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ADOPTION OF PASTURE MANAGEMENT PRACTICES IN RONDÔNIA, BRAZIL:

SOCIAL MEDIA AS AN INFORMATIONAL INFLUENCE

By

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Adoption of Pasture Management Practices in Rondônia, Brazil: Social Media as an Informational Influence

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The welfare of rural households depends on income from agricultural production. The adoption of new agricultural practices can improve farmer welfare by increasing yield and/or lowering production costs, but farmers do not always adopt beneficial practices. I examine whether social media use influences pasture management practices among smallholder cattle farmers in Rondônia, Brazil. This Amazonian state is heavily deforested for use as farmland, especially pasture for beef and dairy cattle. Traditional pasture management degrades soil over time, requiring pasture productivity interventions or deforestation for new land. Nontraditional practices can reduce degradation. Agricultural technology adoption literature explores the influence of risk, credit access, and access to information from agricultural extension or neighbors. Farmers tend to trust experiential information from other farmers most. Social media connects farmers to a greater variety of other farmers than before, providing greater information access at a much lower cost than other information technologies.

Social media use increases the potential to learn about and adopt new agricultural practices, but few researchers have investigated to what extent it influences agricultural decisions. Such a relationship may suffer from selection bias. Farmers who tend to adopt all kinds of new technologies may be more likely to use both social media and new pasture practices. I estimate the effect of social media use on the adoption of pasture management practices using probit regression with covariates, propensity score matching (PSM), and bivariate probit with instrumental variables. Data comes from a 2019 survey by the Connections between Water and Rural Production project, with responses from 1362 smallholder households. Probit and PSM show social media use correlates strongly with the adoption of any, traditional, sustainable, or complex management, by between 3 and 10 percentage points. This holds for probit when internet access is included. Only any and complex management are significant at 7.2 and 9.5 percentage points for PSM with internet access included. In the bivariate probit model with an instrumental variable, only complex management showed significant effects from social media use and only when internet access was included, at a 15.3 percentage point increase.

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Introduction

Pasture productivity is crucial for the welfare of smallholder cattle farmers. Technologies that improve pasture productivity directly affect household welfare by increasing yield, which generates more income for consumption or investment (Singh, Squire & Strauss, 1986). For smallholder farmers, income from agricultural revenues both contributes to future agricultural investment and supports the household in the short run (Singh, Squire & Strauss, 1986; Tambo & Wünscher, 2017). Improved technologies - any new combination of materials and practices that adjusts the relationship between inputs and outputs (Foster & Rosenzweig, 2010) - can improve productivity and farmer welfare when applied properly (Iheke & Nwaru, 2014). However, productivity-improving technologies can only influence welfare if they are actually adopted, and underadoption can lead to lower overall welfare for farming households. For example, a no-till-based technology called Direct Planting System (DPS) was developed in the 1970's to address erosion in Brazil (Assunção, Bragança, & Hemsley, 2013). Despite producing higher revenues and a lack of upfront costs or increased risk, adoption was only around 10% by 2006. Another study in Malawi found some farmers were not using productivity-improving technologies because they lacked awareness or familiarity with their existence (Fisher et al., 2018). To best increase adoption of profitable or more sustainable technologies requires an understanding of which technologies farmers already adopt and why.

To adopt a technology, a farmer must be aware it exists and understand how to implement it (Fisher et al., 2018). Awareness and implementation rely on the availability of accessible, applicable, and trusted information (Baumgart-Getz, Prokopy, & Floress, 2012). Farmers typically receive information from agricultural extension agencies and other farmers (Adegbola & Gardebroek, 2007; Fisher et al., 2018). Now with increased internet and mobile phone usage (HootSuite, 2019), they also can access information via social media platforms. Such increased information access exposes farmers to more diverse perspectives (Tiwari, Lane, & Alam, 2019), and at lower cost than other communication methods (Aker, 2011). I examine the influence social media use has on the adoption of sustainable pasture management practices in Brazil.

Social media exposes farmers to a greater volume and variety of information by connecting them with more people than they could communicate with in person or through other means. This provides more opportunities to learn about and adopt technologies to improve pasture productivity more effectively or at lower cost. The value of social media as an information avenue expands quickly as people around the world use social media at increasing rates (Hootsuite, 2019). More people on a social media platform increases the diversity of information available for any given person to access.

Since social media is a relatively recent phenomenon, research has mostly been conducted on consumer purchases (Zhu et al., 2016; Forbes & Vespoli, 2013). This area of literature demonstrates that information transmitted over social media does influence users' decision-making. Very few studies consider rural or agricultural social media usage, and those that do focus almost entirely on marketing capability (White et al., 2014; Morris & James, 2017; Davis, 2017). A recent notable study by Elfitasari, Nugroho & Nugroho (2018) found that obtaining information via interactions with other farmers on social media reduced costs for farmers. Their findings support the importance of continued investigation into social media usage by agricultural populations.

Information access is important for sustainable agriculture in the Brazilian Amazon frontier. Brazil has the second largest cattle herd in the world, with 29% of that herd located in the Amazon biome (zu Ermgassen et al., 2018). Over half of pastures in the Amazon and Cerrado regions of Brazil exhibit some degree of degradation due to traditional pasture management (de Oliveira Silva et al., 2017). This process of soil damage creates the loss of pasture productivity and the pasture's natural capacity for recovery (Macedo, 2005), so recovery requires periodic external intervention (de Oliveira Silva et al., 2017). When farmers fail to manage the productivity of their pastures, or do so with unsustainable methods, productivity lies well below potential, limiting profit and welfare for farming families (zu Ermgassen et al., 2018). Traditional extensive grazing and limited pasture management are also associated with deforestation in Brazil (Bowman et al., 2011), as farmers respond to degraded pasture by clearing more land. This motivates a body of research in Brazil on agriculture with lower forest impact (zu Ermgassen et al., 2018; Caviglia-Harris, 2003; Bowman et al., 2011). Any improvements to productivity and sustainability in this region thus could have dramatic impact on rainforest conservation and change standard practices for a large portion of the world's cattle farming.

Several agencies have conducted sustainable cattle farming programs in the Amazon in the past decade, showing improvements in yield and profit while reducing carbon emissions (de Oliveira Silva et al. 2017; zu Ermgassen et al., 2018). However, the extension programs run by Instituto Centro de Vida, The Nature Conservancy, Idesam, and IMAFLORA (post-2011) and Embrapa (pre-2000) involved only a few farmers in designated regions of the Amazon, which did not include the state of Rondônia (zu Ermgassen et al., 2018). Additionally, costs associated with initial infrastructure requirements and a suite of restoration activities proved prohibitive for some small farmers to continue, preventing the realization of future increased profits and stymying efforts at sustainability (zu Ermgassen et al., 2018). In the case of the ABC program, a line of credit that encouraged sustainable low-carbon agriculture, few farmers were aware of it, especially in the Amazon region (de Oliveira Silva et al., 2017). Small family farms make up the majority of cattle farms in Rondônia (IBGE, 2017), so any improvements to their welfare via sustainably increased productivity must be more flexible and accessible. Farmers need not qualify for participation in a program or follow strict guidelines of participation to adopt sustainable practices, though. Practices technicians bring to one farmer are spread by word of mouth to others (zu Ermgassen et al., 2018), especially once the initial farmer becomes familiar with the adopted practice (Fisher et al., 2018).

Social media increases the ability of information to spread by word of mouth online. Brazilians already use social media, and in fact increasingly so. Brazil had 10 million new active social media users (7.7% increase) accessing via mobile phone (8.3% increase) between 2018 and 2019 (HootSuite, 2019). This increase in usage outpaced the population growth (HootSuite, 2019), indicating an increase in the rate of overall use among Brazilians. Aker (2011) notes that mobile phone use became more common even in rural populations in poorer countries; this implies mobile phone ownership and the opportunity for social media access among rural Brazilians in 2019 would not be unreasonable. In fact, several extension agencies have already created accounts on Facebook, Instagram, and Twitter. Widespread use of social media apps like Facebook and WhatsApp are not merely incidental, either - Jair Bolsonaro’s 2018 election campaign reached the Brazilian populace virtually exclusively through spreading information on social media, and voters elected him (Brito et al., 2019). The role social media played in the election provides evidence that Brazilians act on information from social media, so farmers may apply information about sustainable production practices to their farms.

Information provides awareness and knowledge of practices, but other factors provide the resources and obstacles to technology adoption. A wealth of previous research demonstrates widespread interest in the influences of adoption in an effort to solve low-adoption rates, showing some commonalities among the farmers who adopt new technologies. Farmers are more likely to adopt technologies that directly improve production, by saving time or labor, producing a higher yield, increasing profits, or reducing costs (Kuehne et al., 2017). Even if a farmer wants to adopt a technology, they may not have access to short-term funds like credit or savings to afford investment in equipment or infrastructure needed for a technology to be effective (Ermgassen et al., 2018). Wealthier farmers with larger farms, more resources and education, and access to quality information tend to adopt technologies and innovations more readily (Foster & Rosenzweig, 2010). These types of farmers could be more likely to adopt because of their knowledge and resources, or the adoption of technologies could improve their welfare, allowing for the accruement of more knowledge and resources (Foster & Rosenzweig, 2010). However, most of these studies examine crop yields, focusing on Africa and Asia (such as Fisher et al., 2017 and Iheke & Nwaru, 2014). Technology adoption research neglects South America, even in global surveys like Bentley et al. (2019), and rarely considers livestock production. This gap exists despite the fact that South America hosts the largest rainforest in the world, threatened by deforestation from cattle-based agriculture. Linking agricultural information to social media, where extensive social networks exist, may improve knowledge access and adoption of sustainable practices for small farmers.

This paper will contribute an analysis of farmers' usage of social media and the potential influence on cattle production methods in Brazil. The examination of social media's effect on the adoption of sustainable pasture management practices in Rondônia, Brazil serves as a case study for the potential of social media to support both farmer welfare and sustainability goals. The state of Rondônia sits on the edge of the Brazilian Amazon and supports agriculture as its main economic activity. Family-run cattle farms make up a majority of the state's agriculture (IBGE, 2017), so examining the behavior of farmers in this region provides information on smallholders' technology adoption decisions.

I use cross sectional survey data from the Connections between Water and Rural Production project, collected in Rondônia in 2019. The dataset contains responses from 1362 rural households. About two thirds of these households used social media in 2019. Forty two percent used some form of pasture management, with 14.9% using sustainable, 21.5% using traditional, and 11.3% using complex management. Households can and often do use more than one management practice, so these percentages are not mutually exclusive.

I compare the effect of social media use on chosen pasture management practices, considering any management, as well as traditional, sustainable, and complex management categories. I treat management as a binary dependent variable, so model outcomes represent change in the likelihood of use. I use probit, propensity score matching, and bivariate probit models to estimate the causal effect of social media on adoption. Influences on technology adoption likely contribute both to decisions to adopt pasture management technologies and social media, so I control for other information sources, farm and household characteristics, and financial capacity. Households may also have unobserved characteristics which influence their tendency to adopt. I include a version of each model which includes internet access as a proxy for the tendency to adopt modern technology. I also include municipal social media use as an instrument for household social media use in the bivariate probit model to reduce the endogeneity bias from such unobserved factors. Probit and propensity score matching results show strong correlations between all kinds of management and social media use. Social media significantly increases adoption of each category by 4.12 to 7.95 percentage points in the probit model with covariates. The propensity score matching model produces a similar range, however, the effect of social media is significant only for any and complex management, at a 10.0 and 8.75 percentage point increase respectively. As expected, including internet access decreases the magnitude and significance of the effect of social media across management categories. With internet included, any and complex management still bear a significant 4.1-5.85 percentage point increase in adoption in the probit model and significant 7.2-9.5 percentage point increase in adoption using propensity score matching. Bivariate probit models with an instrumental variable show no significant results without internet access included. Social media use significantly increases the use of complex management practices by 15.3 percentage points when internet access is included.

