Assessing Peer Effects and Subsidy Impacts in Technology Adoption: Application to Grazing Management Choice with Farm Survey Data

by Yuyuan Che, Hongli Feng, and David A. Hennessy

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Abstract

Rotational grazing provides environmental benefits and is believed by many to be profitable for most graziers. However, the average adoption rate among ranchers is just over 30 percent in the United States. Peer effects are increasingly recognized as an important driver of technology adoption. We develop a model to identify how peer networking affects grazing practice adoption decisions, and also the impacts of subsidies on equilibrium decisions in the aggregate. With farm-level survey data, we apply a simultaneous-equations model to take account of endogeneity issues with peer effects that are measured as the number of adopters a rancher knows or the extent of adoption in a rancher's neighborhood. Empirical analysis provides evidence that there are significant peer effects in the adoption of rotational grazing. This implies that incentive policies will have multiplier effects in the long run on adoption through the peer networking route.

Keywords: Adoption decision, environmental outcomes, infrastructure costs, labor, peer effects, rotational grazing, subsidy

JEL Codes: D91, Q16, Q18, Q57

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Introduction

Rangelands and pastures cover a large proportion of the earth's land, provide important biodiversity reservoirs, and are major sources of income in some rural areas (Crawford et al. 2019). However, grazing especially at high densities can have adverse environmental impacts, including rangeland degradation, forage quality and quantity reductions, and desertification (Steinfeld et al. 2006; Alkemade et al. 2013). Rotational grazing can address many of these concerns and provide multiple potential private benefits (Teague et al. 2009; Jakoby et al. 2015; Searchinger et al. 2018; Park, Ale and Teague 2017). Many government and nongovernmental agencies promote rotational grazing, the adoption of which could require costly investments in additional fencing, water supply infrastructure, and labor inputs. Despite potential benefits and various efforts, the adoption rate of rotational grazing is still low. Therefore, understanding the factors that influence rotational grazing adoption decisions is of major importance to policymakers.

Social interactions have been shown to be important for technology adoption in a variety of contexts, including high-yield seed varieties (Foster and Rosenzweig 1995), a new crop of sunflower (Bandiera and Rasul 2006), new technologies for pineapple production (Conley and Udry 2010), solar photovoltaic panels (Bollinger and Gillingham 2012), and groundwater extraction for agricultural irrigation (Sampson and Perry 2019). Social learning plays different roles among different technologies and many potentially constructive policies that can be used to facilitate peer effects have been proposed. Kolady et al. (2020) find that spatial peer effects are important in the adoption of conservation tillage and diverse crop rotation, but the magnitude of peer effects is not large. With respect to rotational grazing, some studies on dairy farming find that peer effects serve as drivers of system transformation from traditional management to rotational grazing (Nelson et al. 2014; Manson et al. 2016). Others reveal that there is only weak statistical evidence of a social effect on rotational grazing adoption (Baerenklau 2005). However, rigorous theoretical and empirical analysis of the relationship between peer effects and individual decisions to adopt rotational grazing is very limited in the literature.

Separate from peer effects, some studies have also examined subsidies' impacts on the adoption of new technologies or products through the channel of social learning. For example, Dupas (2014) use data from a two-stage randomized pricing experiment of a new antimalarial bed net in Kenya to estimate the effects of one-off subsidies on demand. Evidence is provided that the subsidies have large, increasing effects on the short-run level of adoption, and also that these short-run subsidies have an economically large and statistically significant effect on the long-run adoption through learning effects where information about the product diffuses through spatial networks. Carter, Laajaj, and Yang (2019) study randomized controlled trials of a government-implemented input subsidy program (ISP) in Africa. They find that a once-off input subsidy coupled to chemical fertilizer and improved seeds purchase for Mozambican maize farmers promotes Green Revolution technology adoption, and the subsidy effects persist after subsidies have been removed. These effects are attributed to direct and social learning effects, where spillovers from subsidized farmers to their social networks are observed such that agricultural contacts of subsidized farmers also see increases in technology adoption. Cai, de Janvry, and Sadoulet (2020) apply data from a two-year pricing experiment on the impact of a subsidy on weather insurance take-up. They provide evidence that the social effect of observing payouts in farmers' networks promotes insurance participation among those who are uninsured.

In this paper, we investigate whether and to what extent peer effects may affect the adoption of rotational grazing on the U.S. Great Plains and how subsidies affect adoption when there are peer effects. Peer effects arise when the returns for an individual rancher to adopting rotational grazing are influenced by his or her peers' adoption decisions. There are multiple mechanisms through which peer effects may affect the returns to adopting rotational grazing. One possibility is learning; for example, ranchers likely differ in their knowledge about rotational grazing technology and also in the private costs and benefits of adoption. As more knowledgeable ranchers adopt rotational grazing, other ranchers in their peer networks will learn about detailed operation skills that reduce the potential technology-related costs, or about cost and benefit information that will reduce the uncertainty surrounding a novel technology.

To identify peer effects, we first develop a theoretical framework that depicts how graziers decide on a grazing practice, and also whether and how they develop a social network to learn about a new technology, rotational grazing in this paper. In our model, we assume that ranchers can pursue networking to learn information about rotational grazing from adopters which will produce networking costs and reduce potential technology-related costs. We investigate how each rancher's adoption decision is affected by other ranchers' choices through learning information in their peer network. Then we use a survey sample of 874 beef producers on the Great Plains to examine peer effects. Methodologically, we apply a simultaneous equations model (SEM) due to Maddala (1983) to estimate the interaction effects between ranchers' adoption decisions and peer networking. We apply two kinds of peer networking indicators. One, the number of adopters that each rancher personally knows, measures personal contacts. The other, the estimated percentage of adopters among ranchers in the neighborhood who are within a 20-mile radius of a rancher's property, measures geographic proximity.

Overall, we find strong evidence that peer effects influence ranchers' decisions to adopt rotational grazing, while potential adopters are more willing to network with other adopters and know more information about rotational grazing. Subsidies will promote rotational grazing adoption through peer networking. To be specific, the probability of rotational grazing adoption increases by 0.09 after knowing one additional peer adopter; while the probability of adoption increases by 0.023 when perceiving a 1% increase in the neighborhood adoption. If the one-time subsidy increases by one dollar per acre, then the probability of adopting low-intensity rotational grazing will increase by 0.008; similarly, the probability of adopting management intensive grazing will increase by 0.003. In addition, we also find evidence that perceived additional labor inputs is an important barrier to adoption, which suggests that cost-sharing programs will be more effective if they are also used to alleviate concerns about labor requirements than to offset initial setup costs.

Our paper contributes to the literature in the following ways. First, our theoretical model considers that individuals make technology adoption decisions and actively pursue networking simultaneously. We apply a simultaneous equations model to address these two endogenous decisions of technology adoption and adopter network choices. Most previous work has only studied adoption decisions and has applied linear-in-mean methods to identify peer effects but may induce the so-called "reflection problem" (Manski 1993).[4] Second, our finding that social learning can encourage rotational grazing adoption contributes to the literature on social learning and technology adoption (Foster and Rosenzweig 1995; Bandiera and Rasul 2006; Conley and Udry 2010; Bollinger and Gillingham 2012; Sampson and Perry 2019). Third, we contribute to the literature on the short-run and long-run effects of subsidies and social learning (Dupas 2014; Carter, Laajaj and Yang 2019; Cai, de Janvry and Sadoulet 2020) by showing that subsidies have a multiplier effect on rotational grazing adoption through peer networking. Finally, our work

[4] "Reflection problem" refers to that the average behavior in a group affects the behavior of the individuals within the group and vice versa (Manski 1993).

provides significant insights for policy makers who may be able to leverage peer effects when seeking to promote the adoption of new technologies (Graziano and Gillingham 2015; Sampson and Perry 2019). Understanding how peer effects contribute to conservation practice adoption can help promote the efficient design of policies aimed at obtaining the greatest environmental benefits when managing scarce resources.

In the next section, we provide background on rotational grazing practices and review the factors known to influence adoption decisions. Following that, we provide a comprehensive review of the existing literature on peer effects in technology adoption in the general agricultural sector and as applied in the adoption of grazing practices. We then set up a conceptual framework and identify hypotheses related to rotational grazing adoption decisions. After that, we describe the survey and other data that we analyze and the variables that we construct. In our estimation section, we apply a simultaneous equations model to examine peer effects and subsidy impacts on rotational grazing adoption. After reporting and analyzing the estimation results, we conclude with a brief summary as well as some comments on policy implications and peer effects research.

Background on Rotational Grazing Practice

Different grazing strategies have evolved or been developed (e.g., continuous, rest rotation, and short duration), each with different grass productivity potential and ecological consequences (Roche et al. 2015; Hawkins 2017; Crawford et al. 2019; Windh et al. 2019; Derner et al. 2021). At one extreme is continuous grazing, where a herd is put on one grassland tract for the entire grazing season. Alternatively, under rotational grazing the land is partitioned into a number of paddocks and the herd is rotated over these paddocks during the season. To be specific, under low-intensity rotational grazing (RG), the number of paddocks is relatively small and the herd remains on a paddock for weeks or months before moving to the next. When a large number of paddocks are involved, usually 20 or more, and cattle are moved more frequently, usually every 1 to 7 days, the strategy is referred to as management intensive grazing (MIG) (Undersander et al. 2002).

The potential private and social benefits derived from rotational grazing are multi-faceted. Rotational grazing presents the animals with more uniform, succulent grass and forces them to be less picky whereas animals grazing extensively congregate near shade and water. Damaged, erosion-prone patches where invasive weed and insect species can enter are prevented with more intensively grazed strategies. Under MIG grass can extend its root system deeper during the resting phase, ensuring greater drought resilience while parasite cycles are interrupted when animals are absent during critical stages. In Brazilian beef cattle grazing, production per unit land has been shown to increase with an increase in grazing intensity so that nutrient inputs and greenhouse gas (GHG) emissions per unit production decline (Searchinger et al. 2018). Some research also concludes that rotational grazing strategies can potentially provide both higher profit from ranching (Teague et al. 2009; Jakoby et al. 2015) and mitigate concerns about erosion, runoff, GHG emissions, and grassland ecosystem habits loss (Park et al. 2017).

United States Federal government agencies promote rotational grazing. For example, in 2015, the U.S. Department of Agriculture (USDA) adapted components of the Conservation Reserve Program to support working grasslands, including more intensive grazing, through rental payments and cost-sharing subsidies for fencing and watering infrastructure. Despite the potential benefits and despite various efforts aimed at promoting adoption, the most recent U.S. Census of Agriculture data reveals that the adoption rate of rotational grazing was low (about

33.8%) in 2017 (USDA, 2017). Investigating the reasons behind this phenomenon and developing a better understanding of the mechanisms underlying ranchers' grazing strategy adoption decisions are important in light of the environmental concerns listed above and the need for viable grassland agriculture infrastructure to support ranching activity in the area.

