VALUE OF CONNECTIVITY IN RURAL AREAS: CASE OF PRECISION AGRICULTURE DATA

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ABSTRACT

Practitioners of precision agricultural technology have overcome many obstacles over last two decades. The next gap in the adoption continuum of profitable precision agricultural technologies is data and data use, the so-called Big Data. A pertinent barrier to successful use of precision agriculture data is the connectivity with respect to transferring data from machine to the cloud computing and vice versa, and can be thought of as access to broadband internet. We have addressed this issue in a conceptual framework by proposing two methods; a partial budget approach and a non-parametric data envelopment analysis. Both methods are useful to estimate the foregone value absent 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.

Keywords: Precision agriculture, Broadband, Big Data, telematics, data transfer

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 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. 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. In Schimmelpfennig and Ebel (2011) they show that producers are making gains in yields and in some cases reducing costs for producers who 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. The next big leap in efficiency gain for precision agricultural technologies could be the ability for various forms of this technology to be able to communicate seamlessly with one another wirelessly. 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 capute near real-time data on a wide variety of equipment operations.

Without adequate broadband connectivity speed, 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 in addition to any human error. 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 critcal tasks such as field work and spend less time conducting tasks perceived as noncritical such as uploading and downloading data. With increased access to broadband this issue could be resolved. Gaps in the precision agricultural continuum, such as broadband access, impede the adoption because the true benefits and power of the technology is essentially impossible to capture without real time access to field day and subsequent analytics. 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 not be from larger field machinery therefore increased understanding of 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 an actual dollar value and the level of inefficiency created at the farm level.

There are many examples 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 and may prefer to remotely monitor field operations to assess where equipment and equipment operators are at that time and what has been accomplished up to that time (Griffin et al., 2010). Another example is big data analytics where participating farmers' data is transferred to the cloud based system, analyzed as pooled dataset, and group members receive production recommendations.

According to Holland et al (2013), one of the largest changes between the 2011 and 2013 survey of agricultural service providers as in the use of telemetry for field-to-home office communications. In 2011, only 7 percent of service providers offered the service but 15 percent did in 2013. There were slightly more dealerships offering telemetry in the Midwestern US (17%) than in other states (12%), potentially due to the lack of broadband connectively outside the Midwest. They also report that two-thirds of service providers stated telemetry 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.

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. 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 a result of internet providers in the United States are for-profit private companies and the profit margins in rural regions given the population base do not warrant the investment required (Forntunato, 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 this is not necessary. However, agriculture has become highly information dependent when it comes to marketing crops and decision making.

Given the increased data needs and shortened turnaround times of farmers to make informed decisions and data requirments needed by new machinery, farmers' demand for broadband access continues to grow and solutions must be found to fill in the gaps in coverage. 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 of the 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 manufacture of the technology.