Social Influences on Technology Adoption

The Role of Information in Technology Adoption

The technology adoption literature treats adoption as a household (farm) decision rather than a firm decision. This framework describes agricultural households as both producers and consumers and assumes that farm households make decisions to maximize utility or profit (Singh, Squire & Strauss, 1986). A farm household must weigh the costs and benefits of adopting a new technology to decide whether adoption will achieve the goal of utility and profit maximization. Financial costs include the upfront price of new equipment, inputs, and operational costs associated with adoption. Financial benefits primarily involve future revenues. These affect a household’s profit and ability to purchase more inputs, household necessities, convenience items, and other goods. Non-financial costs and benefits include the time, knowledge, and labor a farmer needs to implement the new technology, and whether those are higher or lower than previous practices required. People tend to discount events in the future, so early costs and benefits will seem more important than later ones, especially when considering that a farm household has immediate needs. This is especially the case for poor households, who are more concerned with meeting short-term needs than increasing long-term profits (Lee, 2005). Households with higher discount rates may not adopt technologies that have delayed benefits. Even households with low discount rates that value future benefits may not adopt a technology if they do not have the funds to cover initial investments. That wealthier farmers are more likely to adopt technologies supports the importance of financial ability in adoption (Foster & Rosenzweig, 2010). Credit access correlates with adoption, as it provides additional funds to cover upfront costs (Deressa et al., 2009; Winters, Crissman, & Espinosa, 2004). Adopting a new technology often comes with risk and uncertainty that will deter a risk-averse household (Wossen, Berger, & Di Falco, 2015). A risk-averse farmer may also choose to adopt a technology if it appears to lower risk compared to not adopting, and this benefit exceeds the cost (Mulwa et al., 2017). Lack of information interferes with a household's ability to assess the profitability or opportunity for success (Wossen, Berger, & Di Falco, 2015), increasing uncertainty associated with a technology and reducing likelihood of adoption.

Farmers with easy access to quality information are more likely to adopt a beneficial technology (Baumgart-Getz, Prokopy, & Floress, 2012; Kassie et al., 2009; Llewellyn, 2007). Several studies cite lack of information as one of the main barriers to adoption (Bryan et al., 2009; Deressa et al., 2009; Nwankwo et al., 2010). In the first place, exposure to new ideas and information provides farmers with the awareness required to even consider adopting a new technology (Fisher et al., 2018; Foster & Rosenzweig, 2010; Adegbola & Gardebroek, 2007; Nwankwo et al., 2010; Glendinning, Mahapatra, & Mitchell, 2001; Caviglia-Harris, 2003). Easy access to information reduces the non-financial costs, as farmers spend less time and effort searching and trying to understand relevant information about a new technology (Aker, 2011; Llewellyn, 2007). Quality information can reduce uncertainty about potential outcomes, such as productivity, so a farmer's perception of possible outcomes more closely matches actual possible outcomes (Llewellyn, 2007). This allows the farmer to more accurately assess the benefit of possible outcomes compared to costs associated with adoption (Nwankwo et al., 2010).

Quality information aimed at changing behavior must be credible, legitimate, and salient to information-users (Cash et al, 2003). This means information provided must adequately address the needs and concerns of the intended audience and be produced in a manner that respects the audience's diverse values and beliefs (Cash et al., 2003). Evaluating information as credible and trustworthy is key to deciding to act on the information, as it reduces the risk of acting on inaccurate information and producing undesired results (Lucassen & Schraagen, 2013). Information-seekers with some familiarity with a topic, but not enough expertise to determine the accuracy of a given piece of information, rely on the perceived credibility of the source (Lucassen & Schraagen, 2013). It follows that farmers lacking knowledge about a particular technology will be more likely to trust information that comes from the historically trusted sources of extension and other farmers.

Extension primarily provides in-person technical information for implementing a practice, (zu Ermgassen et al., 2018; Aker, 2011), positively affecting adoption (Kassie et al., 2009). While extension is fairly trusted by farmers, not all have access to it, and agents often visit or extend program opportunities to farms they think are already more likely to adopt the practice being tested (zu Ermgassen et al., 2018; Wossen et al., 2017; Aker, 2011). The most trusted information source is other farmers, who provide information based on their experiences with using a technology (Fisher et al., 2018). Experiential information is particularly valuable for practices that require more effort to manage, or if management methods vary by location (Adegbola & Gardebroek, 2007), which Nowak (1987) suggests is common for sustainable practices. Talking to other farmers is more likely to generate conversation on location-specific details, such as whether a given practice is applicable to one's soil type and climate or what modifications other farmers have done to make a practice functional and profitable (Adegbola & Gardebroek, 2007; Tambo & Wünscher, 2017). Not only do farmers trust information from other farmers, they rely on it when deciding on their own farm practices (Martinez-García, Dorward, & Rehman, 2013). Nwankwo et al. (2010) note that farmers were less likely to adopt a technology that did not involve farmer participation in information dissemination. Cash et al. (2003) confirm that information is less effective at influencing decision-making across many case studies if stakeholders felt excluded from discussions about what knowledge they need and how to use it. This may explain why memberships in agricultural organizations increase likelihood of technology adoption (Caviglia-Harris, 2003; Kassie et al., 2009).

Whether a farmer has access to information from other farmers and trusts it enough to adopt a technology depends on social capital. Social capital generally refers to the number and strength of relationships a farmer has, and the associated resources and support. The more social connections a household has, the more opportunities they have for accessing information. Wossen et al. (2013) reported that the size of a farmer's social network positively influences their adoption of sustainable natural resource practices. This may be because larger social networks contain relationships that foster several kinds of social capital. Strong, close connections foster “bonding social capital,” which facilitates trust in the information exchanged. We see this in farmers’ reporting neighbors as an important influence on their farming decisions. Bonding social capital tends to be generated among a small number of people, as many strong relationships are difficult to maintain at once. The second type is “bridging social capital”, fostered by weak but diverse social connections. Weak ties do not have to be maintained like strong ties do, so a farmer can have more of them. Weak relationships allow new information to be passed between social groups. Because of these characteristics, bridging social capital exposes farmers to more unfamiliar perspectives, increasing the chances for learning about new technologies. Either type of social capital on its own may fail to result in technology adoption, as a small trusted social circle may become an echo chamber of the same information, reducing the possibility of innovation, and individuals do not always trust and act on information from weak ties (King et al., 2019). Wossen, Berger and Di Falco’s (2015) study in Ethiopia suggests that a household’s risk preferences change according to the kind of social capital as well. High levels of bonding social capital exacerbated risk aversion, which decreases adoption, while households with more bridging kinds of social capital were less risk averse and more likely to adopt technology. Social capital is most effective at facilitating technology adoption when a farmer has a combination of bonding and bridging social capital.

Historically, farmers’ relationships were limited by who they could communicate with in-person. Information communication technologies, or ICT’s, allow quicker communication between more people. According to Okello et al. (2012), ICT's facilitate the communication of knowledge to rural farmers, deliver education and training at low cost, improve access to credit and markets for smallholders, and facilitate and strengthen networks among smallholders. Early ICT’s like posters, newspapers, radio and tv broadcasts were beneficial, but their use was limited in rural areas due to the expense of devices or lack of physical access (Aker, 2011). Mobile phones serve as a more accessible ICT, as they are cheaper than large electronics like TVs (Tumbo et al., 2018) and have a lower cost per-search than other sources (Aker, 2011). Mobile phones have the added feature of interactivity that did not exist before: farmers can communicate directly with each other (Aker, 2011), in real time. ICT's no longer only support passive, unidirectional information transfer, which is less effective at influencing behavior (Cash et al., 2003), especially with the introduction of the internet (Anderson-Wilk, 2009). The internet increases exposure to information, improving awareness of new technologies. Online information is searchable, saveable, and re-findable, unlike information that comes from radio or TV. This makes it easier to find specific and relevant information about technical aspects of using a technology, reducing the cost of learning associated with adoption (Llewellyn, 2007). Mobile phones and the internet pose an opportunity to strengthen existing close relationships through quicker communication with neighbors and other farmers (Tiwari, Lane, & Alam, 2019). A study considering an ICT index of internet, cell phone, landline, and computer usage pre-2000 shows ICT use increases a country's overall agricultural productivity, without requiring higher levels of agricultural resources like labor and inputs (Lio & Liu, 2006). With the internet now accessible on mobile phones, a wealth of online information is directly available to farmers, immediately sharable, and social media apps expand the opportunities for two-way communication further (Anderson-Wilk, 2009).

Social media emphasizes the social aspect of communication, allowing it to occur faster and more easily. Social media platforms provide a space to share and discuss ideas and information available online, along with personal experiences, that any farmer can participate in (Anderson-Wilk, 2009). This ability to share personal experiences can reduce uncertainty regarding the values and variability of potential costs and benefits of a technology. Social media is far more interactive than mobile phones or even the internet alone, as communication can occur between many more people than a farmer may even know personally. Such participatory nature makes farmers feel more involved in information dissemination and more likely to adopt technologies they learn about in this manner (Nwankwo et al., 2010). While information is more easily available online, this also requires information-seekers to evaluate the credibility of tremendously more sources (Metzger & Flanagin, 2013). Information-seekers thus rely on credibility shortcuts: people are more likely to trust information from familiar sources, sources trusted by others, sources that appear professional with few textual mistakes; and information consistent across sources or consistent with the person's prior thoughts and beliefs (Metzger & Flanagin, 2013). This includes sources conceptualized both as websites shared as links on social media and as individual social media users.

Relationship-based evaluation shortcuts seem to be the most salient for information shared on social media. In expanding social networks, social media encourages the development of both bridging and bonding social capital. Using social media enables the development of large, diverse social networks so weak ties can be easily maintained (Tiwari, Lane, & Alam, 2019). People can stay in touch with someone they met once, or meet friends of friends online, or join massive groups that share an interest. This improves the diversity of relationships and perspectives an individual is exposed to. But people can also communicate more easily with others in their community they already know. The utility of this has led to rapidly rising social media use across the globe, including in rural areas. For rural communities, Tiwari, Lane, & Alam (2019) found social media use could be used to enhance and complement social capital that already exists offline. They also found that social media use effectively creates and maintains bridging social capital, especially for heavy users. Abrams & Sackmann (2014) support that finding, more specifically noting that farmers using social media for any purpose correlates with the development of *online* bridging capital. This indicates an expansion of bridging social capital, not just a transition of capital to a new platform. Pan and Chiou (2011) also note that the *perception* of strong ties between contacts on social media can increase trustworthiness of information shared among those contacts – such perceived strong ties develop based on familiarity with online contacts built up through conversations, frequency of exposure, and time spent on a given site.

Impacts of Social Media on Smallholder Agriculture

Since social media has gained popularity only recently, little research exists on how its use affects real-life decisions. Evidence from commercial and marketing studies demonstrates that people make purchasing decisions based on product recommendations and testimonials from other users on social media, even if they are strangers, but especially if they are familiar or part of one's social circle (Zhu et al., 2016; Forbes & Vespoli, 2013; Pan & Chiou, 2011; Metzger & Flanagin, 2013). This real effect on decision-making in the consumer realm suggests that smallholder farmers may also make decisions based on information from trusted people online. These "trusted people" may include people a farmer already knows, such as family and neighbors, people from a shared online community, or simply other people in a trusted category, such as "farmer". The strength of people's reliance on testimonials in these studies supports the idea that farmers' experiences shared on social media may sway other farmers to adopt a technology or not.