Many researchers have studied the factors that affect ranchers' grazing adoption decisions. Additional potential costs of implementing a rotational grazing system are an important constraint, including infrastructural costs and labor costs (Gillespie et al. 2008; Windh et al. 2019; Wang et al. 2020). Compared to continuous grazing, implementing a rotational grazing strategy requires additional expenses in terms of one-time installation expenses and reoccurring maintenance costs. Windh et al. (2019) identify three major cost components, namely fencing infrastructure, water infrastructure, and labor costs, for five grazing management scenarios: i) continuous grazing on one large pasture; rotational grazing with either ii) permanent cross-fencing or iii) temporary electric fencing; iv) continuous grazing with non-contiguous pastures; or v) rotational grazing with non-contiguous pastures. Their study ecosystem is shortgrass steppe, the primary site being the USDA-Agricultural Research Service's Central Plains Experimental Range (CPER) located near Nunn, Colorado. They find that fencing infrastructure costs are the largest component for all five scenarios, accounting for between 69% and 83% of total adoption costs. Gillespie et al. (2008) also identify the main disadvantages of rotational grazing, which include initial capital expenditures and greater investment risks. When assessing the two grazing strategies at comparable stocking rates in Louisiana, they find that fixed expenses per acre including depreciation and interest on machinery and equipment are $23.41 greater for rotational grazing with eight paddocks than for continuous grazing.

There is no consensus, however, concerning labor cost differences between continuous and rotational grazing. For example, Gillespie et al. (2008) analyze a data set using a time and motion study method to determine labor requirements for different grazing strategies in the U.S. Gulf Coast region. They find that rotational grazing systems are more time-intensive than continuous grazing systems due to the additional time required to move livestock among pastures and to maintain the additional infrastructure. By contrast, Windh et al. (2019) calculate the labor costs for both rotational grazing and continuous grazing scenarios. They find that rotational grazing scenarios require approximately 10 hours of additional labor over the grazing season from mid-May to early October to move cattle among pastures with the same total acreage of 3,200 acres, but total labor for rotational grazing remains less than for continuous grazing, due to the shorter checking times associated with smaller pasture area.

A Literature Review on the Peer Effects in Technology Adoption in Agriculture and Rotational Grazing Choices

Theories of social learning indicate that the sign of the relationship between peer effects and technology adoption is ambiguous. Peer effects may hinder the adoption of a technology. The rationale for this ‘holding back’ motive is that it is more beneficial to defer the adoption until many associates have already adopted because they can provide valuable information on the technology’s merits in general and also for a specific operation. On the other hand, the motivation for adopting early may be to gain large profits early if the technology works out. In addition, if the technology works and many people adopt then output prices may fall and late adopters may not achieve as much additional profit as do early adopters.

There are different ways to measure and model peer effects in agricultural technology adoption. One approach to measuring peer effects is based on an individual’s set of close contacts. For example, Granovetter (1985) finds that social ties between farmers and their family and friends are considered strong in the sense that they are long-term, embody mutual trust and reciprocity, and are not easily undone. Foster and Rosenzweig (1995) provide evidence that close contacts are most important for providing information on high-yield seed variety adoption in rural India. Bandiera and Rasul (2006) present evidence on how farmers' decisions to adopt a new crop, sunflower, relate to adoption choices among their network of family and friends in Zambezia Province, Northern Mozambique. They use the number of adopters among the farmer's self-reported network of family and friends as a proxy for social networks. They then apply an estimation strategy that allows for a nonlinear relationship between the probability of adoption and the number of adopters in the network. The inverse-U shaped relationship they find suggests that peer effects are positive when there are few adopters in the network, and negative when there are many.

The empirical literature on social learning has also defined networks based on geographical or cultural proximity (Bertrand, Luttmer and Mullainathan 2000; Munshi and Myaux 2002). In the agricultural context, Munshi (2004) finds that wheat growers place relatively more weight on their neighbors' past acreage allocations and yield realizations than on their own past decisions. Conley and Udry (2010) investigate the role of social learning in the diffusion of new agricultural technology for pineapple production in Ghana's Akwapim South District. The detailed information they collect on who individuals know and talk to about farming is used to define each individual's information neighborhood. In finding evidence that farmers adjust their inputs to align with those of their information neighbors who were surprisingly successful in the previous periods, their work provides further support for social learning in agricultural technology adoption. Strong evidence has also been provided that peer effects influence farmers' decisions to adopt groundwater irrigation. Using a rich dataset on groundwater rights for the period 1943-2014 and a nearest neighbor peer group definition, Sampson and Perry (2019) conclude that one additional neighbor adopting groundwater for irrigation increases the groundwater extraction probability by an average of 0.25 percentage points.

Few studies have addressed peer effects in the adoption of grazing strategies, and most of these are related to dairy farming. Peer effects in some of these studies are measured based on geographical proximity. For example, Baerenklau (2005) considers three mutually exclusive groups of networks among that study's sample farmers, namely in the northern, south-west, and east parts of Wisconsin. The research applies farm-level panel data covering 1996-2000 from 34 Wisconsin dairy farmers to examine the importance of behavioral drivers in rotational grazing adoption. They discern only weak statistical evidence of a peer group effect and the economic significance of this effect also appears to be small. These results suggest that targeting incentives at early adopters in certain areas may not be a very effective approach.

Other papers regarding grazing strategies focus on both measurements of social networking, i.e., close contacts, and geographical or cultural groups. Nelson et al. (2014) conduct 53 interviews with confined herd, low-intensity, and rotational grazing dairy producers as well as 35 interviews with associated network actors in Wisconsin, Pennsylvania, and New York. They find that information exchanges among neighbors and local grazing groups have some influence on how the initial decision on rotational grazing is arrived at. They also conclude that information exchanges or cost-sharing supports from agricultural or natural resource agencies play an important role as drivers of system transformation from traditional management to rotational grazing within the region's dairy production sector. The results indicate that more diverse networks between graziers and government agencies or other institutions will be needed to promote rotational grazing.

Manson et al. (2016) develop a stylized model of peer effects in dairy farming using 53 farms in the same three states as Nelson et al. (2014). While they find that peer effects are important for rotational grazing adoption, the effects differ depending on how farmers are connected with other people. For example, being in a formal organization or being well known to one another through personal relationships promotes adoption. They also find that rotational grazing adoption depends on different aspects of the social landscape, including the number of dairy households, the probability that neighboring farmers share strong network relationships, and how networks are formed geospatially. These findings suggest that initiatives aimed at strengthening various kinds of social networks among ranchers are important for promoting rotational grazing. For example, farmers are more likely to convert to rotational grazing if they get active encouragement from a trusted person, an extension agent or a familiar state actor with a long-term relationship who provides support for those making the transition, or extension agencies and university researchers who can support the formation of peer-learning networks.

Our paper contributes to the literature on peer effects by applying two kinds of indicators for peer networking: one is the number of rotational grazing adopters that each rancher personally knows, which belongs to the above-mentioned class of close contact metrics; the other is ranchers' perceived adoption rate in the neighborhood, which belongs to the class of geographical or cultural proximity metrics. These two measurements provide an integrated perspective for evaluating peer effects on rotational grazing adoption.

Conceptual Framework and Hypotheses

This section describes a theoretical framework that will be subsequently used to guide the empirical estimations. The framework focuses on how ranchers make decisions related to grazing practices and social networking. We begin by assuming that profit under extensive grazing (i.e., continuous grazing) is simplified as

(1) $$\pi_i^{\text{ext}} = pq - l_i^{\text{ext}} - c,$$

where p equals beef price, q equals beef quantity output, l_i^{ext} equals *i*th farm tract-specific labor requirements under extensive grazing, and c equals other costs, including for water and fencing.

On the other hand, profit under intensive grazing (i.e., rotational grazing) is

(2) $$\pi_i^{\text{int}} = pq(1+\delta) - l_i^{\text{ext}} - \hat{l}_i - c + s - \min_{e_i}\{Fh(e_i) + C(e_i, m, \theta_i)\},$$

where $\delta > 0$ represents productivity gain under intensive grazing, since the decision is trivial whenever rotational grazing does not improve productivity ($\delta \leq 0$) but requires additional costs compared to extensive grazing. The term $\hat{l}_i$ represents the *i*th farm additional labor requirements under intensive grazing, a detail that admits heterogeneity in relation to labor intensity and farm conditions. The term s is a subsidy associated with adopting intensive grazing; the case without government subsidy is represented by $s = 0$. The expression $Fh(e_i) > 0$ equals costs associated with the rotational grazing technology where $h(0) = 1$. Here $e_i \geq 0$ refers to adopter network size, so that $h(e_i) \in (0,1]$ is a decreasing function of adopter network size, i.e., $h'(e_i) \leq 0$. The quantity $F = Fh(0) > 0$ denotes the scale of fixed costs needed to adopt intensive grazing for the socially isolated grazier. Thus, $Fh(e_i)$ implies that the costs associated with rotational grazing decrease as a farmer's network size increases. The networking cost is represented by the continuous and appropriately differentiable function $C(e_i; m, \theta_i)$ which is held to be increasing and convex in adopter network size. Further, $m \in [0,1]$, the share of ranchers adopting the technology in the rancher's local region is assumed to reduce networking costs because opportunities to network with adopters are more readily available. Parameter θ_i represents rancher and ranch characteristics. These characteristics can be ordered so that higher values of θ_i reduce the cost of networking, $\partial C(\cdot) / \partial \theta_i \leq 0$. We will also assume that they reduce the marginal cost of networking, $\partial^2 C(\cdot) / \partial e_i \partial \theta_i \leq 0$.