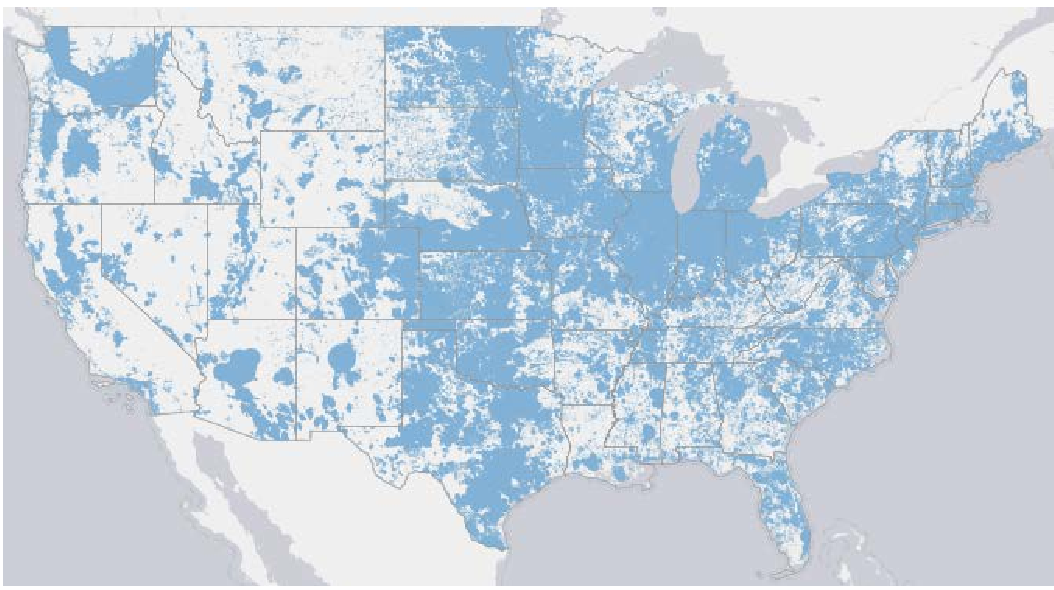

Figure 1. End user access to internet across all platforms except for mobile wireless as of June 13, 2013 (National Telecommunications & Information Adminstration, 2013)

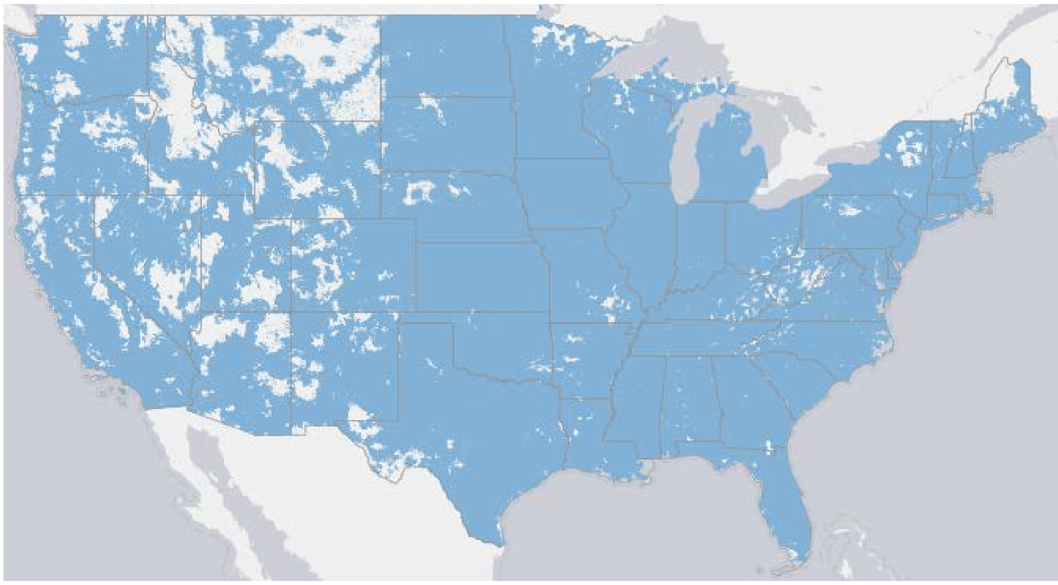

Figure 2. End user access to internet across all platforms including mobile wireless as of June 13, 2013 (National Telecommunications & Information Adminstration, 2013)

Having access to broadband internet is important but just because a farmer has access to broadband does not mean that it can be utilized. Speed of the broadband access is an 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. Transferring packets of data from machine to the cloud requires relatively more bandwidth than transferring prescription maps from the cloud to the machine. Broadband speed requirements are an important area of further research to understand the minimum acceptable speed sufficient so that information can flow unimpeded.

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. Depending upon how integrated the farmer chooses to make the operation and the amount data they will be moving this may or may not be adequate for the farm needs.