Even fewer social media studies consider farmers' usage, and those that exist include recent theses and dissertations (Murphy, 2017; Chang, 2016; Davis, 2017). Like general social media studies, farming-related studies also focus on the capacity for marketing, limited to how farmers can reach consumers to sell agricultural products (White et al., 2014; Engotoit, Kituyi, & Moya, 2016; Murphy, 2017; Davis, 2017). This literature primarily considers farmers in developed, Western countries (Morris & James, 2017; White et al., 2014; Davis, 2017; Murphy, 2017). Factors that deter social media use by Western farmers as in Morris and James (2017) may not apply, as these farmers in the United Kingdom viewed social media solely as an extra entrepreneurial task. Smallholders in developing countries may not be as able or interested in creating and marketing a brand for their farm to sell direct-to-consumer. Some consider how extension agencies might utilize social media (Suchiradipta & Saravanan, 2016; Talib et al., 2018), but do not address the farmers' role in accessing the information from an online extension presence. An aquaculture study by Elfitasari, Nugroho & Nugroho (2018) actually considered the effects of social media use on farmer outcomes and welfare in Java: they found that membership in a fishing Facebook group increased the knowledge and improved the financial situation of participants compared to fish farmers that were not members. This study provides more concrete evidence that social media use can be beneficial to smallholder farmers through the creation of interactive communities where farmers can discuss the best ways to use new technologies and manage farming costs.

While agricultural social media studies are currently thin, existing evidence provides strong support for its importance in the decisions of smallholder farmers. Social media connects farmers to trusted sources of information - extension agencies and other farmers - who have a presence online. This is especially important for isolated rural households who have less opportunity to interact with information sources in person. Examining the impact information from social media has on various management practices will help agencies decide whether social media is a more efficient communication tool, or whether it discourages or has no effect on agricultural technology adoption. Extension agencies have limited resources, so if social media more effectively influences adoption of agricultural technologies, fewer resources need to be spent on organizing in-person connections. Researchers and extension agencies must keep in mind, however, that farmers may have limits beyond lack of information, and support and resources must consider other barriers for truly successful adoption.

Methods

I aim to estimate the effect of social media use on the pasture management practices of cattle farmers in Rondônia, Brazil. First, I will consider the effect on whether a household uses a pasture management strategy at all. The practices considered are reform, recovery, soil treatment, grass variation, pasture rotation, genetic investment, and semi-confinement. I will also consider the effect on the category of pasture management practice used; traditional includes reform and recovery; sustainable includes grass variation and pasture rotation; and complex includes grass variation, genetic investment, and semi-confinement. Soil treatment is included under "any" management, but as a neutral practice is not considered under any of the subcategories.

Adopting a technology (pasture practice) depends on a household's latent (perceived) utility of adoption compared to non-adoption, Y*. As outlined by Wossen et al. (2013), not only must the technology provide utility, it must provide *more* utility than what they were already doing. The unobserved latent utility results in the observed adoption or non-adoption of a pasture practice, Y:

$$Y = \begin{cases} 1 \; if \; Y^* > 0 \\ 0 \; if \; Y^* \leq 0 \end{cases}$$

where Y=1 if the utility of adoption is positive (compared to prior practices) and Y=0 if the utility of adoption is neutral or negative (compared to prior practices). The framing of practices as “adopted” or “not adopted” motivates the use of a model appropriate for binary dependent variables - I use several probit-based methods to allow for nonlinear effects. A household’s adoption decision depends on a variety of factors, taking the basic form:

$$P(Y=1|x,S) = \beta_0 + \beta_k x_k + \gamma S + e_1$$

where P(Y) is the probability of adoption, S represents each household’s social media use, x_k represents a series of control variables, and β and γ serve as coefficients. The control variables fall under the categories of information sources, farm and household characteristics, and financial capacity. Since social media is the explanatory variable of interest, I include controls for other sources of information that may influence management decisions. These include extension contact, agricultural programs participation, and the number of memberships of cooperatives or other associations.

Farm and household characteristics include farm size, family size, and farmer experience, age, and education. Farm size provides a sense of a farm’s potential productivity and the degree of management required. I measure farm size with two variables: hectares of pasture indicates the physical size of the grazing area on the property; herd size indicates the extent of the household’s cattle operation, including on other properties, as in Caviglia-Harris (2003) and Martinez-García, Dorward, and Rehman (2013). Family size, or number of family members living on the lot, influences both labor availability and household consumption; ie. the amount the household can produce and the amount they need to produce to support themselves. Experience, age, and education affect how the household accesses and interprets information for decision-making.

Financial capacity includes wealth and off-farm income. Wealth here refers to the number of different kinds of physical household assets (bikes, cell phones, various appliances, etc.). Off-farm income demonstrates the level of commitment to (or reliance on) activities other than cattle agriculture. Off-farm income could provide supplementary funds for investment in agriculture, or represent diversification of risk by pairing variable agricultural income with a steady waged income to support the household. Credit access is commonly included, but almost all households had access if needed, making active credit use an endogenous decision. Total income is excluded as it correlates with production, which depends on the size of the cattle herd.

I use several methods to estimate the effect of social media use on pasture practice adoption. First, I estimate a probit regression of social media on pasture management outcomes. The marginal effects of a probit regression show the difference in likelihood of using a pasture management practice between users and nonusers of social media, while allowing for nonlinearity. A simple probit model without covariates shows the correlation between social media use and pasture management, but the coefficient will also reflect the influence of omitted factors that correlate with both the explanatory variable and the outcome. To consider the effect causal, I must be sure no omitted factors correlated with social media use and the outcome actually explain the effect attributed to social media. I estimate a second probit regression including the above controls (informational sources, farm and household characteristics, and financial capacity) as covariates likely to affect both social media and pasture management adoption. This method is the most efficient estimator if the additional included factors sufficiently control for all influences on technology adoption.

However, possible unobserved personal characteristics may contribute to the adoption of pasture management practices and social media alike. The households most likely to adopt a new pasture technology may also be more likely to adopt any kind of new technology, including social media. These households may have an affinity for novelty and experimentation that positively biases the coefficient on social media. The inclusion of internet access on the property serves as a proxy for the tendency to adopt technology to reduce this bias. A proxy variable has to correlate with the unobserved trait of interest. A tendency to adopt new technologies would influence internet installation decisions. A proxy must also meet two assumptions for unbiased estimates. First, the proxy must not correlate with the error term; in other words, the proxy would not affect the outcome if the true unobserved factor could be controlled for (Wooldridge, 2012). Internet access does not meet this assumption, as information from the internet could also affect management outcomes. Second, for internet access to be a "good" proxy, the error between the proxy and the unobserved factor must not correlate with the other variables (Wooldridge, 2012). This means with the inclusion of the proxy, the unobserved factor no longer correlates with the other variables. Again, internet access may not totally satisfy this assumption, as affinity for technology could still partially correlate positively with social media use. In this case, some positive bias may remain in the effect of social media, but less so than if internet access were not included at all.

The marginal results in the probit regressions show the average difference in probability of management between households that use social media and those that do not. Ideally, I would compare the management outcome Y(S) of a given household with and without social media use (S=1 and S=0) (adapted from Wossen et al., 2017):

$$ATET = E[Y(1) \mid S=1] - E[Y(0) \mid S=1]$$

where the average treatment effect on the treated households *ATET* is the difference in the expected management outcomes with social media use Y(1) and without Y(0). Of course, such a counterfactual alternative Y(0) does not exist to compare to, given that the household already chose to use social media (S=1). But comparing outcomes between all households that do and do not use social media may reflect that social media users are most likely to benefit from social media use; households that perceived low utility (benefit) choose not to use it. Propensity score matching (PSM) addresses this problem by comparing households to their closest existing counterfactuals - households that are similar in every observable respect except social media use. This method first generates each household's propensity score, or the estimation of the probability of using social media *P(S=1)* based on observable traits x, using a probit regression:

$$P(S=1|x) = \beta_k x_k + e_1$$

where households with similar observable characteristics x receive similar propensity scores. PSM matches households with similar propensity scores but which differ by actual social media use *S*. I use the nearest neighbor method to match each social media-using household once with the most similar control household, with replacement (control households may be matched to multiple treated households). Then the management outcomes *Y* of matched households are compared, and the differences attributed to social media use (adapted from Wossen et al., 2017):

$$ATET = E[Y(1) \mid S=1, P(S=1|x)] - E[Y(0) \mid S=0, P(S=1|x)]$$

However, PSM assumes that differences in outcomes are random, that no systematic differences in unobservables exist between households that do and do not use social media, which I have suggested may be false. To address this, I estimate the PSM model twice: once with covariates, and again with internet access included. As in the probit regression with covariates, including internet access serves as a proxy for the unobserved affinity for technology, removing some of the potential systematic difference between social media users and non-users.

I also use an instrumental variable (IV) to discern the causal effect of social media on pasture technology adoption. For a causal estimate to occur, the instrumental variable must correlate with social media use and be unrelated to unobservable endogenous influences (Wooldridge, 2012). That is, the instrument cannot affect pasture technology adoption choices except through social media. The less the instrument correlates with unobserved characteristics in the error term, the more consistent the estimate will be. The stronger the correlation between the instrument and the endogenous variable, the more closely it will predict the true effect of the biased variable on the outcome.

Here I discuss possible instruments. Ownership of a device that can access social media could be a strong predictor. However, the survey did not inquire about computers, and the popularity of cell phones (with no distinction for smartphones) leaves little variation in the data. A household is more likely to use social media if people they know are also using it already, so I consider the social media use of others in the community. Neighbors' and friends' use may have the strongest influence on a household's use, being the people a household would most want to communicate with; however, a household is also a neighbor and friend to others, influencing their social media use too. This makes the direction of causality ambiguous, as households that use social media may cause more of their friends to do so, or may adopt social media themselves because of the number of friends who do so. Instead, I use the proportion of households in the whole municipality that use social media to predict the effect of household social media use. If the broader municipal community has more social media users, a given household is more likely to adopt it to facilitate communication, but that household cannot meaningfully affect the overall ratio of social media users in the entire municipality.

A household that does not use social media may still acquire information from other community members who do. This undermines the assumption that the IV only affects pasture management directly through social media use. But the sheer amount of information available on social media is less easily conveyed through offline methods such as printing or word-of mouth. Households would make decisions based on social media much less efficiently or at all if they must rely on second-hand snippets instead of searching for detailed, relevant information and building online relationships themselves. This slight endogeneity bias likely would have little to no influence on the estimated effect.

Standard linear two-stage procedure is insufficient for estimating the effect of social media use on pasture management practices. Firstly, standard linear IV models do not constrain fitted values to a unit interval, so predicted probabilities may exceed 1 or appear negative (Lewbell, Dong, & Yang, 2012). Standard errors in linear IV can also be too large “for meaningful hypothesis testing”, especially when probability of treatment is close to 0 or 1 (Chiburis, Das, & Lokshin., 2011, p. 16). This can be solved by using a non-linear probability model, such as probit mentioned above. Secondly, according to Wooldridge (2002), 2SLS can handle binary endogenous regressors “with no special considerations” (p. 622), but only with a linear function for the outcome. Attempting to use linear methods to estimate a binary endogenous variable in a probit model creates inconsistent estimates, earning the title “forbidden regression” (Wooldridge, 2002, p.477). Instead I use bivariate probit (via the Stata command *biprobit*) as recommended for cases of a probit model with a binary endogenous explanatory variable (Greene, 2012). Bivariate probit provides the joint probability of two probit stages occurring together: one predicting social media use and one predicting pasture management adoption. Simulations by Chiburis, Das, and Lokshin (2011) show bivariate probit is a more efficient estimator than linear IV when covariates are included, with smaller standard errors than linear IV.