Social networking can have different effects and the effects may differ at different stages of novel technology adoption and diffusion. According to Xiong et al. (2016), the main conduit for social network effects at the early stage is through information acquisition whereas experience effects and externality effects are most important at intermediate stages and maturity stages, respectively. Information effects refer to an individual is informed about the new technology and obtain basic information including the suitability of the technology from their peers, be they adopters or non-adopters. Experience effects refer to when an individual obtains knowledge and resources from peers who are current users, and so will help to reduce technological costs of adoption and to mitigate uncertainty. Externality effects occur when an individual is forced to decide whether to adopt the technology by peer pressure that is not directly related to the new technology's profitability (Xiong et al. 2016). While it is likely that networking will, to some extent, impose all three types of effects at all stages of adoption and innovation. Identifying the predominant effects of different stages facilitates analysis.[5]

In our case, rotational grazing adoption and diffusion seem to be most appropriately characterized as being at the intermediate stage, with an average adoption rate of just over 30%

[5] A separate but closely issue is that of production network costs, typically due to agglomeration economies that may not have to do with learning. See Cowan and Gunby (1996), Roe, Irwin and Sharp (2002), Holmes and Lee (2012), and Arora et al. (2021).

in the United States. Thus, we focus on the experience effects, assuming that the motive for peer networking in our case is to learn more information about rotational grazing practice and reduce the adoption cost.[6] Thus the adopter chooses $\min_{e_i} Fh(e_i) + C(e_i, m, \theta_i)$, with the first-order condition $Fh'(e_i) + C_{e_i}(e_i, m, \theta_i) = 0$, to obtain optimal adopter network size $e_i^*(\cdot)$ where $h'(e_i^*) \leq 0$ and $C_{e_i}(e_i^*, m, \theta_i) \geq 0$. A corner solution exists, i.e., $e_i^*(\cdot) = 0$ whenever $-Fh'(\cdot) < C_{e_i}(\cdot)$ for $e_i = 0$. It is readily shown that $de_i^*(\cdot)/dm \geq 0$ whenever $d^2C(\cdot)/de_i dm \leq 0$ and $de_i^*(\cdot)/d\theta_i \geq 0$ whenever $d^2C(\cdot)/de_i d\theta_i \leq 0$. Writing $J(F, m, \theta_i) \equiv \min_{e_i} Fh(e_i) + C(e_i, m, \theta_i)$, the envelope theorem implies that $J(F, m, \theta_i)$ is increasing in the first argument and decreasing in the other two. The adopter's profit function can be re-written as

(3) $$\pi_i^{\text{int}} = pq(1+\delta) - l_i^{\text{ext}} - \hat{l}_i - c - J(F, m, \theta_i) + s.$$

Here the positive decreasing function $J(F, m, \theta_i)$ characterizes network economies obtained from being able to learn about the intensive grazing technology from other adopters in the local region. This network spillover could alternatively have been included as a benefit in increasing revenue but the effect would be essentially the same.

We turn now to understanding how ranchers' adoption choices and network decisions respond to a change in the (privately) exogenous characteristics such as θ_i and m. With a higher value of θ_i, the optimal adopter network size $e_i^*(F, m, \theta_i)$ will increase. Also the sum of technological costs and networking costs $J(F, m, \theta_i)$ will decrease, which will increase the probability of adopting rotational grazing. Thus, the optimal adopter network size and the

[6] We could posit that the experience effects occur after a rancher has learned from early networking whether rotational grazing is likely to be suitable for the ranch. Other ranchers have decided that rotational grazing is not suitable for their farm and so will not make further networking efforts. Thus, the network size in our analytical framework is additional to such early network size. This is consistent with our empirical data where network size exceeds zero for some non-adopters.

rotational grazing adoption probability change in the same direction as the change in θ_i. Similar effects occur when there is an increase in the share of adopters in the local region, *m*. Therefore, we come to the following hypothesis:

Hypothesis 1: *The probability of adopting intensive grazing and the choice of adopter network size are positively associated with each other.*

However, it is hard to justify any causality between the two endogenous decisions: intensive grazing adoption and network size. That is, we simply cannot claim that intensive grazing adoption causes larger optimal network size or the other way around as both of these are endogenous decisions. In our empirical section, we apply a simultaneous-equations model to account for this endogeneity issue.

Rancher utility from extensive grazing is given as the sum of an idiosyncratic term, η_i^{ext}, and profit, π_i^{ext}. Similarly, producer utility from intensive grazing is given as the sum of an idiosyncratic term, η_i^{int}, and profit, π_i^{int}. These terms are held to follow extreme value distributions and the producer is assumed to make the choice that maximizes expected utility:

(4) $$\max[\eta_i^{\text{ext}} + pq - l_i^{\text{ext}} - c, \eta_i^{\text{int}} + pq(1+\delta) - l_i^{\text{ext}} - \hat{l}_i - c - J(F, m, \theta_i) + s].$$

Following standard arguments (McFadden 1974) the probability that tract i is intensively grazed is then

(5) $$\Pr(\text{int}) = \frac{e^{\lambda\times[pq(1+\delta) - l_i^{\text{ext}} - \hat{l}_i - c - J(F,m,\theta_i) + s]}}{e^{\lambda\times[pq(1+\delta) - l_i^{\text{ext}} - \hat{l}_i - c - J(F,m,\theta_i) + s]} + e^{\lambda\times[pq - l_i^{\text{ext}} - c]}} = \frac{e^{\lambda\times[pq\delta - \hat{l}_i - J(F,m,\theta_i) + s]}}{e^{\lambda\times[pq\delta - \hat{l}_i - J(F,m,\theta_i) + s]} + 1};$$

where λ is a positive constant which reflects the smoothing that arises from integrating over random variables in (4). In equilibrium, it will be the case that $\Pr(\text{int}) = m$ and so

(6) $$m = \frac{e^{\lambda\times[pq\delta - \hat{l}_i - J(F,m,\theta_i) + s]}}{e^{\lambda\times[pq\delta - \hat{l}_i - J(F,m,\theta_i) + s]} + 1}.$$

Figure 1 illustrates two possible shapes of equation (6) where more than one solution is shown. Differentiation and then use of relation (6) above provides

(7) $$\frac{dm}{ds} = \frac{\lambda m(1-m)}{1+\lambda J_m(F,m,\theta_i)m(1-m)}.$$

The effect of a change in labor requirement differential, $d\hat{l}_i$, on equilibrium share will of course be of the same magnitude but opposite in direction.

Three further comments are warranted regarding (7). One is that the derivative is small in value whenever the share is either very small or very large, $m \approx 0$ or $m \approx 1$. To be specific, after dividing both numerator and denominator by $m(1-m)$, the equation (7) becomes

$\frac{dm}{ds} = \frac{\lambda}{\frac{1}{m(1-m)} + \lambda J_m(F,m,\theta_i)}$, which is closer to zero whenever $1/[m(1-m)]$ goes to infinity with $m \approx 0$ or $m \approx 1$. This is because then the profit differential is so large, in one direction or the other, that the subsidy is unlikely to sway any producers. Either intensive grazing is so uncompetitive that the subsidy has little impact on adoption or intensive grazing is so competitive that all are adopting and here too the subsidy has no impacts on adoption.

The second comment is that the extent of these positive network effects depends on the marginality of the adoption decision, through $m(1-m)$, on smoothing induced by idiosyncratic factors as represented by λ, and also on the sensitivity of profits to adoption as represented by $J_m(F,m,\theta_i)$. Expression $m(1-m)$ is largest when $m = 0.5$ and the median grazier encounters equal profits, $\pi_i^{\text{ext}} = \pi_i^{\text{int}}$. Notice here too that $m(1-m)$ provides the inverse U shape discussed in Bandiera and Rasul (2006). That is, leaving $J_m(\cdot)$ aside, $\text{sign}\{dm/ds\}$ inherits the inverse U shape.

The final comment is that, assuming $\lambda J_m(F, m, \theta_i) m(1-m) > -1$, the responsiveness to subsidy exceeds $\lambda m(1-m)$ which would be responsiveness were there no network effect on adoption cost. Turning to adopter network size, we may write

$$\text{(8)} \qquad \frac{de_i^*(F, m(s), \theta_i)}{ds} = \frac{de_i^*(F, m(s), \theta_i)}{dm}\frac{dm}{ds} = \frac{de_i^*(F, m(s), \theta_i)}{dm}\frac{\lambda m(1-m)}{1+\lambda J_m(F, m, \theta_i) m(1-m)} \geq 0,$$

and so we have

Hypothesis 2: *With a subsidy for intensive grazing, a rancher will choose a larger adopter network size and is more likely to adopt intensive grazing.*

Expression (7) may be written as

$$\text{(9)} \qquad \frac{dm}{ds} = \lambda m(1-m)\left\{1 + z + z^2 + \quad ... \quad \right\}; \qquad z = -\lambda J_m(F, m, \theta_i) m(1-m) > 0.$$

The polynomial terms $z + z^2 + \quad ...$ represent network feedback effects whereby subsidy-induced adoption in the region induces further adoption by increasing practice profitability. Given the above, it is noteworthy that the presence of positive network spillovers provides a rationale for a subsidy. The theory of supermodular games establishes that all Nash equilibria in choice settings such as ours will be below the value that maximizes each grower's payoff, see Theorem 7 in Milgrom and Roberts (1990). Thus, and assuming that there are no other external effects such as similar complementarities for choosing extensive grazing, the sum of grower payoffs will increase with a subsidy. This inference is separate from the ecological impacts unaccounted for in grower objective functions that would arise from increased adoption.

Based on these remarks, we have the following hypothesis:

Hypothesis 3: *Subsidies have a multiplier effect on intensive grazing adoption through peer networking.*

As previously mentioned, we will apply a simultaneous-equations model to examine the above hypotheses. Before that, however, we will describe the data and data context that will be used.

Survey Data Description

Survey Basic Information

To better understand rotational grazing strategies and ranchers' adoption decision mechanism, we sent out a survey to beef operators in 49 counties in North Dakota and 58 counties in South Dakota as well as 81 counties in Central and North Texas in early 2018. The screening criterion for rancher selection was that each respondent operated at least 100 non-feedlot cattle.[7] We purchased contact information for 4,500 randomly selected ranchers in three states from Survey Sampling International.[8] The survey was implemented by following the Dillman mail survey administration method (Dillman, Smyth and Christian 2014). During the period from late January 2018 to early April 2018, we sent out an advance letter of notification, two survey questionnaire mailings, and two postcard reminders. In late June 2018, a final survey packet was re-sent to secure a higher response rate. A total of 874 recipients completed and returned the survey questionnaires. The overall response rate was 20.6%, with state-level response rates of 16.5% in North Dakota, 22.4% in South Dakota, and 22.9% in Texas. Among all the respondents, the average sum of native rangeland and improved pasture acreage was about 2,800, and the average number of cattle per respondent was 364. The percentage of respondents' total household income from ranching operation was typically between 20% and 40%. The mail survey also requested detailed information on ranch operation, ranch management practices and

7 To account for the differences in the number of qualified ranches in each county, we used proportional sampling to select 1,500 ranches in each state. The sample size for each county is obtained from multiplying 1,500 by a ratio, the ratio being the number of qualified farms for each county over the total number of qualified farms across each state's selected counties (Wang et al., 2020).
8 As of July 2021, the company is now part of Dynata. https://www.dynata.com/press/announcing-new-name-and-brand-research-now-ssi-is-now-dynata/.

land use, as well as information on adoption status, peer networking, perceptions about the infrastructure costs and labor inputs, and rancher characteristics. Below we describe parts of the survey and the variables to be used in our empirical analysis.

Adoption Status and Decisions

The survey provides ranchers' adoption information at both extensive (whether to adopt) and intensive (the number of pastures per group of animals to choose) margins. At the extensive margin, the questionnaire asked survey participants about grazing practices on their owned and rented lands. We define a rancher as an adopter if the rancher was currently practicing rotational grazing; otherwise, the rancher was a non-adopter. A discrete choice variable is set to represent each rancher's adoption status. It equals one whenever the rancher was an adopter and zero otherwise. Among 874 ranchers in the sample, 59% were currently practicing rotational grazing, and 41% never adopted or had discontinued its practice. The distribution of surveyed adopters can be found in Figure 2. The adoption rate in the sample exceeded the 2017 average adoption rate (33%) among the three states of North Dakota, South Dakota and Texas (USDA NASS, 2017). To test for basic differences among adopters (n=520) and non-adopters (n=354), we compared rangeland and pasture acreage and beef cattle numbers among these two groups. On average, native rangeland and improved pasture acreage were 3,082 and 2,396 for adopters and non-adopters, respectively, which is statistically different (t=-1.897, p=0.058). The average number of cattle were 381 and 240 for adopters and non-adopters, respectively (t=-1.090, p=0.276).