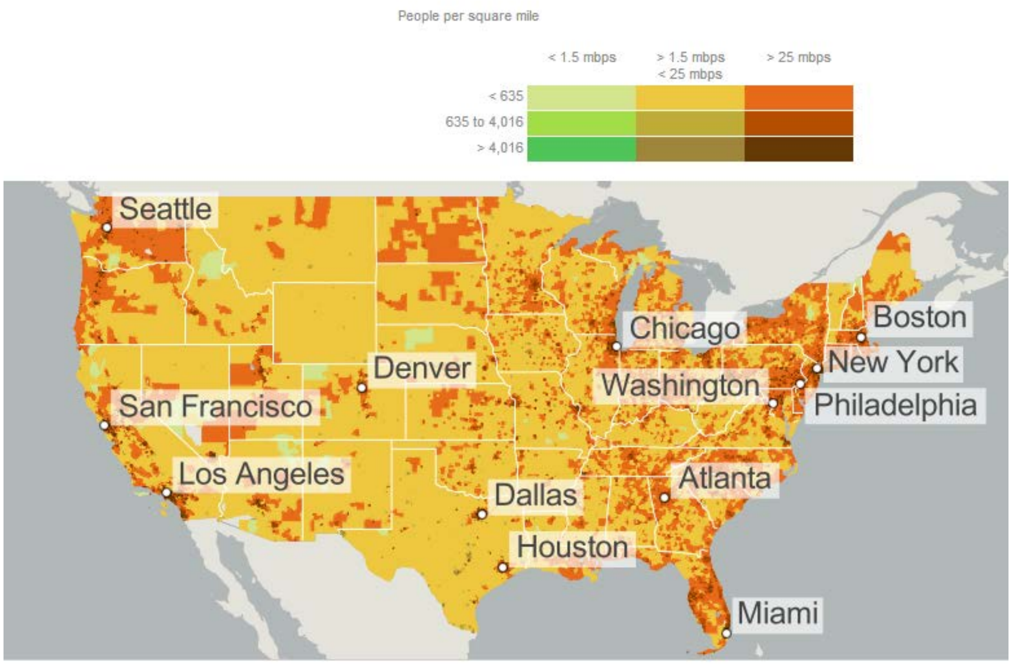

FIGURE 3. Broadband availability across demographics and connection speeds as of June 30, 2013 (National Telecommunications & Information Adminstration, 2013). Includes mobile wireless.

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. 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 the can best utilize it to improve farm profitability and efficiency. One example of spatial technology this is on almost every new combine is a yield monitor; just like GPS enabled guidance is almost ubiquitous on tractors.

According to Schimmelpfennig and Ebel (2011), find that yield monitor adoption has increased to between 35 and 45 percent 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 pointed out a three-stage adoption process that farmers tend to follow. 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 becasuse many farmers have concluded that several years of yield data are needed before farm management decisions should be made. Stage two is the increased usage of soil mapping technologies. This includes the usage of grid sampling, spectral reflectance sensors, and electrochemical sensors. These typicaly 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 and 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 is the time commitment required to assimilate the data , perform analysis, and 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 can allow transmitters to communicate with receivers, move the data, format the data, and interact with automated processes, and either send to a consultant hired to analyze the data or to a file were the producer can conduct the analysis at a later date. The ability to achieve these types of efficiencies is going to be needed to continue meeting the demand for food of a growing population.

CONCEPTUAL FRAMEWORK

In a perfect world there would be access to internet everywhere and information would flow seamlessly. This would allow machines that are collecting information or needing information to complete various tasks in real-time. This transmission would also allow for a central storage location for the data collected so it can be analyzed and results translated into the next task for the machine. Under this scenario farmers could fully utilize the capabilities of precision agriculture and allow farms to be operated 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 can do this; however, there are significant acreage in the United States that this is not possible. Speed of the internet connection can also play a role and may make this an impossible task even in areas where broadband is available.

Two methods will be used to assess the value of having a broadband connection that would allow for the full integration of telematics into the farming operation. The first methodology used will utilize a traditional partial budgeting approach. The second framework developed looks at technical efficiency of a farm that has broadband access and is able to implement telematics relative to those without access.

The partial budget framework, shown in Figure 4, uses added revenue, added costs, reduced revenue, and reduced costs of the implementation of telematics. It is expected that a primary driver of the adoption of telematics will be the opportunity to reduce the labor requirement of manually transferring the data. Another driver will be the availability of broadband access and more importantly the speed of the access. The speed of the access determines the ability and amount of time needed to transfer data. Additionally it is expected there will be additional income generated by being able to fully integrate all data from the operation. One area that is still currently unknown on whether it will be a revenue source or a cost to the operator is if the farm will be paid for sharing data or if farmers will have to pay to share data.

