves are in their infancy with the majority being rudimentary at best; the lack of analytics services is an artifact of not only theoretical development but also a lack of critical mass suitable for big data analytics (i.e. network externalities). (Katz and Shapiro, 1994) In other words, until there is sufficient amount of data for big data analytics to be operational, there will not be an incentive for farmers and agricultural businesses to provide data or connectivity to allow for analysis, and vice versa. Until farmers provide data and connectivity exists, there won’t be reasonable incentive for analysts to develop and offer analytics-as-a-service tools.

The fee that farmers are willing to pay for analytics will be a function of the benefit of the service. However, many levels of spatial analyses are likely to exist, and services below a minimum critical level of quality may provide inadequate information disguised as equivalent to appropriate spatial analyses. Currently, the market for spatial analysis services is suffering from a network externality (Katz and Shapiro, 1994), i.e. until either farmers or analysts demand or offers the service, respectively, then the other is not likely to make a move. To complicate things even further, benefits of analysis to farmers are a function of the treatment being tested and are expected to differ between farmers, crops, and years.

Future Work

Moving forward the lack of broadband will influence the usage of real-time systems in precision agriculture. This analysis gives a conceptual framework for where to start analyzing the issue but additional work needs to be done in looking at the market structure of telematics companies. This is needed to understand how these companies develop and to obtain more insight into their investment strategies. Beyond this will be the issue of how these companies might utilize the data in pricing of equipment or other inputs. Farmers will require some education on what happens to their data and given the independent nature of farmers; data privacy could be a significant hurdle. One last area of interest is, what are the impacts on society if broadband is not ubiquitous across the country? For example, how would food prices increase or decrease if broadband was available to all and farmers were able to fully integrate telematics? Or, how much of an environmental benefit would occur (from reduced runoff and lower resource use) if all farmers optimally allocated nutrients to their fields?
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