At the intensive margin, adopters were queried about their current and desired number of pastures per group of animals on the ranch, and were given five-choice options (1='no more than

5’, 2=‘6-11’, 3=‘12-18’, 4=‘19-30’ and 5=‘more than 30’). The last four categories are combined. Among adopters 45.8% reported having no more than 5 pastures per group of animals on the ranch. Similarly, we also aggregated into two categories the desired number of pastures reported by adopters. On average the desired number of pastures exceeded the current number, indicating that adopters are more likely to choose higher intensity levels in the future.

For non-adopters, we further analyze their willingness to adopt rotational grazing at both extensive (whether they are likely to adopt) and intensive (the ideal number of pastures per group of animals in the future) margins. At the extensive margin, non-adopters were asked about the likelihood of adopting RG or MIG in the next five years. They were also asked whether they would adopt RG or MIG if a one-time subsidy were provided, the subsidy level alternatives being $10/acre, $30/acre, 50/acre and $70/acre. At the intensive margin, non-adopters were asked to provide the number of pastures per group of animals that they thought as ideal for future adoption and were, as with adopters, given five options. Compared with adopters, the distribution of non-adopters’ intensity level choices tended to be lower.

Peer Networking

We have two indicators for adopter network size, one being ‘number of adopters known’, and the other is ‘perceived neighborhood adoption’. The survey provided two corresponding sets of questions. One was “how many ranchers do you personally know who have already adopted RG or MIG?” with four options (1= ‘none (0)’, 2=‘some (1-5)’, 3=‘quite a few (6-12)’ and 4=‘many (>12)’); the other was “in your best estimation, what percentage of all ranchers within a 20-mile radius of your property use RG or MIG?", with five options (1='nobody (0%)', 2='some (1-20%)', 3='quite a few (20-40%)', 4='many (>40%)', and 5='have no clue').[9]

Our survey also listed five information sources that might affect their rotational grazing decision-making, these being government agencies (such as NRCS), associations (such as Grassland Coalition, Society for Range Management), university extension, independent consultants, and other ranchers. Respondents were asked to assess the importance of the above information sources by indicating five levels (1='not important', 2='slightly important', 3='somewhat important', 4='quite important', 5='very important'). From National Agricultural Statistics Service (USDA NASS, 2017), we also collected county-level data on rotational grazing share in cattle, goat, and sheep operations.

Infrastructure Costs and Labor Costs

Compared to continuous grazing, implementing a rotational grazing strategy requires additional expenses for infrastructure and labor. 'Initial cost' refers to the estimated initial investment costs in $/acre for both fencing and water systems, and five categories were provided for responses, namely 1='less than $10', 2='$10-$25', 3='$26-$40', 4='$41-$70' and 5='more than $70'.[10] 'Labor' refers to the effects of rotational grazing adoption on labor and management time needed to operate the ranch. Five response alternatives were provided: 1='significantly decreased', 2='slightly decreased', 3='no influence', 4='slightly increased' and 5='significantly increased.'

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[9] Respondents who choose ='have no clue' are dropped when we analyze peer networking. We use the mean value of each category to generate a continuous variable for each of two adopter network size indicators.

[10] For initial costs, only non-adopters were required to choose among the five options. Adopters were asked to report the exact values of initial costs. To be consist, we converted the continuous variables of adopters into five discrete categories.

Rancher and Ranch Characteristics

In order to understand the factors influencing adoption decisions, variables that describe rancher and ranch characteristics will be included in our estimations. ‘Operating years’ and ‘education’ depict rancher characteristics, where ‘operating years’ refers to the number of years a rancher has been the primary operator on any part of her or his current farm or ranch. ‘Education’ refers to the highest level of completed education, which is categorized using five discrete values with 1=‘less than high school’, 2=‘high school’, 3=‘some college/technical school’, 4=‘4-year college degree’, 5=‘advanced degree.’

Variables that describe ranch characteristics include ‘internal fences’ (a dummy indicator for whether the ranch has some internal or cross fencing), ‘ranch size’ (the total number of cows and replacement heifers), ‘distance’ (the estimated distance in miles from a rancher’s home to her or his largest tract of grazing land), and ‘ranching income.’ ‘Ranching income’ refers to the approximate percentage of total household income that comes from ranching operations, and is categorized using 1=‘less than 20%’, 2= ‘20% up to 40%’, 3=‘40 up to 60%’, 4= ‘60% up to 80%’ and 5=‘80% or more.’ In addition, we purchased each respondent’s exact farm address from SSI, which allowed us to collate survey information with public domain data (e.g., land quality in the vicinity).

We collected land capability classification (LCC) and slope variables from the United States Department of Agriculture Natural Resource Conservation Service SSURGO database. LCC ascription is based on the severity of limitations for crop production, which is used to proxy soil quality. Classes I and II soils have few limitations and are typically cropped intensively while Class III soils have moderate limitations for crop production. Class IV soils are very marginal for crop production while Class V–VIII soils are seldom cropped. The ‘LCC I&II’

variable denotes the share of all land that has LCC equal to I or II (and so productive under crop production) within 1-mile of the ranch's location. A 1-mile radius is chosen because we would like to appropriately indicate the extent of productive land in the ranch's vicinity. Similarly, the variable 'Slope less than 3%' refers to the share of the area within a 1-mile radius that has a slope no greater than 3%. This variable is also used as a proxy for better quality land in that such land is easier to manage and is less prone to erosion under intensive use. The description and definitions of the above-mentioned variables can be found in Table 1.

Empirical Methods

Identifying Peer Effects

One key issue about peer effects identification by the existing literature is that clustering behavior among individuals in the same group can stem from one or both among impacts due to peers' characteristics (exogenous or contextual effects) or impacts due to peers' outcomes (endogenous effects) (Manski 1993). Exogenous or contextual effects refer to similar behavior among individuals in the same group due to the exogenous characteristics of the group. Examples in our grazing practice adoption context include similarities in soil characteristics and climate. Endogenous effects refer to the interactions through which an individual's behavior is causally affected by the behavior of others in the same group. These effects may arise through learning information from peers. For example, a rancher may obtain information from another ranching friend that reveals something about the costs and benefits of rotational grazing. In this paper, we are interested in endogenous effects, and especially through the learning information channel.

Distinguishing between endogenous effects and contextual effects may be difficult because of simultaneity in behavior among interacting individuals, which is also referred to as the "reflection problem" (Manski 1993). To be specific, the average behavior in a group affects the behavior of the individuals within the group and vice versa. In our case, this problem is of little significance in several respects. First, our conceptual framework describes a rancher who decides to choose a grazing practice and actively pursues networking simultaneously. To address this simultaneity, we apply SEM that is captured in equations (10) – (12) to be discussed in detail. We take the average adoption rate in a large geographic unit as exogenous, and our estimations test interactive effects between adoption and the network, which is different from the reflection problem in which individuals behave interactively within the same group.[11]

Second, the influence of an individual's decision to adopt rotational grazing is likely to only be felt through a lag due to the time needed to complete fencing and water infrastructure. We follow the recent literature and assume that an individual's networking information may depend on the "installed base" of adoption decision within the group (Bollinger and Gillingham 2012; Sampson and Perry 2019). The installed base is the cumulative adoption up to the previous calendar year and is taken as being exogenous.

Third, many recent studies reveal that the identification of peer effects depends on the network's structure, and endogenous peer effects can be identified under intransitivity, when peers' peers are not peers (Bramoullé, Djebbari and Fortin 2009; Bramoullé, Djebbari and Fortin 2020). We do not assume that individuals interact in groups as in the linear-in-means model by Manski. Our surveyed ranchers are not partitioned into some closed groups in which individuals

[11] The network effects modeled in our analysis are similar to the "indirect network effect" as defined by Rysman (2019). The key feature of the indirect network effect is that the utility from adopting depends on the existence of intermediate goods or the amount of intermediate goods in the network, but does not depend directly on the group mean adoption rate or other distributional measures of group adoption. The number of adopters a rancher knows, and the extent of adoption in a rancher's neighborhood measure indirect network effects as they are not group mean but are affected by group mean.

are affected by all others in their group and by none outside of it.

Finally, our data on peer information indicators are self-reported, which is related to "motivated beliefs" (Bénabou 2015) that investigate how and why "people believe what they want to believe" (Epley and Gilovich 2016) in the extensive economics and psychology literature. Our SEM approach can capture the possibility that an adopter is more likely to network with other adopters, and also that a rancher's self-reported extent of adoption in personal contacts or neighborhood can be affected by the rancher's views and choices.

Simultaneous Equations Model

Following our conceptual framework, the main objectives pursued in empirical modeling are to examine how ranchers make decisions about choosing grazing practices and also adopter network size as well as how subsidies affect decision processes. To be specific, we examine four questions: (1) how ranchers' adoption decisions respond to peer networking and vice versa when no subsidies are provided; (2) with a hypothetical subsidy, how non-adopters' willingness to adopt rotational grazing responds to peer networking and vice versa, and also the effects of subsidy; (3) at the intensive margin, whether ranchers' choices are affected by peer networking, i.e., whether peer networking affects the choice between RG and MIG; (4) how other factors (including initial costs and labor requirement) affect ranchers' above-described decisions.

Our conceptual framework implies that adoption decisions would more properly be viewed as jointly or simultaneously determined with adopter network size choices, rather than being treated as exogenous. If we apply a single logit or probit equation to examine the factors that influence adoption with the network indicators as independent variables, then a non-zero covariance between the disturbance term and the independent variables exists. To correct for this simultaneity bias, a simultaneous equations model (SEM) (Maddala 1983) is used here to examine the factors affecting rotational grazing adoption. The two endogenous variables are adoption decision and the networking effort choice, where the first of these endogenous variables is binary. The SEM is applied as below:[12]

(10) $$A_i^* = \beta_0 + \beta_1 e_i + \beta_2 X_i + \beta_3 s_i + \varepsilon_1 ,$$

(11) $$e_i = \gamma_0 + \gamma_1 A_i^* + \gamma_2 m_i + \varepsilon_2 ,$$

(12) $$A_i = \begin{cases} 1 \text{ whenever } A_i^* > 0 \\ 0 \text{ otherwise} \end{cases} ,$$

where A_i is a dichotomous variable indicating a rancher's adoption decision (i.e., whether a rancher has adopted rotational grazing, or whether a non-adopter will be likely to adopt it in the future with a subsidy, or whether a rancher chooses a high intensity level), and A_i^* is the associated latent variable. The peer network indicator is given as e_i, and s_i is a one-time subsidy. The share of rotational grazing operations in the total number of cattle, goat, and sheep operations within each respondent's county is given as m_i, and all the other influencing factors are denoted as X_i. For easy references, all variables have been described in Table 1. The parameters β_0, β_1, β_2, β_3, γ_0, γ_1, and γ_2 are to be estimated, while ε_1 and ε_2 are the error terms.