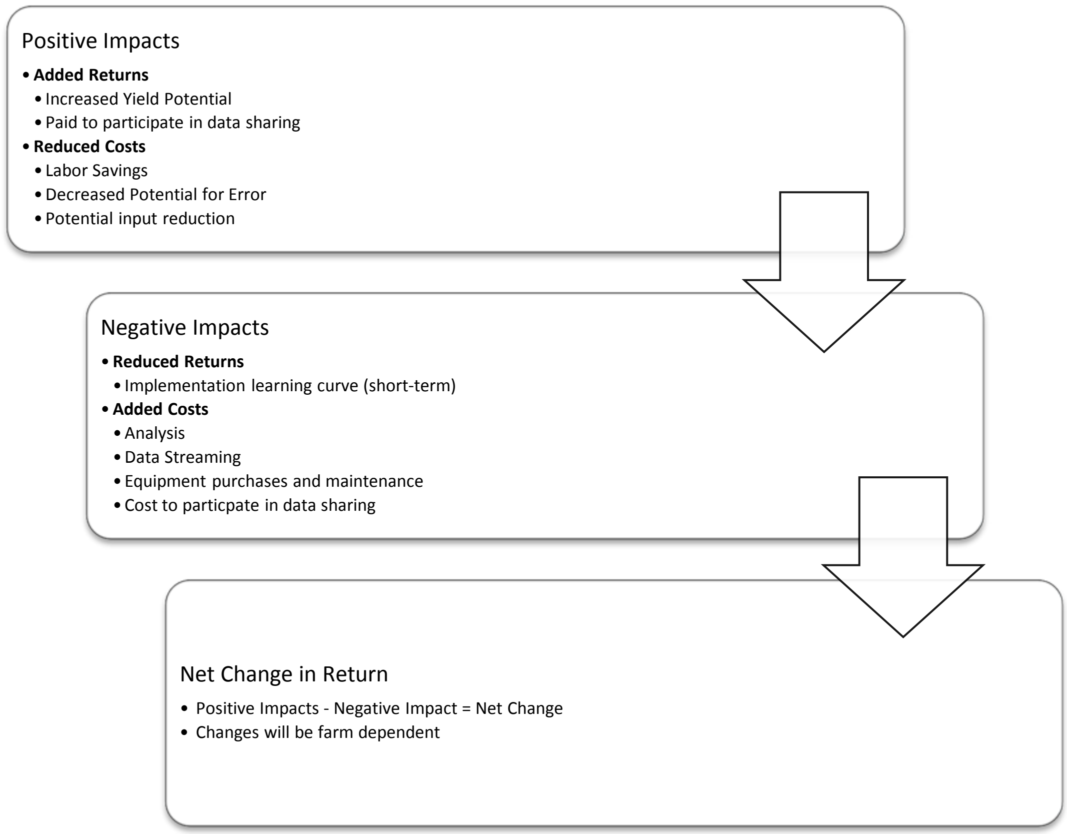

FIGURE 4. Conceptual partial budget framework for the adoption of telematics.

The second method used to assess the value of having broadband access via data envelopment analysis (DEA). Technical efficiency given a production function can be evaluated through the usage of DEA (Figure 4). In this generic example Y is output and X is input, Y^* would have a technical efficiency score of 1 and Y^1 will be something less. Since farming operations tend to have multiple outputs and multiple inputs DEA will be used to assess the efficiency of a farm that has the ability to fully integrate telematics verses those that are not. This will allow for assessment of the value of broadband internet access.

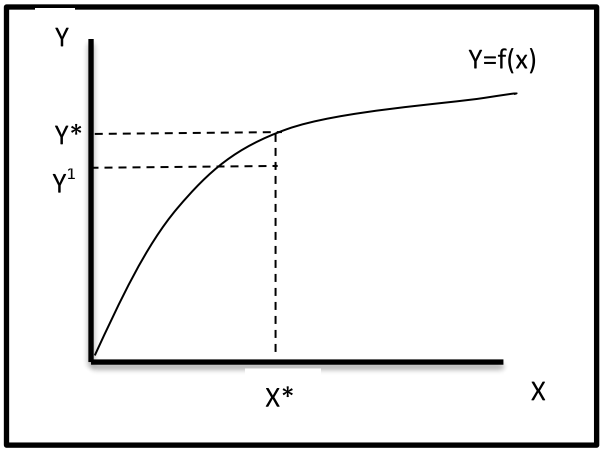

Figure 5. Illustration of technical efficiency.