As in the single probit model, the binary adoption outcome Y depends on the latent utility of adoption Y*. Just like with technology adoption, farmers will choose to use social media or not for information if the latent utility of use S* is net positive. These stages can be written as:

$$P(Y=1|x, S) = \beta_{ky} x_k + \gamma S + e_1$$

$$P(S=1|x, z) = \beta_{ks} x_k + \alpha z + e_2$$

where the utility of social media use S* is predicted by the instrument of municipal social media use *z*, and the predicted social media outcome S affects the utility of management practices Y*. Each stage has its error term, e_1 and e_2 respectively. I include the set of controls that generally influence technology adoption in both steps as x_k, with the coefficients β_{ky} and β_{ks}. In the modified specification, these controls also include internet access as a proxy for an affinity for technology.

Data

Study Region

I use farm-level cross-sectional survey data collected from agricultural households in the state of Rondônia, Brazil in 2019. The federal government founded the state in the 1970's, building highways to facilitate development as part of Operation Amazonia (Foresta, 1992). To encourage settlement, the government instituted the Land Redistribution Program in 1971 (Foresta, 1992), further supported by the Northwest Brazil Integrated Development Program in the 1980's (Brown, 2001). These programs allocated free property to migrants from other parts of the country via the National Colonization and Agrarian Reform Agency (INCRA) (Foresta, 1992). That settlements were intended for agricultural development established farming as the primary occupation in the state (Foresta, 1992), still reflected in the over 70,000 cattle farms as assessed by the 2017 Agricultural Census (IBGE, 2017). The initial allocation of land makes property rights fairly secure, so land tenure is not a concern in this paper.

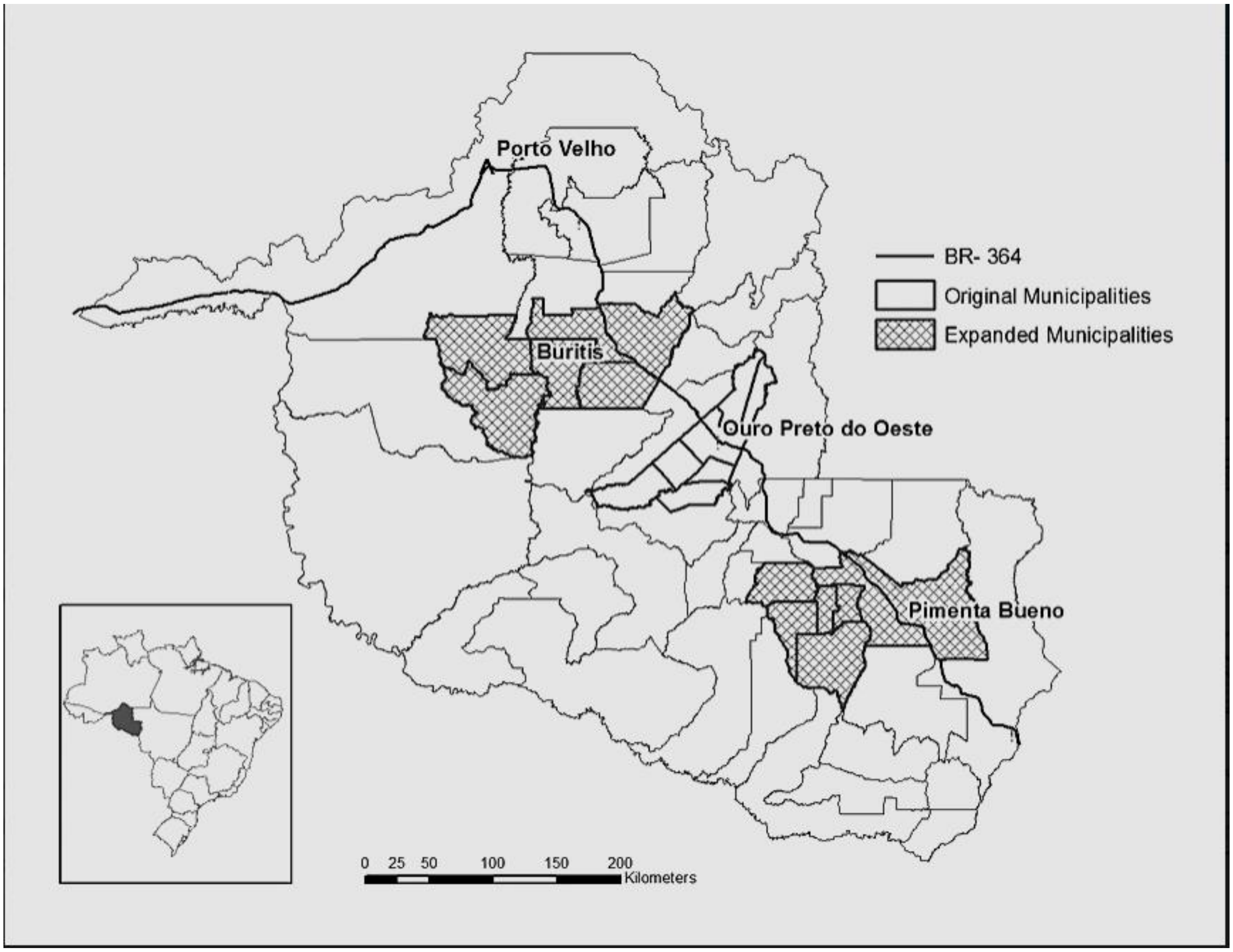


Figure 1: Map of study region from Connections between Water and Rural Production project

Agriculture in Brazil is supported by extension from organizations including EMATER, EMBRAPA, CEPLAC, SEDAM, SENAR, and IDARON. These organizations have Facebook pages and groups and Instagram pages for disseminating information about events and program updates. EMATER and EMBRAPA have the largest social media presence, with the most Facebook pages and groups and the only organizations easily found on Twitter. These two also host a plethora of accounts on each platform, tailored to each region of Brazil. Extension accounts and groups distribute information on upcoming events, like demonstration days, and what kinds of technologies the organization currently promotes. Farmers can follow agencies' pages or join Facebook groups for more interactive discussions. People can also join message groups on WhatsApp, though this platform does not make groups easy to find without exclusive invites.

The study region encompasses 17 municipalities across three field sites in Rondonia, each centered on an urban area: Ouro Preto do Oeste, Ariquemes, and Rolim de Moura. The sample includes households from previous panel research in Ouro Preto do Oeste, with new stratified random sampling from each municipality to balance representation from each field site. About 80% of agriculture in this region consists of family farms (IBGE, 2017). The survey included questions about household and farm characteristics, including income from various sources, involvement in organizations, pasture management or improvement practices, and social media use. All questions were framed temporally as having occurred "in the past 12 months."

The dataset contains survey responses for 1362 households. Internet access in each municipality ranged from 54.7% to 87.5%. Cell reception by municipality ranged from 59.7% to 91.7%**,** and 91.3% of households surveyed owned a cell phone. A majority of surveyed households used social media across several platforms. WhatsApp was by far the most commonly used, followed by Facebook (both the app and its associated Messenger app). Milk sales provided average revenues of R$30,971.72 ($8,023.76) for the 596 households that reported milk income (using exchange rate of R$3.86 per $1 as of June 30, 2019 according to x-rates.com). Only 35 households reported beef income, averaging R$50,347.14 ($13,043.30), while calf sales averaged R$69,891.96 ($18,106.73) across 202 households. In comparison, households spent a mean of R$2872.61 ($744.20) on pasture inputs, including expenditures for lime, chemical or natural fertilizer, pesticide, and soil analysis. These represent a farm's variable costs of pasture management. The majority of farms did not have input expenditures at all. The households that used any kind of pasture practice had higher average costs of R$5610.10 ($1453.39), while households not managing their pastures spent R$917.26 ($237.63).

Surveyed households used a variety of management practices. Pasture-related management practices include "reforma" (reform), "recuperaçao" (recovery), "trata solo" (soil treatment), "varia pastagem" (grass variation), and "rotaçao" (pasture rotation). These practices are not mutually exclusive and a farmer may use several practices at once. Households that used at least one of these practices count as users of "any" management. I put these practices (except soil treatment) into "sustainable," "traditional," and "complex" categories.

In this paper, I consider recovery and reform "traditional" practices, as these sets of treatments are performed periodically to restore degraded soil, depending on the severity of degradation. After too much grazing, the grass no longer resprouts on its own and the pasture must be recovered or reformed (de Oliveira Silva et al., 2017; Boddey et al., 2004; Macedo, 2005). Recovery is used to restore productivity to degraded pasture where some grass still grows. It involves intensive soil treatments, such as lime or fertilizer applications, harrowing, and weed management, including mowing and application of chemicals (IEPEC.com). When the pasture is so unhealthy the grass will not regrow, farmers turn to reform, akin to starting over from scratch. Reform involves reseeding and intensive soil treatments such as fertilizer and harrowing in addition to lime (IEPEC.com). Both methods usually involve a visit from a private technician for soil testing to determine what substances to apply to the soil, which adds an extra cost.

Farmers can also apply soil treatments intermittently so pasture will not degrade enough to need the more extreme measures of recovery and reform. This includes applications of lime, natural or chemical fertilizer. The use of such inputs also contributes to a household's overall expenditures on pasture management. While farmers employ soil treatments as a pasture productivity management practice, I do not assign it to any of the subcategories: "traditional" management typically does not involve soil maintenance practices (zu Ermgassen et al., 2018; de Oliveira Silva, 2017), and application methods could make its use more or less "sustainable".

I consider grass variation and pasture rotation "sustainable" practices, as they are intended to maintain pasture quality so traditional interventions are unnecessary. Grass variation involves planting more productive grass varieties. Different grass types popular in Brazil perform better under different soil conditions (Macedo, 2005), so planting a grass suited to the nutrient ratios will improve pasture productivity. Pasture rotation involves segmenting pasture with fencing and rotating the cattle between segments. In contrast, traditional free range grazing permits cattle to graze across the whole pasture as they please (de Oliveira Silva et al., 2017). Free range grazing more often leads to degradation, as cattle trample or eat new growth (Boddey et al., 2004). Rotation maintains pasture productivity by protecting new growth, allowing the grass to reestablish itself before cattle revisit the segment.

Cattle-related management practices include genetic investment and semi-confinement. Along with grass variation, these practices are considered "complex" due to their high knowledge requirements. To replace a grass variety to one that will be more productive given the climatic and soil conditions, a farmer must know which grasses will perform better and obtain the seeds. Similarly, to invest in cattle specifically as breeding stock or selecting the right sperm to purchase for artificial insemination, a farmer must understand which breeds and lineages survive and produce milk or beef best. Semi-confinement of cattle is the opposite of free range grazing, limiting cattle to a small area and supplementing their diet with feed grown elsewhere.

This is done to reduce the amount of land needed on the farmer's own lot. Practicing semi-confinement requires knowledge of how to manage cattle in confinement, what to feed them, and how to obtain it, whether they grow feed themselves or purchase it. As a relatively new practice, how to use confinement is not yet common knowledge.