Inserting (11) into (10), we obtain:

(13) $$A_i^* = \frac{\beta_0 + \beta_1\gamma_0}{1-\beta_1\gamma_1} + \frac{\beta_1\gamma_2}{1-\beta_1\gamma_1} m_i + \frac{\beta_2}{1-\beta_1\gamma_1} X_i + \frac{\beta_3}{1-\beta_1\gamma_1} s_i + \frac{1}{1-\beta_1\gamma_1}(\varepsilon_1 + \beta_1\varepsilon_2) ,$$

which reveals that peer effects may involve a multiplier on subsidy under some conditions.

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[12] This corresponds to Maddala's (1983, pp. 244-245) model 3.

Response to subsidy changes from β_3 to $\beta_3 / (1-\beta_1\gamma_1)$. Therefore, the subsidy will have a greater impact given feedback mediated through peer networking whenever $\beta_1\gamma_1 \in (0,1)$.

In the equilibrium outcome, it will be the case the weighted sum of adoption decision A_i among all the ranchers in the county should equal to average adoption rate m_i. The subsidy impacts on the adoption rate in the equilibrium can be derived from equations (10)-(11), which is connected to our theoretical framework. However, data inavailability places limits on the empirical analysis; for example, we do not know the peer networking structure among our surveyed ranchers and whether ranchers' peers are included in our sample. It is also difficult to obtain all the ranchers' responses in each county. Although our empirical approach does not quantify the subsidy's impacts on the equilibrium, it provides insights on how the subsidy affects ranchers' adoption and adopter network size choices in the decision process.

The SEM is a two-stage estimation procedure in which the first step is to eliminate that part of the endogenous variable that is correlated with the disturbance terms. This stage involves regressing the adoption and network variables on exogenous variables to arrive at predicted values. In the second stage, these predictions are then used to compute the maximum likelihood estimates of the explanatory variables.

To estimate the system (10)-(12), the reduced form equations are

(14) $A_i^* = \pi_1' Z_i + \upsilon_1$,

(15) $e_i = \pi_2' Z_i + \upsilon_2$,

where π_1' and π_2' are parameter vectors to be estimated, while υ_1 and υ_2 are error terms. The term Z_i is a matrix of all the exogenous variables in (10) and (11), which includes county-level adoption rate m_i and all variables in X_i (i.e., initial infrastructure costs, labor costs, operating years, education level, percentage of total household income from ranching operation, the existence of internal fences, ranch size, distance from home to ranch, and land quality). The choice of these variables as exogeneous is mainly based on Feder et al. (1985) who extensively review factors affecting agricultural technology adoption. They identify the following variables as major determinants of adoption: labor availability, capital, farm size, off-farm income sources, tenure, supply constraints and prices of agricultural outputs and inputs. Because A_i^* is not observed, we can only estimate π_1' / σ_1, where $\sigma_1^2 = \mathrm{Var}(\upsilon_1)$. Hence, we have

(16) $$A_i^{**} = \frac{A_i^*}{\sigma_1} = \frac{\pi_1'}{\sigma_1} Z_i + \frac{\upsilon_1}{\sigma_1} = \pi_1^{*\prime} Z_i + \upsilon_1^* .$$

In the first stage, we estimate equation (15) by OLS to obtain $\hat{\pi}_2'$ and $\hat{e}_i$, and also estimate equation (16) using maximum likelihood estimation by probit method to obtain $\hat{\pi}_1^{*\prime}$ and $\hat{A}_i^{**}$. In the second stage, we estimate equation (17) below by using maximum likelihood estimation on a probit specification, and we estimate equation (18) by OLS:

(17) $$A_i^{**} = \frac{\beta_1}{\sigma_1} \hat{e}_i + \frac{\beta_2}{\sigma_1} X_i + \frac{\beta_3}{\sigma_1} s_i + \frac{\varepsilon_1}{\sigma_1} ,$$

(18) $$e_i = \gamma_1 \sigma_1 \hat{A}_i^{**} + \gamma_2 m_i + \varepsilon_2 .$$

The above two-stage estimation procedure follows the broad approach given in Maddala (1983) and Keshk (2003).

Results and Discussions

Summary Information about Adopters and Non-adopters

Table 2 provides adoption variable and explanatory variable descriptive statistics for both adopters and non-adopters. At the extensive margin, the adoption rate in our sample is 59% with

520 adopters and 354 non-adopters. Among non-adopters, 36% (13%, respectively) reported being likely to adopt RG (MIG, respectively) in the next five years. At the intensive margin, the average desirable intensity level (the number of desired pastures per group of animals on the ranch) exceeds the current level among adopters, which may be caused by limiting ranch conditions. For non-adopters, the ideal intensity level (55% at > five pastures) in the future approximately equals the adopters' average current level (54% at > five pastures).

Lack of information is one potential barrier to adoption for many ranchers. Among our surveyed respondents 37.7% of non-adopters and 22.9% of adopters reported 'lack of information' to be 'some challenge, 'quite a challenge, or a 'great challenge.' Several potential information sources can provide information about rotational grazing, including government agencies, associations, university extension, and independent consultants. Mean response values in Table 3 show that adopters ranked all sources as more important than non-adopters, which suggests that adopters were willing to expand their social network to obtain information. Moreover, the two most important sources are government agencies and other ranchers. To be specific, 40.7% of adopters and 30% of non-adopters reported government agencies as 'quite important' or 'very important'; while 36.1% of adopters and 28.7 of non-adopters considered other ranchers to be 'quite important' or 'very important.'

Although rotational grazing usually requires additional infrastructure costs including fencing and water as well as labor requirement, adopters and non-adopters have different opinions about initial costs and labor inputs. The average initial investment costs reported by adopters were about '$26-$40' per acre, while non-adopters perceived slightly higher initial costs compared to adopters. Adopters reported that the effect of rotational grazing on labor and management time was between 'significantly decreased' and 'slightly decreased', while non-adopters thought rotational grazing needed more labor than adopters.

Peer Effects and Adoption Decisions

Table 4 presents SEM estimation results for adoption decisions and peer networking without subsidies. Columns 1 and 2 present results with the number of adopters that each rancher knows as the peer networking indicator where Column 2 does not control for ranch and rancher characteristics. Columns 3 and 4 present results with perceived neighborhood adoption rate as the peer networking indicator where, as with column 2, column 4 does not control for ranch and rancher characteristics. Looking across specifications, our results demonstrate robust evidence of peer effects in the adoption of rotational grazing with two indicators. Table 5 presents the corresponding marginal effects and standard errors. For example, controlling for rancher and ranch characteristics, the effect of knowing one additional adopter increases the probability of adoption by 0.09. Also the effect of perceiving a 1% increase in neighborhood adoption increases the probability of adoption by 0.023.

Results in the lower part of Table 4 also show that adopters know more friends and neighbors who adopt and are more willing to network. By learning more information about rotational grazing technology and management techniques, adopters will likely improve grazing performance and reduce adoption costs. The positive coefficients on adoption also indicate that a rancher’s self-reported estimate of practice prevalence in her/his close contact or neighborhood is affected by the rancher’s own choices. Moreover, the coefficients on lagged county-mean adoption rate in the previous year are positive and statistically significant across all four specifications, which indicates that greater adoption rates in the geographic unit will provide more opportunities for ranchers to network with adopters.

In addition, Table 4 also shows that rotational grazing adoption is discouraged by greater labor requirements and also restricted by small ranch size. Rotational grazing may require more time inputs to move livestock among pastures and to maintain additional infrastructure compared to continuous grazing (Gillespie et al. 2008), so ranchers are less likely to adopt it when they perceive these additional labor requirements. With regard to the positive coefficients on ranch size, ranchers grazing a larger number of animals are more likely to adopt rotational grazing probably because fixed costs can be spread over more cattle units. On the other hand, greater ranch sizes are associated with greater initial investment costs when implementing rotational grazing, which is reflected in the positive coefficient on initial costs in column 2, where operator characteristics have not been controlled for.

Peer Effects and Subsidy Impacts on Adoption Decisions among Non-adopters

In order to promote rotational grazing adoption, it is important to directly understand how non-adopters' arrive at their decisions. Tables 6 and 7 present estimation results and marginal effects for non-adopters' willingness to adopt rotational grazing when given a hypothetical one-time subsidy. Our results provide evidence of peer effects in the willingness to adopt RG among non-adopters, but no evidence to support peer effects in the MIG adoption decision.[13] This indicates that peer networking affects non-adopters' willingness to adopt general rotational grazing, but does not influence the further choice of intensity level (i.e., shifting from RG to MIG). The potential reason might be that ranchers refer to information from other adopters when making initial decisions on whether to adopt rotational grazing, but subsequent technical choices about intensity levels will depend on their own operational experience.

[13] Most non-adopters did not know many MIG adopters, for example, about 86% of non-adopters knew no MIG adopters and 84% of them thought nobody adopted MIG in their neighborhood.

However, a one-time subsidy plays an important role in promoting RG and MIG adoption. If the one-time subsidy increases by one dollar per acre then the probability of adopting RG increases by 0.008; similarly, the probability of adopting MIG increases by 0.003. One advantage of a one-time subsidy is that ranchers have the flexibility to recompense both initial infrastructure costs and labor costs since column 2 in Table 6 also shows that these additional costs discourage RG adoption. Therefore, as indicated in Figure 1, subsidies will have a multiplier effect on rotational grazing adoption through peer effect feedbacks. To be specific, subsidies can attract some non-adopters to adopt rotational grazing and the resulting peer network will induce further adoption.

Land quality is also an important factor that affects non-adopters' willingness to adopt RG. If land quality is poor, then a non-adopter is more willing to adopt RG. This willingness to adopt might be motivated by the positive ecological effects of rotational grazing, which allows each divided pasture a longer recovery period and thus protect against land degradation. In addition, evidence among non-adopters shows that ranch size is important for RG adoption, perhaps because of scale effects. Wang et al. (2018) have recently reported that the relative benefits of rotational grazing over continuous grazing may be limited for small farms (Wang et al. 2018).

Adoption Decisions at Intensive Margin

Table 8 presents estimation results for intensity choices among ranchers. These choices include whether adopters currently have or desire to have greater than five pastures per group of animals on the ranch and whether non-adopters want to have greater than five pastures per group of animals in the future. There is no evidence of peer effects in the intensity choices, and ranchers' intensity choices do not depend on the number of adopters among their personal contacts or adoption rate in the neighborhood. Neither are other variables found to have much impact.