Ali and Seifod (1993) set forth an output oriented DEA framework that will be utilized. Specifically, this model will consider one output and *m* different inputs. A separate linear programming problem will be solved for each decision making unit (DMU) in the model. For the variable returns to scale (VRS) DEA model for the *i-th* DMU the formulation is as follows:

$$\max_{\phi_i \lambda_j} \phi_i$$

subject to:

$\sum_{j=1}^{n} \lambda_j y_j - \phi_i y_i - s = 0$

$\sum_{j=1}^{n} \lambda_j x_{kj} + e_k = x_{ki}$ $\qquad k = 1,\ldots, m$ inputs;

$\sum_{j=1}^{n} \lambda_j = 1$ $\qquad j = 1,\ldots, n$ DMU

$\lambda_j \geq 0; s \geq 0; e_k \geq 0$

where ϕ_i is the proportional increase in output possible for each DMU; s is the output slack; e_k is the k-th input slack; and λ_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 ϕ 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 will be 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 gain from having access to broadband compared to and no access.

Overall, it is expected that operations that have access to broadband will be more efficient than those operations that do not have access.

In order to illustrate how this works an example data set was generated via simulation to be analyzed with an example DEA model constructed as stated above. The example data set is simulated to meet criteria based on experiences and expectations for operations implementing these technologies. One hundred farm decision making units (DMU) were created. Farm sizes ranged from 500 to 7,500 acres. Agronomic intensity was randomly assigned to be between 1 and 1,000. Broadband connectively were randomly added to the 100 farms. A yield monitor was randomly added to only farms with more than 1,400 acres. Telematics were randomly added to only those farms with a yield monitor. Data analysis using Big Data techniques were randomly added to only those farms with telematics. The base net farm income was calculated as up to $50 per acre plus the 10% of agronomic intensity squared. Net farm income (NFI) was increased for farms making use of big analytics by adding a random value up to an additional 8%. 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.

Results shown in Figure 6 show the relative efficiency between decision making units (DMU) or farm firms are directly compared with other farm DMU's within a given group (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 6). 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 being answering this question.

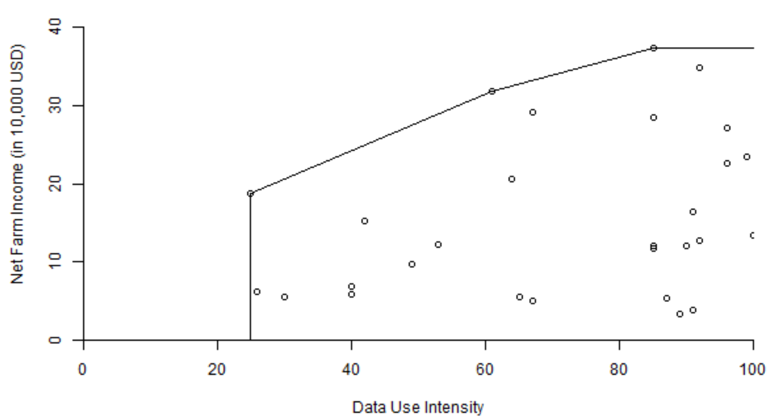

Figure 6. DEA using simulated data for only those users that have access to broadband and potential to use telematics.

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 increasing 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 key so that data can move seamlessly. Producers that have to move data manually are less likely to use the data because of the time required to move the data, 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 often times the investment they have already made in equipment that is already installed on their equipment.

As broadband continues to expand its coverage area and speed it is expected there will be efficiency gains at the farm level that will then 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 in the connectivity of agriculture equipment providing raw data to cloud-based analytics services.

Analytics services themselves are in their infancy with the majority being rudimentary at best; and the lack of analytics services is an artefact of not only theoretical development but network externalities of lack of critical mass of data suitable for big data analytics. In other words, until there is sufficient amount of data for big data analytics to be operational, there hasn't been an incentive for farmers and agricultural businesses to provide data or connectivity to allow for analysis, and vice versa. Until farmer provided data, and connectivity exists then there hasn't been 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. In addition, 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. This analysis gives a conceptual framework for where to start analyzing the issue but additional work needs to be done looking at the market structure of telematics companies. This is needed to understand how these companies develop. 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 give 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?

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