Dependent variables

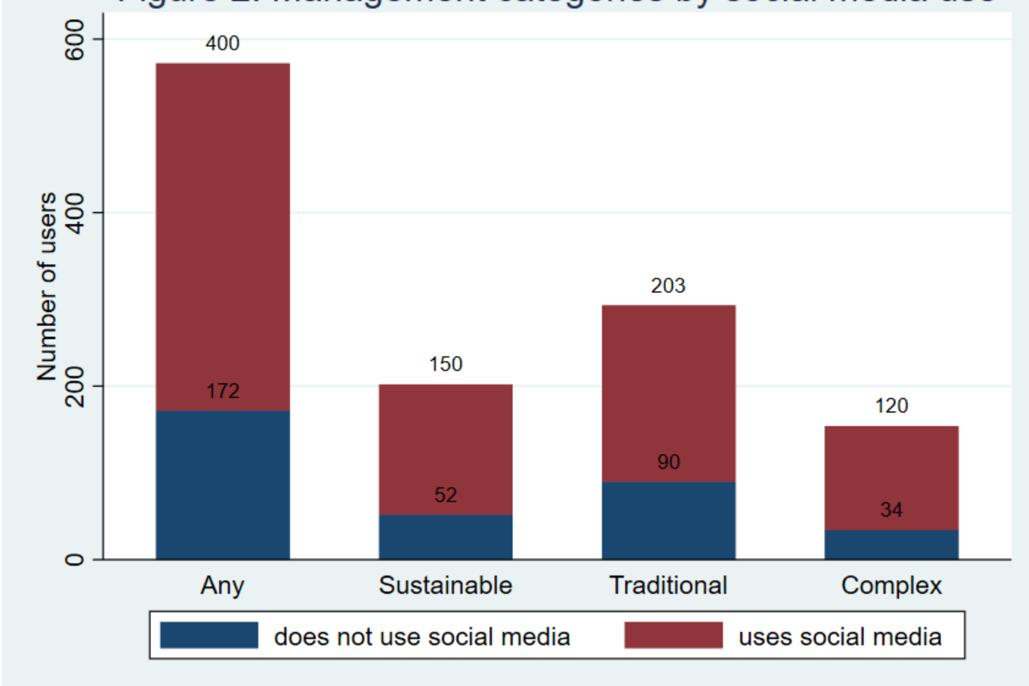
Table 1: Pasture practices

	Number of users
Reform	248
Recovery	69
Soil treatment	279
Rotation	181
Vary grasses	38
Genetic investment	67
Semi-confinement	71
N	1362

The main dependent variable is the use of any practices to manage pasture and cattle productivity. Of the 1362 farm households, 574 use any of the described management practices**,** with 788 using none of them. Table 1 shows the number of households using each practice. Soil treatment was the most popular practice, with applications by 279 farmers in the past year. This number includes those who listed soil treatment as something they are doing to raise pasture productivity, or those who indicated costs for lime, natural (leaf) fertilizer, or chemical fertilizer. This indicates that farmers are making an effort to maintain soil health through inputs. Reform has the second highest number of practitioners, at 248. This popularity demonstrates that a high portion of farmers rely on a traditional, degrading pasture management cycle. Pasture rotation is a fairly common management practice, with 179 practicing households. Only a few specified they use rotation to improve pasture productivity, but many indicated that they use it to address water availability, which directly affects pasture productivity. Very few households practiced grass variation (less than 40), while recovery, genetic investment, and semi-confinement each had about 70.

Main explanatory variables

Figure 2: Management categories by social media use



The main explanatory variable is social media. Of 1338 respondents, 855 used social media and 483 did not. Respondents who did not answer the initial survey question but indicated in later questions that they did not use social media were imputed as “no” and included in the previous number. Figure 1 shows that social media use is popular across all practice categories. About 70% of households using any management practice also use social media. About the same percentage of traditional managers use social media. Households using sustainable and complex practices each have higher percentages of social media users, at 74% and 78% respectively.

Control variables

Table 2 shows the summary statistics for financial, farm, household, and informational characteristics that serve as control variables.

Table 2: Control characteristics

	Mean	Standard deviation	Min	Max
Asset count	9.90	1.92	0	15
Off-farm income (R$1000s)	5.69	52.71	0	1800
Pasture area (hectares)	67.86	135.63	0	2178
Heads of cattle (100s)	1.86	4.03	0	62
No. of family members	3.74	2.18	0	15
Experience (years on farm)	23.96	13.37	0	59
Mean education of 3 most educated (years)	3.82	3.13	0	14
At least 1 head aged 60+	0.08	0.28	0	1
Extension contact	0.32	0.47	0	1
Program participation	0.04	0.21	0	1
No. of association memberships	0.52	0.70	0	5
N	1362			

Asset count here refers to the number of different kinds of physical assets a household owns. Assets considered in the count include: tv, satellite dish, landline, cell phone, fridge, freezer, milk tank, washing machine, microwave, fan, bicycle, and air conditioning. Owning multiples of any one asset does not affect the count. Households had an average of almost 10 different kinds of assets. The average household earned R$5,690 in off-farm income. The average pasture covered just under 70 acres of the lot. The average herd had 186 heads of cattle across all property in operation. On average, households had about 4 family members living on the lot, ranging up to 15. I approximated experience by the number of years the family has owned the property. The mean is around 24 years of property ownership, though a handful had 40-59 years if their family moved to Rondônia early on. The survey requested the years of education of the male and female household heads, as well as of the most educated member of the household. The mean of these three (or two, if a head was the most educated) values serves as the education measure. Most households had 10 or fewer years of average education, while the mean was just under 4 years. The survey categorized the ages of family members as “adult” (aged 15-59) or “old” (aged 60 or more), so exact averages, while ideal, were not possible. Instead I consider whether both heads were under 60 years old or not. Only two households had both heads older than 60, so they count as “at least one head over 60”. The table shows 8% of households had at least one head above 60 years.

Over 400 households (or 32%) received information or assistance from technicians from extension agencies like EMATER, EMBRAPA, CEPLAC, SEDAM, SENAR, IDARON, or from a dairy operation, Rio Terra, University of UNIR, the Municipal Secretary of Agriculture, or a private company, among others. Only 60 participated in the programs Balde Cheio and Rural Sustentável, which focus on farming sustainably and profitably to reduce deforestation. EMBRAPA engaged farmers in a sustainable cattle program which included practices like pasture rotation and grass-legume mixing, but the program did not involve any farmers located in Rondônia (Ermgassen et al., 2018). It is possible farmers could hear about sustainable practices from these agencies, but agents do not seem to be actively encouraging use of the practices I consider in Rondônia. Households averaged less than one membership of a farmer’s cooperative, credit union, or other agriculture-related association. Households that responded they were not members of any association were added in as “0”, with the maximum number of memberships reaching 5 for any given household.

Results

Probit

Table 3 shows the average marginal effect of social media alone on each pasture management category. This provides the most basic correlation between the management and social media use. Social media increases likelihood of using any management practice by 12.91 percentage points, more than double the positive increase of 6.01 percentage points on traditional management. Sustainable and complex management practices have similarly-sized effects from social media, with 7.83 and 7.98 percentage point increases respectively. Each of these positive results is significant in this specification.

Table 3: Marginal probit results for social media's effect on pasture practices

	Any	Traditional	Sustainable	Complex
Social media use	0.1291^{***}	0.0601^{***}	0.0783^{***}	0.0798^{***}
	(0.02)	(0.02)	(0.02)	(0.02)
N	1359.0000	1359.0000	1359.0000	1359.0000

Errors clustered by municipality. SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Table 4 shows the average marginal probit results when other covariates are included (full results in Appendix C). Social media has a positive relationship with all kinds of management explored here. While the effect is lower, it remains significant for all categories. Social media use increases the use of any management the most, by 7.95 percentage points. Traditional management increases the least, by 4.12 percentage points. Sustainable management increases in likelihood by 6.11 percentage points with social media use. Complex management increases by 5.45 percentage points.

Table 4: Marginal probit results for social media's effect on pasture practices with covariates

	Any	Traditional	Sustainable	Complex
Social media use	0.0795^{***}	0.0412^{*}	0.0611^{**}	0.0545^{***}
	(0.03)	(0.02)	(0.03)	(0.02)
N	1082.0000	1082.0000	1082.0000	1082.0000

Covariates include asset count, off-farm income, pasture area, herd size, extension, association membership, program participation, experience, household size, age, and average education. Errors clustered by municipality. SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

To see if social media and internet access are measuring the same effect, Table 5 shows marginal probit results where internet access is included as a control for a household's access to modern technology. Social media still has a positive effect on all categories, which is significant for any and complex management. This decrease in coefficients suggests that internet access explains some of the effect of social media presented in Tables 3 and 4, but not all.

Table 5: Marginal probit results for social media's effect on pasture practices with covariates

	Any	Traditional	Sustainable	Complex
Social media use	0.0585**	0.0337	0.0487	0.0410**
	(0.03)	(0.03)	(0.03)	(0.02)
N	1081.0000	1081.0000	1081.0000	1081.0000

Internet used as a control for modernity and affinity for technology. Covariates include asset count, off-farm income, pasture area, herd size, extension, association membership, program participation, experience, household size, age, and average education. Errors clustered by municipality. SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Propensity Score Matching

Propensity score matching results for social media with covariates, and social media with covariates including internet are in Tables 6 and 7 respectively. Table 6 shows social media has a significant effect for any management and complex management. Households with social media are on average 8.65 percentage points more likely to use complex management. Households using social media are nearly 10 percentage points more likely to use any kind of management than similar households without social media. Use of traditional management is just over 6 percentage points more likely for households using social media than those who do not, and sustainable management is 4.76 percentage points more likely for households using social media than not.

Table 6: Difference in practice use by social media use with PSM including covariates

	Any	Traditional	Sustainable	Complex
ATET				
Social media use	0.1009**	0.0605	0.0476	0.0865**
	(0.04)	(0.04)	(0.04)	(0.03)
N	1080.0000	1080.0000	1080.0000	1080.0000

Covariates include asset count, off-farm income, pasture area, herd size, extension, association membership, program participation, experience, household size, age, and average education. SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Internet is included as a control with social media in Table 7. Any management and complex management remain the only categories with significant effects, at 9.52 and 7.22 percentage point increase in likelihood respectively, compared to households that do not use social media. Likelihood of using sustainable management slightly increases to 5.05% increase compared to households without social media. With internet included, the households with social media become only 2.02% more likely to use traditional management compared to those without social media.

Table 7: Difference in practice use by social media use using PSM with covariates

	Any	Traditional	Sustainable	Complex
ATET r1vs0.Social media use	0.0952**	0.0202	0.0505	0.0722**
	(0.05)	(0.04)	(0.03)	(0.03)
N	1079.0000	1079.0000	1079.0000	1079.0000

Internet used as control for affinity for technology/modernity. Covariates include asset count, off-farm income, pasture area, herd size, extension, association membership, program participation, experience, household size, age, and average education. SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Bivariate Probit with Instrumental Variable

Table 8: Marginal bivariate probit results for social media's effect on pasture practices using IV

	Any	Traditional	Sustainable	Complex
Social media use	0.0131	0.0679	0.0434	-0.2329
	(0.31)	(0.22)	(0.13)	(0.47)
N	1082.0000	1082.0000	1082.0000	1082.0000

Municipal social media use used as IV. Covariates include asset count, off-farm income, pasture area, herd size, extension, association membership, program participation, experience, household size, age, and average education. Errors clustered by municipality. SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Tables 8 and 9 show the average marginal results from bivariate probit estimations using instrumental variables. (Full results of both stages are available in Appendix C.) Table 8 uses the ratio of municipal social media use in the stage estimating household social media use with covariates. This stage confirms a strong correlation between municipal and household social media use. In this specification, no results are significant. Likelihood of adopting any practice increases by 1.31 percentage points. Likelihood of using traditional or sustainable management increases by 6.79 and 4.34 percentage points respectively. Use of complex management decreases in this model by 23.29 percentage points.