Conclusion and Further Discussions

Adopting technologies that can protect public resources, is an important topic in the economics literature with direct policy implications. This is especially the case given that some important conservation technologies, including rotational grazing, seem to have adoption rates that are much lower than is desirable for society. This paper seeks to better understand how peer effects and subsidies affect rotational grazing adoption. We develop a theoretical model of grazing practice adoption by assuming that ranchers actively pursue information through peer networking. In doing so we show how subsidies can have a multiplier effect on rotational grazing adoption through indirect peer effects. With farm-level survey data, we apply a simultaneous-equations model to take account of endogeneity issues with peer effects that are measured by two indicators, based on personal close contact and geographic proximity.

Our findings contribute to technology adoption literature by highlighting the importance of peer effects and subsidy impacts in rotational grazing adoption. First, we provide evidence that peer effects promote rotational grazing adoption. Our work adds to the agricultural technology adoption research of Bandiera and Rasul (2006) for a new crop of sunflower, Conley and Udry (2010) for new technologies for pineapple production, and Sampson and Perry (2019) for groundwater rights in that we use a relatively large survey sample, utilize two kinds of peer networking indicators and consider the interaction relationship between adoption decision and networking. Second, our results show that subsidies will have long-run multiplier effects on adoption mediated through the peer networking route. This result provides support for the generality of the findings in Dupas (2014) regarding a new antimalarial bed net and in Carter, Laajaj, and Yang (2019) regarding Green Revolution technology adoption in Mozambique.

Our peer networking estimates have policy importance beyond just documenting the existence of peer effects and subsidy multiplier effects. A strand of the existing literature argues that many approaches can be taken to promote the adoption of novel technologies through managing peer effects (Baerenklau 2005; Bandiera and Rasul 2006; Bollinger and Gillingham 2012; Singh et al. 2018; Kolady et al. 2020). The findings on peer effects and subsidy impacts are especially relevant for policy makers who apply incentive programs such as cost-sharing to encourage voluntary adoption of agricultural conservation practices. Peer effects can provide insights into increasing the efficiency of incentive policies aimed at improving environmental quality through conservation technologies (Baerenklau 2005). For example, policy makers can apply area-targeted policies to promote rotational grazing, i.e., incentive subsidies can be reduced apropriately in areas with higher adoption rates by using the potential power of peer effects so that supportive resources can be concentrated in areas with lower adoption rates.

In addition to government agencies, our surveyed ranchers reported other ranchers, university extension, and associations as important information resources that affected their rotational grazing adoption decisions. University extension could distribute the existing knowledge about the costs and benefits of rotational grazing through ranchers' peer networks. Conservation associations could take some efforts to compensate ranchers who participate in rotational grazing research and education in a manner similar to information provision at solar photovoltaic panel demonstration sites (Bollinger and Gillingham 2012) and cover crop field days (Singh et al. 2018). Our findings also suggest that efforts to leverage peer effects might be most effectively targeted at ranchers with larger ranch scales and a greater number of beef cattle, but of course this approach may conflict with access, inclusion and other policy goals. Overall, governmental and non-governmental agencies could devise a mix of targeted policies, programs, and outreach efforts to scale up the adoption of rotational grazing by utilizing peer effects.

Concerning how to identify peer effects on technology adoption this paper provides insights into theoretical modeling by including network economies, and into empirical methods by addressing the endogeneity issue. However, more efforts should be taken to conduct a comprehensive study of peer effects. One set of matters is the specific nature of peer effects and how they may change over time. Xiong et al. (2016) decompose peer effects into information transmission, experience sharing, and externality effects.. Our current analysis focuses on the experience effects through which experiential knowledge and resources from earlier adopters matter most. Further analysis could explore the dynamic trajectory of peer networking and also investigate how externality effects will influence ranchers' adoption decisions, which may promote or discourage adoption (Xiong et al. 2016).

A further, and very ambitious, topic is to seek for the mechanisms behind peer effects. Our analysis assumes that peer effects occur when people learn information from other adopters and thus technology-related costs will be reduced. However, we do not know the roles that conformity, complementarities, risk sharing, and other motives may play in giving rise to peer effects. Understanding the mechanism behind peer effects is likely to provide insights into policy designs that will promote technology adoption. Progress has been made progress in this regard through structural estimation of theoretical models (Banerjee et al. 2013) and through well-designed experiments (Beugnot et al. 2019; Breza and Chandrasekhar 2019).

Perhaps most important as future research issues are to establish why graziers express limited interest in adoption and whether subsidies to encourage adoption would improve social welfare. These two questions are of course connected because unmeasured costs may be important deterrents to adoption and these costs will enter any social welfare calculation. We have not addressed either question because in each case further information is required.

The survey we conducted did query ranchers about the nature of constraints that they faced in the adoption decision (Che, Feng and Hennessy 2021), but did not request the sort of information that would be required to understand the shadow price of these constraints. That work pointed in particular to capital constraints as an impediment to practice adoption. However, given the detailed nature of the problem and the distinctiveness of each farming operation, a more personalized data gathering endeavor is needed. Doidge, Hennessy and Feng (2020) conducted focus group meetings for landowners in the same general area, along the James River east of the Missouri River in North and South Dakota, to collect data on private costs and benefits of converting grassland to cropland. Intensive data collection endeavors to cost impediments to embracing rotational grazing might best focus on costing out water availability, fencing costs and credit constraints.

The most problematic aspect of addressing whether subsidies directed at encouraging more intensive grazing would improve social welfare is addressing the nature and extent of environmental benefits likely to accrue as a result. A comprehensive accounting of these benefits would be a large-scale endeavor, accounting for local ecosystem effects, water quality consequences right through to lake and ocean levels, and greenhouse gas emission consequences. In addition, indirect land use effects may arise to the extent that the subsidies encourage grass-based agriculture instead of crop-based agriculture.

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Reference

Alkemade, R., R.S. Reid, M. van den Berg, J. de Leeuw, and M. Jeuken. 2013. Assessing the Impacts of Livestock Production on Biodiversity in Rangeland Ecosystems. *Proceedings of the National Academy of Sciences* 110 (52): 20900–20905.

Arora, G., H. Feng, D.A. Hennessy, C.R. Loesch, and S. Kvas. 2021. The Impact of Production Network Economies on Spatially-Contiguous Conservation–Theoretical Model with Evidence from the US Prairie Pothole Region. *Journal of Environmental Economics and Management* 107: 102442.

Baerenklau, K.A. 2005. Toward an Understanding of Technology Adoption: Risk, Learning, and Neighborhood Effects. *Land Economics* 81 (1): 1–19.

Bandiera, O., and I. Rasul. 2006. Social Networks and Technology Adoption in Northern Mozambique. *The Economic Journal* 116 (514): 869–902.

Banerjee, A., A.G. Chandrasekhar, E. Duflo, and M.O. Jackson. 2013. The Diffusion of Microfinance. *Science* 341 (6144): 1236498–1236498.

Bénabou, R. 2015. The Economics of Motivated Beliefs. *Revue d'Économie Politique* 125 (5): 665–685.

Bertrand, M., E.F. Luttmer, and S. Mullainathan. 2000. Network effects and welfare cultures. *The Quarterly Journal of Economics* 115 (3): 1019–1055.

Beugnot, J., B. Fortin, G. Lacroix, and M.C. Villeval. 2019. Gender and Peer Effects on Performance in Social Networks. *European Economic Review* 113: 207–224.

Bollinger, B., and K. Gillingham. 2012. Peer Effects in the Diffusion of Solar Photovoltaic Panels. *Marketing Science* 31 (6): 900–912.

Bramoullé, Y., H. Djebbari, and B. Fortin. 2009. Identification of Peer Effects through Social Networks. *Journal of Econometrics* 150 (1): 41–55.

Bramoullé, Y., H. Djebbari, and B. Fortin. 2020. Peer Effects in Networks: A Survey. *Annual Review of Economics* 12 (1): 603–629.

Breza, E., and A.G. Chandrasekhar. 2019. Social Networks, Reputation, and Commitment: Evidence From a Savings Monitors Experiment. *Econometrica* 87 (1): 175–216.

Cai, J., A. de Janvry, and E. Sadoulet. 2020. Subsidy Policies and Insurance Demand. *American Economic Review* 110 (8): 2422–2453.

Carter, M., R. Laajaj, and D. Yang. 2019. Subsidies and the African Green Revolution: Direct Effects and Social Network Spillovers of Randomized Input Subsidies in Mozambique. No. w26208, National Bureau of Economic Research. Available at: http://www.nber.org/papers/w26208.pdf [Accessed November 1, 2020].

Che, Y., H. Feng, and D.A. Hennessy. 2021. *Grazing Practice Choices, Capital Constraints, and the Environment.* Selected Paper for Lightning Session Presentation at AAEA Annual Meeting, Austin, TX, Aug. 1-3, 2021.

Conley, T.G., and C.R. Udry. 2010. Learning about a New Technology: Pineapple in Ghana. *American Economic Review* 100 (1): 35–69.

Cowan, R., and P. Gunby, P.1996. Sprayed to Death: Path Dependence, Lock-in and Pest Control Strategies. *The Economic Journal* 106(436): 521-542.

Crawford, C.L., Z.M. Volenec, M. Sisanya, R. Kibet, and D.I. Rubenstein. 2019. Behavioral and Ecological Implications of Bunched, Rotational Cattle Grazing in East African Savanna Ecosystem. *Rangeland Ecology & Management* 72 (1): 204–209.

Derner, J.D., D.J. Augustine, D.D. Briske, H. Wilmer, L.M. Porensky, M.E. Fernández-Giménez, D.E. Peck, and J.P. Ritten. 2021. Can Collaborative Adaptive Management Improve Cattle Production in Multipaddock Grazing Systems? *Rangeland Ecology & Management* 75: 1–8.

Dillman, D.A., J.D. Smyth, and L.M. Christian. 2014. *Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method*. John Wiley & Sons.

Doidge, M., D.A. Hennessy, and H. Feng. 2020. The Role of Economic Returns in Land Use Change: Evidence from Farm-Level Data in the US Northern Great Plains. *Journal of Soil and Water Conservation* 75(5): 669-679.

Dupas, P. 2014. Short-Run Subsidies and Long-Run Adoption of New Health Products: Evidence from a Field Experiment. *Econometrica* 82 (1): 197–228.

Epley, N., and T. Gilovich. 2016. The Mechanics of Motivated Reasoning. *Journal of Economic Perspectives* 30 (3): 133–40.

Feder, G., R.E. Just, and D. Zilberman. 1985. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development & Cultural Change* 33 (2): 255–298.

Foster, A.D., and M.R. Rosenzweig. 1995. Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture. *Journal of Political Economy* 103 (6): 1176–1209.

Gillespie, J.M., W. Wyatt, B. Venuto, D. Blouin, and R. Boucher. 2008. The roles of labor and profitability in choosing a grazing strategy for beef production in the U.S. Gulf Coast Region. *Journal of Agricultural & Applied Economics* 40 (1): 301–313.

Granovetter, M. 1985. Economic Action and Social Structure: The Problem of Embeddedness. *American Journal of Sociology* 91 (3): 481–510.