Table 9: Marginal bivariate probit results for social media's effect on pasture practices using IV

	Any	Traditional	Sustainable	Complex
Social media use	0.0357	0.0993	-0.1123	0.1533*
	(0.44)	(0.12)	(0.23)	(0.08)
N	1081.0000	1081.0000	1081.0000	1081.0000

Municipal social media use used as IV. Internet included as a control. Covariates include asset count, off-farm income, pasture area, herd size, extension, association membership, program participation, experience, household size, age, and average education. Errors clustered by municipality. SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Table 9 includes internet access as a control. Only complex management produces a significant result, with a 15.33 percentage point increase in likelihood of use. Social media use increases the likelihood of using any management by 3.5 percentage points, increases likelihood of using traditional management by 9.93 percentage points, and decreases sustainable management by 11.23 percentage points.

Discussion

Significance and direction of social media’s effect varied across models. The probit regressions without controls showed significant positive correlations between social media use and all management types. Any and complex management had the most significant results in probit and PSM models with covariates included. Traditional and sustainable management still had positive effects from social media use, but these were only significant in the probit model. When internet access was included among the controls as a proxy for a preference for technology, any and complex management retained their large positive significance. The effects on traditional and sustainable management remained positive but were not significant for either probit or PSM. The bivariate probit model with IV and covariates, in contrast, did not produce any significant results, though effects were positive for all categories except complex. With internet included as a proxy in the bivariate probit IV model, complex management had a significant positive effect, higher than any of the other categories.

The lack of significance in the two-stage models could suggest a lack of relationship between social media use and pasture management practices, or indicate an inadequate choice of IV. Despite a high correlation in the first stages, municipal social media use might influence a household's decisions even if they do not use social media themselves. It is also possible that the lack of significance has to do with the nature of IV models. IV models tend to have higher standard errors because the use of an instrument does not perfectly predict the variable of interest. The real influence of social media could just be small, which makes it more difficult for coefficients to achieve significance when paired with higher errors.

The direction of the coefficients on the control variables is stable across estimations. Control results can be found in Appendix C. Average education tends to have a significant positive effect on complex management across estimations. Age significantly decreases traditional management across all estimations. Larger families decrease likelihood of complex management, but this effect is only sometimes significant. Experience significantly decreases complex management across all estimations, and in the bivariate probit model, increases traditional management. Program participation and more association memberships significantly increase complex management across most estimations. More memberships also significantly increases any management in some estimations. Extension contact significantly increases any management across all estimations, and, in the bivariate probit model, also sustainable. For all models, larger pastures significantly increase likelihood of all management types except traditional, while larger cattle herds significantly increase any and traditional management. Off-farm income significantly decreases likelihood of traditional management across estimations, and either any or sustainable management tend to have a significant positive effect depending on the model. Asset count has a positive effect for all categories across estimations, but sometimes the effect on traditional or sustainable is not significant. Internet access has a significant positive influence on complex management in the probit model, but not bivariate probit.

Some of the covariates that predicted the use of management also predict social media use, suggesting they may help control for the tendency to adopt any new technologies. Asset count, off-farm income, pasture area, extension contact, program membership, and education all positively correlated with adoption of social media and all kinds of management. Experience decreased the likelihood of social media use, while increasing the likelihood of using all management categories except complex. That these are included in both stages of the bivariate probit models suggests the tendency for the adoption of new technologies is controlled for.

Conclusion

Traditional pasture management practices in Brazil typically result in degraded pasture over time (de Oliveira Silva et al., 2017). Pasture degradation threatens the productivity of cattle farms, limiting the income and welfare of cattle farmers. Farmers must invest in restoring soil and pasture health, a costly periodic practice for smallholder farmers (de Oliveira Silva et al., 2017), or may resort to deforestation to expand productive land (Bowman et al., 2011). Avoiding degradation altogether may reduce the need for deforestation or costly pasture reinvigoration. Farmers may accomplish this by using non-traditional management practices to maintain productivity. However, since these practices require ongoing management rather than periodic interventions, farmers need more information on effective implementation. According to prior research, the most trusted information comes from other farmers who have experience with a given practice (Fisher et al., 2017; Martinez-García, Dorward, & Rehman, 2013). Whether a farmer can access and utilize such information depends on having a communication link with those other farmers.

ICT's allow farmers to exchange information over large physical distances. The widespread use of cell phones fulfills this need, and the newly popular social media provides an even more convenient communication pathway for detailed agricultural information (HootSuite, 2019). Social media also has the advantage of connecting farmers who do not know each other in person, expanding the potential for information exchange. Despite this potential, little research has investigated the influence social media use has on agricultural decisions, focusing mainly on direct-to-consumer marketing in developed countries (White et al., 2014; Engotoit, Kituyi, & Moya, 2016; Murphy, 2017; Davis, 2017).

I investigate whether social media use influences farmers in the state of Rondônia, Brazil to manage their pastures with sustainable or complex practices, instead of traditional degrading practices or none at all. Basic probit regressions estimates without covariates show a strong correlation between social media and all kinds of management, providing evidence that some relationship exists. This could be because farmers that use social media also have other characteristics that make them more likely to adopt new technology in general. In probit regressions and propensity score matching results that include covariates, all categories continue to show positive effects. However, only the positive effects on any and complex management are still significant. The endogeneity of technology adoption decisions may linger even with these controls, as farmers who adopt social media or management practices may have unobserved characteristics that influence any technology adoption, biasing effects upward. One solution is to include internet access as a proxy for an affinity for novelty or the adoption of new technology. The inclusion of internet access slightly decreases the effect of social media on all management categories, though the high significance on any and complex management persists. This is as expected, whether internet access accounts for affinity for technology or as a method for accessing social media.

Another method of addressing endogeneity bias is through IV. I estimate bivariate probit models using municipal rates of social media use as an instrument to predict social media use. These results show no significant results on any kind of management. With internet access added again as a proxy for affinity for technology, social media use has a significant positive effect on complex management. This instrument may not be totally exogenous, as farmers may be able to access information that originates on social media from a friend or neighbor who uses social media. If this is the case, I expect the bias on coefficients to be positive but small. The use of IV in general also produces larger standard errors, as the instrument reduces variation in the explanatory variable. This makes significance harder to achieve, especially if the true effect of social media on adoption is not large.

My findings suggest that social media may cause households to adopt complex management practices. This is likely due to the knowledge-intensive nature of complex management practices. Households receiving information from social media may be better able to access the detailed information that allows them to recognize the benefits of complex management and successfully implement such practices. This suggests social media is a relevant avenue for agricultural agencies to disseminate information on complex management practices and increase the likelihood of their adoption. However, the strong correlation between social media use and all management types means many households with high potential for adoption already use social media, so social media provides a convenient way for agencies to reach them. Sharing high quality information on social media may help these households adopt at lower cost and more efficiently, or they can share details they've learned from the adoption experience for agencies to pass along. That many extension agencies already have a presence on Facebook, Instagram, and sometimes Twitter implies agencies are aware of this opportunity. In addition to sharing information about upcoming demonstration days, project descriptions, and marketing, extension agencies could emphasize how specific technologies empirically affect production. In particular, programs like Balde Cheio (by EMBRAPA) and Rural Sustentavel that aim to facilitate sustainable and innovative technology transfer could utilize social media to more broadly share results from agricultural experiments on test farms.

Agricultural social media use remains an important area to investigate for understanding how improved information access can affect the productivity and welfare of smallholder farmers. My results suggest social media use increases the use of complex management practices, as expected, but with no significant effect on sustainable management. Further research could use different instrumental variables, such as smartphone ownership, to more accurately estimate social media use. Research into sustainable management should consider a broader variety of agricultural practices, such as management of water resources, sustainable agroforestry, and low-carbon emission practices, which meet Brazil's carbon and forest goals.

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Appendix A: Economic Theory of Adoption

I follow the assumptions of Agricultural Household Models (Singh, Squire & Strauss, 1986; Tambo & Wünscher, 2017). This framework describes agricultural households as both producers and consumers and assumes that farm households make decisions to maximize utility and profit together. Households maximize the utility function:

$$U = U(Y, C, F)$$

dependent on yield of agricultural products Y, consumption of other market goods C, and leisure time F. Yield depends on the farm's production function:

$$Y=Y(Q_{input}, L_a, X)$$

where Y is the farm's yield, Q_{input} is the quantity of inputs used (such as fertilizer), L_a is time spent on agricultural activities (hours of farm labor), and X is a set of other factors affecting production (such as farmland area and rainfall). Time is a limiting factor for production and utility:

$$T= F+A+L_w$$

where T is total time available and L_w is time spent on off-farm (waged) labor. Utility is also subject to a budget constraint:

$$P_cQ_c=PY - P_{input}Q_{input} + IL_w$$

where P_c is the set of prices of goods consumed, Qc is the quantity of goods consumed, P is the set of sale prices for agricultural products, Pi is the set of input costs, and I is off-farm income. The adoption of a technology adjusts these relationships by changing the cost of required inputs and altering the production function itself, which determines the farm's new revenues and profit available for purchasing goods.

Costs and benefits often take a financial form, but also include non-financial considerations. Financial costs include prices of inputs and financial benefits include income.

These affect a household's profit and ability to purchase more inputs, household necessities, convenience items, and other goods. Non-financial benefits include a reduced need for labor or time to achieve a given output level, and the avoidance of soil and pasture degradation. A farmer may also need to spend extra time learning how to use a technology, or a technology might make another farm task more difficult despite higher output. This may reduce the time available for off-farm waged labor or leisure.

Farmers may face costs and benefits of a technology at different times. Decision-makers tend to prioritize costs and benefits in the present over those experienced in the future. This is especially the case for poor households, who are more concerned with making enough to meet short-term needs such as sufficient food than increasing long-term profits (Lee, 2005). Often costs occur right away, when a farmer invests time and money into acquiring, installing, and learning how to use a new technology. Benefits such as a reduced need for labor may also occur quickly, but benefits like gradual cost savings can take time to add up enough to outweigh the initial costs. The more a decision-maker prefers the present, the more future costs and benefits are discounted and the less influence they have on utility. This can make technologies with early costs and late benefits appear to provide low utility, so they are not adopted. The discounting effect should be lower for farmers for whom the initial costs are a surmountable barrier. Farmers with enough income or wealth to cover the initial costs are more likely to consider later-accruing costs and benefits more heavily. Farmers with secure land tenure are more likely to care about long term costs and benefits since they can make alterations to their land at will, whereas farmers with short tenures or who rent are more concerned with what will help them produce in the short term. Farmers with credit access can take out loans to help cover costs, so they are not limited by short-term income, allowing them to discount future costs and benefits less.

The new technology may bear some risk or uncertainty that will deter a risk-averse household. With a risky technology, the household has a certain probability of achieving a higher utility, so a household may prefer to avoid the known chance of achieving a lower utility. The household may also have an uncertain probability, where they do not know the likelihood of achieving a higher utility from a new technology, and prefer to keep the certainty of their familiar existing practices. Farmers may attempt to mitigate risk by diversifying production methods so they do not rely on any particular one to succeed. Farmers can diversify income sources by working both on and off the farm for guaranteed waged labor in addition to production revenues, or by producing many kinds of agricultural products with a variety of production strategies.

Appendix B: Empirical Findings for Adoption

Existing research contains studies focusing on a wide range of technologies, from high yield seeds to storage techniques to water conservation strategies. While many factors theoretically could influence adoption of new technology, empirical studies present mixed, often correlational findings. An economic review by Foster & Rosenzweig (2010) found the adoption of new technologies correlates with schooling, larger farms, wealth, and neighbors' adoption, but the causality of these factors has been ambiguous. In the US, access to and quality of information, financial capacity, positive environmental attitudes, and being connected to agency or local networks of farmers or watershed groups have the largest impact on adoption of best management practices (Baumgart-Getz, Prokopy, & Floress, 2012). The factors expected to be influential here are grouped into categories of farm and household characteristics, financial capacity, and information sources.

Farm, Household, and Financial Characteristics

Higher overall financial resources and wealth should increase the likelihood of adopting a new technology as it implies a higher flexibility in decision-making and access to resources (Nowak, 1987). Many find this to be true across the literature (Baumgart-Getz, Prokopy, & Floress, 2012; Foster & Rosenzweig, 2010; Deressa et al., 2009; Bryan et al., 2009). Income is the main financial determinant. Higher household income correlates with adoption (Iheke & Nwaru, 2014). Off-farm income may increase or decrease adoption likelihood, as it contributes to overall financial capacity and also represents diversification of investment for risk mitigation. The differing empirical results reflect this. Winters, Crissman, and Espinosa (2004) found off-farm income was positively related to altering agricultural practices by providing extra financing for farm investments. Others found a negative relationship, possibly indicating that farmers with other jobs had less reliance on farm income, and less interest in investment in improving farming practices (Martinez-García, Dorward, & Rehman, 2013). Profitability is related to income for smallholder farmers and should increase a household's ability to afford the costs associated with a new technology. Turinawe, Mugisha, and Kabirizi (2012) and Howley, Donoghue, and Heanue (2012) both reported that the profitability of a dairy operation has a positive relationship with the decision to use a new technology. However, this correlation could also be explained as the use of technology increasing profitability.

While income represents funds a farm has immediate access to, credit poses an external financial aid that could assist technology adoption. As expected, access to credit typically correlates with adoption, likely because it enables investment in capital required for technologies (Deressa et al., 2009; Winters, Crissman, & Espinosa, 2004). Winters, Crissman, and Espinosa (2004) found credit access matters most in the short term to cover up-front costs of new technologies. Bryan et al. (2009) found credit access is more important for wealthier farmers, while Wossen et al. (2017) report credit access strengthens the effect of cooperatives on adoption. However, Adegbola and Gardebroek (2007) found that for farmers who received technology-related information from other farmers, credit access had a negative effect on adoption.

Farm size is expected to increase the likelihood of adoption because of the increased resources associated with size. Many studies confirm this when considering land area of farms, though reasoning varies (Adnan et al., 2019; Foster & Rosenzweig, 2010; Bravo-Monroy, Potts, Tzanopoulos, 2016; Nowak, 1987; Martinez-García, Dorward, & Rehman, 2013). El-Osta and Morehart (2002) measure size by number of cattle instead. They found that larger US dairy farms (up to 358 milking cows) were more likely to adopt capital-intensive technologies. The likelihood of adopting management-intensive technologies was highest for small (less than 129 cows) and very large operations, possibly because small dairies lacked capital and large dairies require efficient monitoring of their numerous cows. As beef and dairy farmers in Rondônia tend to be smallholders, this suggests they may be more likely to adopt management-intensive technologies than capital-intensive ones. Using the same study region as this paper, Caviglia-Harris (2003) considered both lot size and number of cattle owned. Number of cattle influenced adoption

Tenure is theoretically expected to aid adoption, as farmers have more decision-making power for land they own or have access to long-term (Nowak, 1987). But tenure is not important for all cases: Winters, Crissman, and Espinosa (2004) found that tenure was insignificant for farmers in Ecuador, as the mountainous terrain requires farmers to have multiple scattered plots. Tenure may be less relevant for Rondônian farmers, as they tend to operate on at least some owned land, and the survey asked about land they leased out, not whether they used rented land themselves.

A couple other farm and household characteristics might influence adoption in theory. Household size could influence farmers toward or against technology adoption. A larger household increases the labor available, decreasing the need for or increasing the ability to use a new technology. Farms closer to the market or urban center were more likely to adopt because of increased market access (Winters, Crissman, & Espinosa 2004).

The empirical findings for the effect of age on adoption is mixed. Adegbola and Gardebroek (2007) found older farmers were more likely to adopt new technologies, though this result was only significant for farmers informed by other farmers. They suggest that older farmers without extension contacts relied on their accumulated capital and availability of land to adopt technologies. Others show that farmers who are younger are generally more likely to adopt new technologies (Howley et al., 2012; Adnan et al., 2019; Deressa et al., 2009). Whether this relationship can be explained by generational differences in education, longer-term thinking by young farmers early in their career, or something else, is uncertain.

Most studies show formal education correlates with adoption (Iheke & Nwaru, 2014; Bravo-Monroy, Potts, Tzanopoulos, 2016; Deressa et al., 2009). The commonly accepted explanation is that higher levels of education improve the ability of farmers to access, accept, and understand new information (Elfitasari, Nugroho & Nugroho, 2018; Glendinning, Mahapatra, & Mitchell, 2001). Education may also be associated with a more "progressive" outlook that encourages consideration of new technologies (Glendinning, Mahapatra, & Mitchell, 2001). In contrast, Adegbola and Gardebroek (2007) report a negative effect of education on the adoption of a pesticide to protect stored corn. While it was only statistically significant for farmers informed by other farmers, they found no positive correlation for education in any of the farmers. In this case, educated farmers likely shared the perception that chemical insecticides tend to be toxic, and so refrained from adopting an improved pesticide.

Higher amounts of farming experience generally increases adoption (Adnan et al., 2019). One dairy study found this to be true for both management- and capital-intensive technologies (El-Osta & Morehart, 2002). Caviglia-Harris (2003) confirmed this relationship for sustainable agroforestry technologies as well. Caviglia-Harris suggests this is because more experienced farmers have access to more resources, and the longer a household operates a farm, the more motivated the farmers are to keep it sustainable enough to pass onto the next generation. However, in Winters, Crissman, and Espinosa's (2004) study, experience decreased adoption, possibly because more experience leads farmers to become set in their ways and less experimental.

Informational Factors

Assuming the technology is beneficial, farmers with easy access to quality information are more likely to adopt a technology (Baumgart-Getz, Prokopy, & Floress, 2012; Kassie et al., 2009). Historically, agricultural information access has taken the form of contact with extension agents, participation in agricultural programs, or contact with other farmers at cooperatives or unions, or in informal conversations.

Agricultural extension in various locations is frequently found to be an important beneficial means of sharing agricultural techniques and technologies with farmers (Iheke & Nwaru, 2014; Wossen et al., 2017; Baumgart-Getz et al., 2012; Wossen et al., 2013; Deressa et al., 2009; Álvarez & Romaní, 2017). This kind of information sharing typically involves an agent from a governmental or other agricultural agency visiting properties or holding meetings. The positive effect was stronger for poorer farmers (Bryan et al., 2009), and farmers who receive more frequent extension visits are more likely to adopt a new technology (Glendinning, Mahapatra, & Mitchell, 2001).

Extension is also often tied to promoting agricultural techniques through participation in a program. Winters, Crissman, and Espinosa (2004) found that conservation programs like PROMUSTA in Ecuador that alter the practices of the agricultural system for short-term profitability show lasting adoption and improvements to short-term income and soil quality. However, external selection of households by program and extension agents can bias estimates of impacts. In the PROMUSTA case, communities were chosen to receive program support based on specific criteria, including pre-existing community organization and low levels of migration. Because of the selection criteria, participants were also more likely to be members or leaders of several organizations, confirmed by the probit model (Winters, Crissman, & Espinosa, 2004). This makes it difficult to discern whether farmer characteristics or adoption behaviors are correlated meaningfully or causally with extension and program involvement.

Households that participate in one or more farmer cooperatives or associations are more likely to adopt a new technology (Iheke & Nwaru, 2014; Wossen et al., 2017; Bravo-Monroy, Potts, & Tzanopoulos, 2016; Cavigilia-Harris, 2003). Wossen et al. (2013) summarize that literature on cooperatives demonstrates a direct influence on adoption of innovations, lowering transaction cost barriers and improving market power. This occurs through access to credit, stable prices, and shared equipment provided by the cooperative organizations, eliminating the need for farmers to individually secure funds, customers, and necessary equipment. Caviglia-Harris (2003) demonstrates that not only are union and cooperative memberships important, but adoption is increasingly likely the more memberships a farmer has, supporting the importance of social network size and community involvement.

Appendix C: Further Tables of Results

Probit

Table 10: Probit results for social media's effect on pasture practices with covariates

	Any b/se	Traditional b/se	Sustainable b/se	Complex b/se
Main				
Social media use	0.2201***	0.1372*	0.2549**	0.2925***
	(0.07)	(0.07)	(0.11)	(0.09)
Asset count	0.0805***	0.0521*	0.0589**	0.0867**
	(0.02)	(0.03)	(0.03)	(0.04)
Off-farm income R$1k	0.0073*	-0.0020**	0.0027	0.0011
	(0.00)	(0.00)	(0.00)	(0.00)
Pasture area (ha.)	0.0023***	0.0004	0.0014***	0.0018***
	(0.00)	(0.00)	(0.00)	(0.00)
Heads of cattle (100s)	0.0574*	0.0396**	-0.0105	0.0207
	(0.03)	(0.02)	(0.01)	(0.03)
Extension contact	0.2486***	0.1542	0.0994	0.1279
	(0.09)	(0.15)	(0.06)	(0.10)
Assoc. memberships	0.1088*	0.1172	0.0021	0.1291**
	(0.06)	(0.09)	(0.05)	(0.06)
Program participation	0.2053	0.1922	0.1701	0.4948**
	(0.20)	(0.18)	(0.23)	(0.23)
Experience	0.0025	0.0043	0.0056	-0.0075**
	(0.00)	(0.00)	(0.00)	(0.00)
Household size	-0.0249	-0.0271	-0.0167	-0.0423**
	(0.02)	(0.02)	(0.03)	(0.02)
At least 1 head aged 60+	-0.0442	-0.3541***	0.1215	-0.1115
	(0.13)	(0.10)	(0.16)	(0.21)
Average education	0.0043	-0.0002	0.0133	0.0338**
	(0.02)	(0.01)	(0.01)	(0.02)
constant	-1.3905***	-1.5078***	-2.0082***	-2.3710***
	(0.13)	(0.24)	(0.25)	(0.38)
N	1082.0000	1082.0000	1082.0000	1082.0000

Errors clustered by municipality. SE in parentheses.
* $p < .10$, ** $p < .05$, *** $p < .01$

Table 11: Probit results for social media's effect on pasture practices with covariates