Graziano, M., and K. Gillingham. 2015. Spatial Patterns of Solar Photovoltaic System Adoption:

The Influence of Neighbors and the Built Environment. *Journal of Economic Geography* 15 (4): 815–839.

Hawkins, H.J. 2017. A global assessment of Holistic Planned Grazing^{TM} compared with season-long, continuous grazing: meta-analysis findings. *African Journal of Range & Forage Science* 34 (2): 65–75.

Holmes, T.J., and S. Lee. 2012. Economies of Density versus Natural Advantage: Crop Choice on the Back Forty. *Review of Economics and Statistics* 94(1): 1-19.

Jakoby, O., M.F. Quaas, S. Baumgärtner, and K. Frank. 2015. Adapting livestock management to spatio-temporal heterogeneity in semi-arid rangelands. *Journal of Environmental Management* 162: 179–189.

Keshk, O.M.G. 2003. CDSIMEQ: A Program to Implement Two-stage Probit Least Squares. *The Stata Journal* 3 (2): 157–167.

Kolady, D., W. Zhang, T. Wang, and J. Ulrich-Schad. 2020. Spatially Mediated Peer Effects in the Adoption of Conservation Agriculture Practices. *Journal of Agricultural & Applied Economics* 1–20.

Maddala, G.S. 1983. *Limited-Dependent and Qualitative Variables in Econometrics*. Cambridge University Press.

Manski, C.F. 1993. Identification of Endogenous Social Effects: The Reflection Problem. *The Review of Economic Studies* 60 (3): 531–542.

Manson, S.M., N.R. Jordan, K.C. Nelson, and R.F. Brummel. 2016. Modeling the effect of social networks on adoption of multifunctional agriculture. *Environmental Modelling & Software* 75: 388–401.

McFadden, D. 1974. The Measurement of Urban Travel Demand. *Journal of Public Economics* 3 (4): 303–328.

Milgrom, P., and J. Roberts. 1990. Rationalizability, Learning, and Equilibrium in Games with Strategic Complementarities. *Econometrica* 58 (6): 1255–1277.

Munshi, K. 2004. Social Learning in a Heterogeneous Population: Technology Diffusion in the Indian Green Revolution. *Journal of Development Economics* 73 (1): 185–213.

Munshi, K., and J. Myaux. 2002. Development as a Process of Social Change: An Application to the Fertility Transition. *University of Pennsylvania, mimeo*.

Nelson, K.C., R.F. Brummel, N. Jordan, and S. Manson. 2014. Social Networks in Complex Human and Natural Systems: The Case of Rotational Grazing, Weak Ties, and Eastern US Dairy Landscapes. *Agriculture & Human Values* 31 (2): 245–259.

Park, J.Y., S. Ale, and W.R. Teague. 2017. Simulated Water Quality Effects of Alternate

Grazing Management Practices at the Ranch and Watershed Scales. *Ecological Modelling* 360: 1–13.

Roche, L.M., B.B. Cutts, J.D. Derner, M.N. Lubell, and K.W. Tate. 2015. On-Ranch Grazing Strategies: Context for the Rotational Grazing Dilemma. *Rangeland Ecology & Management* 68 (3): 248–256.

Roe, B., E.G. Irwin, and J.S. Sharp. 2002. Pigs in Space: Modeling the Spatial Structure of Hog Production in Traditional and Nontraditional Production Regions. *American Journal of Agricultural Economics* 84(2): 259-278.

Rysman, M. 2019. The Reflection Problem in Network Effect Estimation. *Journal of Economics & Management Strategy* 28(1): 153-158.

Sampson, G.S., and E.D. Perry. 2019. The Role of Peer Effects in Natural Resource Appropriation – The Case of Groundwater. *American Journal of Agricultural Economics* 101 (1): 154–171.

Searchinger, T.D., S. Wirsenius, T. Beringer, and P. Dumas. 2018. Assessing the Efficiency of Changes in Land Use for Mitigating Climate Change. *Nature* 564 (7735): 249–253.

Singh, A., B. MacGowan, M. O'Donnell, B. Overstreet, J. Ulrich-Schad, M. Dunn, H. Klotz, and L. Prokopy. 2018. The Influence of Demonstration Sites and Field Days on Adoption of Conservation Practices. *Journal of Soil & Water Conservation* 73 (3): 276–283.

Steinfeld, H., P. Gerber, T.D. Wassenaar, V. Castel, M. Rosales, M. Rosales, and C. de Haan. 2006. *Livestock's Long Shadow: Environmental Issues and Options*. Food & Agriculture Org.

Teague, W.R., U.P. Kreuter, W.E. Grant, H. Diaz-Solis, and M.M. Kothmann. 2009. Economic Implications of Maintaining Rangeland Ecosystem Health in a Semi-arid Savanna. *Ecological Economics* 68 (5): 1417–1429.

Undersander, D.J., B. Albert, D. Cosgrove, D. Johnson, and P. Peterson. 2002. *Pastures for Profit: A Guide to Rotational Grazing*. Cooperative Extension Publications, University of Wisconsin-Extension.

USDA National Agricultural Statistics Service. 2017. NASS - Quick Stats. USDA National Agricultural Statistics Service. https://data.nal.usda.gov/dataset/nass-quick-stats. Accessed 2019-11-03.

Wang, T., H. Jin, U. Kreuter, H. Feng, D.A. Hennessy, R. Teague, and Y. Che. 2020. Challenges for Rotational Grazing Practice: Views from Non-adopters Across the Great Plains, USA. *Journal of Environmental Management* 256: 109941.

Wang, T., W. R. Teague, S.C. Park, and S. Bevers. 2018. Evaluating Long-term Economic and Ecological Consequences of Continuous and Multi-paddock Grazing - A Modeling Approach. *Agricultural Systems* 165: 197–207.

Windh, J.L., J.P. Ritten, J.D. Derner, S.I. Paisley, and B.P. Lee. 2019. Economic Cost Analysis of Continuous-Season-long versus Rotational Grazing Systems. *Western Economics Forum* 17 (1837-2019–947): 62–72.

Xiong, H., D. Payne, and S. Kinsella. 2016. Peer Effects in the Diffusion of Innovations: Theory and Simulation. *Journal of Behavioral & Experimental Economics* 63: 1–13.

Figures and Tables

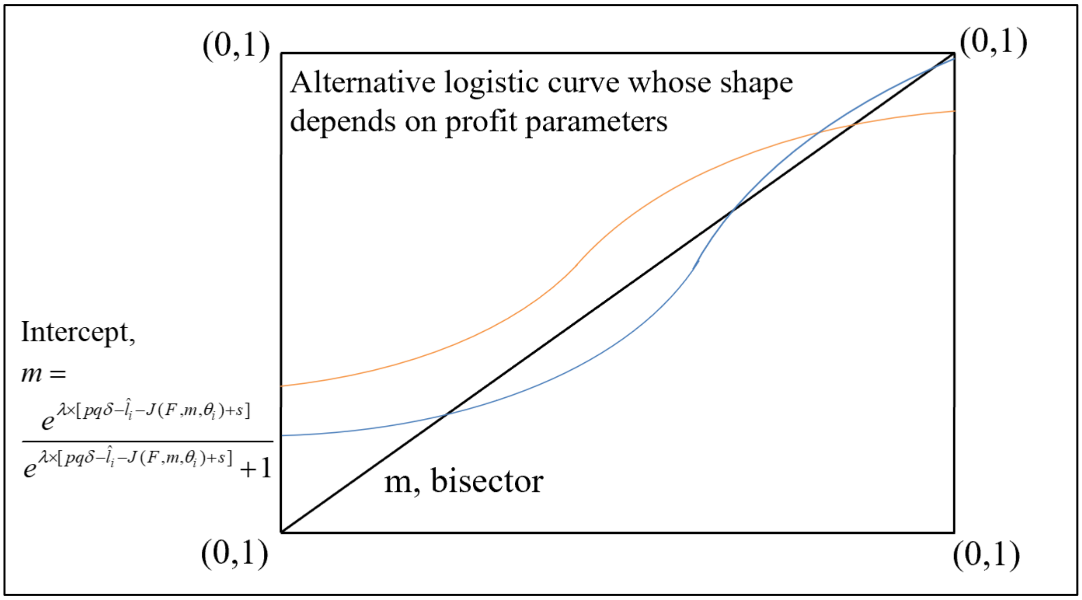

Figure 1 The probability of adopting intensive grazing system as a function of neighborhood adoption rates

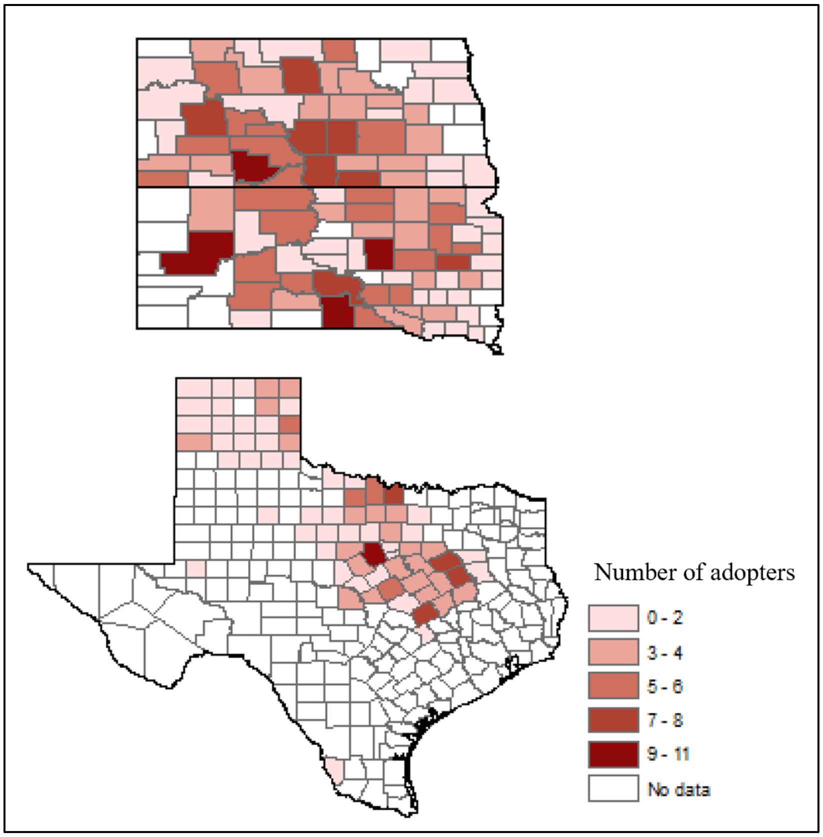

Figure 2 The distribution of adopters in the survey

Table 1 Variable definitions and data sources

Category	Variable	Description	Source
Adoption decisions	Adoption	Adoption status indicator, 1='adopter', 0='non-adopter'	Survey
	Willingness to adopt (for non-adopters)	Willingness to adopt RG or MIG given a one-time subsidy	Survey
	Current intensity (for adopters)	Number of pastures per group of animals that adopters currently have on the ranch, 0='no more than 5', 1='greater than 5'	Survey
	Desired intensity (for adopters)	Number of pastures per group of animals that adopters desire to have on the ranch, 0='no more than 5', 1='greater than 5'	Survey
	Future intensity (for non-adopters)	Number of pastures per group of animals that non-adopters desired to have, 0='no more than 5', 1='greater than 5'	Survey
Network indicators	Number of adopters known	Number of rotational grazing adopters that the rancher personally knows	Survey
	Perceived neighborhood	Perceived percentage of rotational grazing adopters within a 20-mile radius of home	Survey
	Rotational grazing share in county	Share of rotational grazing in cattle, goat and sheep operations at county-level	NASS, 2017
Costs and labor	Initial cost	Estimated initial investment costs	Survey
	Labor	Perceived effects of rotational grazing on needed labor and management time	Survey
Rancher Characteristics	Operating years	Number of years as primary operator	Survey
	Education	Highest level of education	Survey
	Ranching income	Percentage of total household income from ranching operation	Survey
Ranch characteristics	Internal fences	Whether the ranchers have some internal or cross fencing	Survey
	Ranch Size	The number of cows and replacement heifers (by 1,000)	Survey
	Distance	Distance in miles from home to largest land	Survey
	LCC I & II	Share of land with LCC equal to I and II	SSURGO[14]
	Slope less than 3%	Share of land with slope no greater than 3%	SSURGO

[14] SSURGO database is from the United States Department of Agriculture Natural Resource Conservation Service.