	Any	Traditional	Sustainable	Complex
Main				
Social media use	0.1621**	0.1120	0.2032	0.2205**
	(0.08)	(0.09)	(0.13)	(0.10)
Internet access	0.1292	0.0581	0.1104	0.1605*
	(0.09)	(0.09)	(0.12)	(0.09)
Asset count	0.0795***	0.0518*	0.0578**	0.0852**
	(0.02)	(0.03)	(0.03)	(0.04)
Off-farm income R$1k	0.0072*	-0.0020**	0.0027	0.0012
	(0.00)	(0.00)	(0.00)	(0.00)
Pasture area (ha.)	0.0023***	0.0004	0.0014***	0.0018***
	(0.00)	(0.00)	(0.00)	(0.00)
Heads of cattle (100s)	0.0571*	0.0395**	-0.0107	0.0208
	(0.03)	(0.02)	(0.01)	(0.03)
Extension contact	0.2460***	0.1519	0.0965	0.1241
	(0.09)	(0.15)	(0.07)	(0.10)
Assoc. memberships	0.1021	0.1143	-0.0027	0.1232**
	(0.06)	(0.09)	(0.05)	(0.06)
Program participation	0.2054	0.1925	0.1695	0.4978**
	(0.20)	(0.18)	(0.24)	(0.24)
Experience	0.0027	0.0044	0.0057	-0.0074**
	(0.00)	(0.00)	(0.00)	(0.00)
Household size	-0.0279	-0.0286	-0.0185	-0.0451**
	(0.02)	(0.02)	(0.03)	(0.02)
At least 1 head aged 60+	-0.0452	-0.3538***	0.1221	-0.1117
	(0.13)	(0.10)	(0.16)	(0.21)
Average education	0.0036	-0.0004	0.0125	0.0330**
	(0.02)	(0.01)	(0.01)	(0.02)
constant	-1.4174***	-1.5209***	-2.0292***	-2.4071***
	(0.13)	(0.23)	(0.25)	(0.39)
N	1081.0000	1081.0000	1081.0000	1081.0000

Internet used as a control for modernity and affinity for technology. Errors clustered by municipality. SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Propensity score estimation

Table 12 shows the probit results of the effects of each covariate in determining propensity scores for the first stage of propensity score matching.

Table 12: Estimation of propensity to use social media (first stage of PSM)

Social media use	Covariates only	Covariates + internet
Asset count	0.1064***	0.0695***
	(0.02)	(0.03)
Off-farm income R$1k	0.0098**	0.0084**
	(0.00)	(0.00)
Pasture area (ha.)	0.0012**	0.0009
	(0.00)	(0.00)
Heads of cattle (100s)	0.0093	0.0173
	(0.02)	(0.02)
Extension contact	0.1081	0.0928
	(0.09)	(0.10)
Assoc. memberships	0.0278	-0.0494
	(0.06)	(0.06)
Program participation	0.2161	0.2042
	(0.20)	(0.22)
Experience	-0.0124***	-0.0084**
	(0.00)	(0.00)
Household size	0.0073	-0.0233
	(0.02)	(0.02)
Both heads <60	0.0000	0.0000
	(.)	(.)
At least 1 head aged 60+	-0.3055**	-0.2865*
	(0.15)	(0.16)
Average education	0.0329**	0.0179
	(0.01)	(0.02)
Internet access		1.4563***
		(0.10)
Constant	-0.6874***	-1.1813***
	(0.23)	(0.26)
N	1080.0000	1079.0000

SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Full bivariate probit results

Table 13 shows the full bivariate probit results using municipal social media use as an IV for household social media use. Table 14 shows the full bivariate probit results including internet as a control.

Table 13: Bivariate probit results for social media's effect on pasture practices using IV

	Any	Traditional	Sustainable	Complex
Main				
Social media use	0.0562	0.3616	0.2749	-1.1263
	(1.32)	(1.30)	(0.89)	(1.91)
Asset count	0.0865*	0.0434	0.0582	0.1150***
	(0.05)	(0.07)	(0.04)	(0.04)
Off-farm income R$1k	0.0077*	-0.0021*	0.0026*	0.0017
	(0.00)	(0.00)	(0.00)	(0.00)
Pasture area (ha.)	0.0023***	0.0003	0.0014**	0.0020***
	(0.00)	(0.00)	(0.00)	(0.00)
Heads of cattle (100s)	0.0580*	0.0392**	-0.0106	0.0184
	(0.03)	(0.02)	(0.01)	(0.03)
Extension contact	0.2540***	0.1452	0.0988	0.1516
	(0.08)	(0.13)	(0.07)	(0.10)
Assoc. memberships	0.1103*	0.1142	0.0019	0.1217
	(0.07)	(0.10)	(0.06)	(0.08)
Program participation	0.2175	0.1744	0.1685	0.5065*
	(0.25)	(0.27)	(0.22)	(0.27)
Experience	0.0018	0.0053	0.0057	-0.0114**
	(0.01)	(0.01)	(0.01)	(0.00)
Household size	-0.0243	-0.0280	-0.0168	-0.0306
	(0.02)	(0.02)	(0.03)	(0.03)
At least 1 head aged 60+	-0.0627	-0.3283*	0.1238	-0.2233
	(0.17)	(0.17)	(0.20)	(0.24)
Average education	0.0060	-0.0029	0.0131	0.0412***
	(0.03)	(0.02)	(0.02)	(0.01)
Constant	-1.3431***	-1.5608***	-2.0137***	-1.4747
	(0.42)	(0.31)	(0.34)	(1.66)

Social media use				
% Municipal social media use	2.6075***	2.6212***	2.6050***	2.6531***
	(0.30)	(0.26)	(0.25)	(0.46)
Asset count	0.1035***	0.1034***	0.1033***	0.1026***
	(0.02)	(0.02)	(0.02)	(0.02)
Off-farm income R$1k	0.0089**	0.0086*	0.0088**	0.0080***
	(0.00)	(0.00)	(0.00)	(0.00)
Pasture area (ha.)	0.0012**	0.0012**	0.0012**	0.0011
	(0.00)	(0.00)	(0.00)	(0.00)
Heads of cattle (100s)	0.0064	0.0071	0.0065	0.0088
	(0.02)	(0.02)	(0.02)	(0.03)
Extension contact	0.1176	0.1192	0.1195	0.1062
	(0.07)	(0.07)	(0.08)	(0.08)
Assoc. memberships	0.0142	0.0154	0.0158	0.0113
	(0.05)	(0.05)	(0.05)	(0.06)
Program participation	0.2849*	0.2760**	0.2780**	0.3206***
	(0.15)	(0.13)	(0.13)	(0.12)
Experience	-0.0127***	-0.0127***	-0.0127***	-0.0121***
	(0.00)	(0.00)	(0.00)	(0.00)
Household size	0.0042	0.0046	0.0045	0.0030
	(0.03)	(0.03)	(0.02)	(0.02)
At least 1 head aged 60+	-0.3365**	-0.3305**	-0.3330**	-0.3523***
	(0.13)	(0.13)	(0.13)	(0.13)
Average education	0.0360***	0.0360***	0.0360***	0.0371***
	(0.01)	(0.01)	(0.01)	(0.01)
Constant	-2.2990***	-2.3080***	-2.2975***	-2.3203***
	(0.23)	(0.22)	(0.22)	(0.34)
/				
Athrho	0.1014	-0.1408	-0.0124	1.0305
	(0.81)	(0.83)	(0.55)	(2.11)
N	1082.0000	1082.0000	1082.0000	1082.0000

Municipal social media use used as IV. Errors clustered by municipality. SE in parentheses.
* $p < .10$, ** $p < .05$, *** $p < .01$

Table 14: Bivariate probit results for social media's effect on pasture practices using IV

	Any	Traditional	Sustainable	Complex
Main				
Social media use	0.1541	0.5296	-0.5705	1.2092**
	(1.92)	(0.68)	(1.07)	(0.51)
Internet access	0.1334	-0.1604	0.4936	-0.3681

	(0.95)	(0.34)	(0.53)	(0.27)
Asset count	0.0797*	0.0426	0.0690***	0.0545***
	(0.05)	(0.04)	(0.02)	(0.02)
Off-farm income R$1k	0.0072	-0.0022**	0.0035**	0.0007
	(0.00)	(0.00)	(0.00)	(0.00)
Pasture area (ha.)	0.0023**	0.0003	0.0015***	0.0014***
	(0.00)	(0.00)	(0.00)	(0.00)
Heads of cattle (100s)	0.0571*	0.0386**	-0.0087	0.0197
	(0.03)	(0.02)	(0.01)	(0.02)
Extension contact	0.2462***	0.1398	0.1058*	0.0907
	(0.07)	(0.14)	(0.06)	(0.10)
Assoc. memberships	0.1020	0.1175	-0.0104	0.1256**
	(0.07)	(0.09)	(0.05)	(0.05)
Program participation	0.2059	0.1657	0.2056	0.3894*
	(0.27)	(0.21)	(0.22)	(0.23)
Experience	0.0027	0.0054*	0.0036	-0.0042*
	(0.01)	(0.00)	(0.01)	(0.00)
Household size	-0.0279	-0.0257	-0.0216	-0.0349
	(0.02)	(0.02)	(0.03)	(0.03)
At least 1 head aged 60+	-0.0459	-0.3152***	0.0535	-0.0023
	(0.17)	(0.11)	(0.16)	(0.19)
Average education	0.0037	-0.0027	0.0150	0.0230
	(0.02)	(0.01)	(0.01)	(0.02)
Constant	-1.4165***	-1.5500***	-1.8196***	-2.2929***
	(0.27)	(0.24)	(0.54)	(0.23)
Social media use				
% Municipal social media use	1.9499***	1.9336***	1.9250***	1.5589*
	(0.61)	(0.48)	(0.57)	(0.83)
Internet access	1.4365***	1.4354***	1.4414***	1.4422***
	(0.10)	(0.10)	(0.09)	(0.09)
Asset count	0.0681***	0.0691***	0.0658***	0.0640***
	(0.02)	(0.02)	(0.02)	(0.02)
Off-farm income R$1k	0.0079**	0.0079***	0.0078***	0.0078***
	(0.00)	(0.00)	(0.00)	(0.00)
Pasture area (ha.)	0.0010*	0.0010*	0.0011*	0.0011**
	(0.00)	(0.00)	(0.00)	(0.00)
Heads of cattle (100s)	0.0152	0.0162	0.0119	0.0211
	(0.02)	(0.02)	(0.02)	(0.02)

Extension contact	0.1027	0.0996	0.0948	0.1097
	(0.07)	(0.08)	(0.07)	(0.07)
Assoc. memberships	-0.0556	-0.0560	-0.0620	-0.0370
	(0.06)	(0.06)	(0.06)	(0.06)
Program participation	0.2519	0.2479*	0.2664*	0.1873
	(0.17)	(0.14)	(0.16)	(0.16)
Experience	-0.0086*	-0.0087**	-0.0082*	-0.0087**
	(0.00)	(0.00)	(0.00)	(0.00)
Household size	-0.0257	-0.0259	-0.0281	-0.0259
	(0.03)	(0.03)	(0.03)	(0.03)
At least 1 head aged 60+	-0.3021***	-0.2835**	-0.3149**	-0.2496*
	(0.11)	(0.12)	(0.14)	(0.14)
Average education	0.0200	0.0192	0.0216	0.0163
	(0.01)	(0.01)	(0.01)	(0.01)
Constant	-2.3842***	-2.3736***	-2.3472***	-2.1113***
	(0.48)	(0.40)	(0.49)	(0.57)
/				
Athrho	0.0047	-0.2521	0.4698	-0.6975
	(1.12)	(0.44)	(0.70)	(0.51)
N	1081.0000	1081.0000	1081.0000	1081.0000

Municipal social media use used as IV. Internet included as a control. Errors clustered by municipality. SE in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$