Table 2 Descriptive statistics

Variable	All samples Obs	All samples Mean	All samples Std. Dev.	Adopters Obs	Adopters Mean	Adopters Std. Dev.	Adopters Min	Adopters Max	Non-adopters Obs	Non-adopters Mean	Non-adopters Std. Dev.	Non-adopters Min	Non-adopters Max
Adoption	874	0.59	0.49	520	1	0	1	1	354	0	0	0	0
Willingness to adopt (RG) (for non-adopters)									286	0.36	0.48	0	1
Willingness to adopt (MIG) (for non-adopters)									259	0.13	0.34	0	1
Current intensity (for adopters)				480	0.54	0.50	0	1					
Desire intensity (for adopters)				419	0.70	0.46	0	1					
Future intensity (for non-adopters)									249	0.55	0.50	0	1
Number of adopters known (RG)	857	7.54	3.66	513	8.76	2.40	0	12	344	5.72	4.40	0	12
Number of adopters known (MIG)	802	3.18	4.37	475	3.85	4.56	0	12	327	2.21	3.89	0	12
Perceived neighborhood adoption (RG)	825	14.92	12.02	497	19.05	12.38	0	40	328	8.66	8.14	0	40
Perceived neighborhood adoption (MIG)	753	3.92	6.25	447	4.44	6.23	0	40	306	3.16	6.22	0	40
Rotational grazing share in county	873	0.39	0.13	520	0.41	0.12	0.19	0.65	353	0.37	0.13	0.19	0.68
Initial cost	522	3.37	1.39	286	3.31	1.55	1	5	236	3.44	1.17	1	5
Labor (RG)	748	1.83	0.68	459	1.67	0.61	1	3	289	2.09	0.70	1	3
Labor (MIG)	381	2.08	0.88	136	1.5	0.73	1	3	245	2.41	0.78	1	3
Operating years	857	36.23	12.71	515	35.26	11.94	2	68	342	37.69	13.68	0	75
Education	850	3.24	0.97	514	3.27	0.91	1	5	336	3.19	1.04	1	5
Ranching income	845	3.62	1.38	508	3.72	1.36	1	5	337	3.47	1.40	1	5
Internal fences	783	0.68	0.47	479	0.69	0.46	0	1	304	0.67	0.47	0	1
Ranch Size	846	0.24	0.33	506	0.26	0.23	0	2.33	340	0.22	0.44	0	7.15
Distance	847	11.23	24.25	511	11.06	23.28	0	200	336	11.48	25.69	0	300
LCC I & II	867	43.83	40.77	516	44.56	39.75	0	100	351	42.76	42.25	0	100
Slope less than 3%	867	43.13	38.26	516	39.99	37.62	0	100	351	47.75	38.78	0	100

Table 3 Mean values and T-tests for the importance of information sources between non-adopters and adopters

Sources	All samples		Adopters		Non-adopters		T-test	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	t value	Pr (|T| > |t|)
Government agencies (such as NRCS)	2.921	1.307	3.074	1.277	2.679	1.320	-4.305	0.000
Associations (such as Grassland Coalition, Society for Range Management)	2.270	1.223	2.403	1.263	2.057	1.126	-3.988	0.000
University extension	2.682	1.195	2.809	1.180	2.480	1.194	-3.891	0.000
Independent consultants	2.114	1.144	2.148	1.152	2.060	1.131	-1.078	0.282
Other ranchers	2.886	1.199	3.012	1.140	2.685	1.264	-3.859	0.000

Note: t-test of equivalence of means of adopters versus non-adopters.

Table 4 SEM estimates for adoption decisions and peer effects

	Adoption			
VARIABLES	(1)	(2)	(3)	(4)
Number of adopters known (RG)	0.228*	0.310***		
	(0.120)	(0.104)		
Perceived neighborhood adoption (RG)			0.059*	0.090***
			(0.031)	(0.033)
Initial cost	0.007	0.041	0.007	0.036
	(0.049)	(0.048)	(0.047)	(0.048)
Labor (RG)	-0.578***	-0.430***	-0.581***	-0.418***
	(0.119)	(0.111)	(0.117)	(0.116)
Operating years	-0.001		-0.005	
	(0.006)		(0.005)	
Education	-0.107		-0.052	
	(0.094)		(0.069)	
Ranching income	0.052		0.054	
	(0.050)		(0.047)	
Internal fences	-0.056		0.020	
	(0.131)		(0.127)	
Ranch size	0.514*		0.482*	
	(0.306)		(0.287)	
Distance	-0.002		0.000	
	(0.003)		(0.002)	
LCC I&II	-0.001		0.001	
	(0.002)		(0.001)	
Slope less than 3%	-0.000		-0.001	
	(0.002)		(0.002)	
	Number of adopters known (RG)		Perceived neighborhood adoption (RG)	
Adoption	1.344***	1.063***	4.599***	4.050***
	(0.276)	(0.351)	(0.923)	(1.137)
Rotational grazing share in county	3.464***	3.262***	10.354**	9.593**
	(1.229)	(1.230)	(4.041)	(3.966)
Observations	475	506	463	492

Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table 5 Marginal effects (ME) and standard errors (SE) for adoption decision and peer effect models

VARIABLES	Adoption							
	(1)		(2)		(3)		(4)	
	ME	SE	ME	SE	ME	SE	ME	SE
Number of adopters known (RG)	0.090*	0.047	0.123***	0.041				
Perceived neighborhood adoption (RG)					0.023*	0.012	0.035***	0.013
Initial cost	0.003	0.019	0.016	0.019	0.003	0.019	0.014	0.019
Labor (RG)	-0.228***	0.047	-0.171***	0.044	-0.229***	0.046	-0.162***	0.046
Operating years	-0.000	0.002			-0.002	0.002		
Education	-0.042	0.037			-0.021	0.027		
Ranching income	0.021	0.020			0.021	0.018		
Internal fences	-0.022	0.052			0.008	0.050		
Ranch size	0.203*	0.121			0.190*	0.113		
Distance	-0.001	0.001			0.000	0.001		
LCC I&II	-0.000	0.001			0.000	0.001		
Slope less than 3%	-0.000	0.001			-0.000	0.001		

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6 SEM estimates for non-adopters' willingness to adopt when offered a hypothetical one-time subsidy

	Willingness to adopt (Non-adopters)			
VARIABLES	(1) RG	(2) RG	(3) MIG	(4) MIG
Subsidy	0.029***	0.029***	0.030***	0.029***
	(0.003)	(0.003)	(0.010)	(0.005)
Number of adopters known (RG)	0.232*			
	(0.120)			
Perceived neighborhood adoption (RG)		0.111**		
		(0.050)		
Number of adopters known (MIG)			1.422	
			(3.269)	
Perceived neighborhood adoption (MIG)				-0.303
				(0.214)
Initial cost	-0.059	-0.115**	0.059	-0.107
	(0.070)	(0.054)	(0.448)	(0.095)
Labor (RG)	-0.081	-0.192**		
	(0.098)	(0.095)		
Labor (MIG)			0.973	-0.306
			(2.441)	(0.228)
Operating years	0.000	-0.005	0.015	0.019*
	(0.006)	(0.005)	(0.021)	(0.010)
Education	-0.158	0.059	-0.525	-0.028
	(0.124)	(0.063)	(1.177)	(0.108)
Ranching income	0.006	0.045	-0.428	-0.022
	(0.049)	(0.044)	(0.780)	(0.089)
Internal fences	0.013	0.059	0.009	0.126
	(0.140)	(0.131)	(0.774)	(0.241)
Ranch size	0.608**	0.854***	-1.837	-0.873
	(0.250)	(0.271)	(3.004)	(0.582)
Distance	-0.003	0.000	-0.016	0.005
	(0.004)	(0.003)	(0.035)	(0.007)
LCC I&II	-0.005**	-0.005***	-0.010	0.008
	(0.002)	(0.002)	(0.028)	(0.005)
Slope less than 3%	-0.000	-0.003*	-0.001	0.004
	(0.002)	(0.002)	(0.006)	(0.004)
	# adopters known	Neighborhood adoption	# adopters known	Neighborhood adoption
Willingness to adopt (RG)	0.499**	-0.012		
	(0.199)	(0.354)		
Willingness to adopt (MIG)			-0.042	0.124
			(0.189)	(0.277)
Rotational grazing share in county	4.938***	11.410***	0.779	5.471***
	(1.141)	(2.086)	(1.117)	(1.610)
Observations	792	770	657	644

Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table 7 Marginal effects (ME) and standard errors (SE) for non-adopters' willingness to adopt models

	Willingness to adopt (Non-adopters)							
	RG				MIG			
VARIABLES	(1)		(2)		(3)		(4)	
	ME	SE	ME	SE	ME	SE	ME	SE
Subsidy	0.008***	0.001	0.008***	0.001	0.003**	0.001	0.003***	0.001
Number of adopters known (RG)	0.066*	0.034						
Perceived neighborhood adoption (RG)			0.032**	0.014				
Number of adopters known (MIG)					0.135	0.312		
Perceived neighborhood adoption (MIG)							-0.030	0.021
Initial cost	-0.017	0.020	-0.033**	0.016	0.006	0.042	-0.011	0.010
Labor (RG)	-0.023	0.028	-0.055**	0.027				
Labor (MIG)					0.092	0.233	-0.030	0.023
Operating years	0.000	0.002	-0.002	0.001	0.001	0.002	0.002*	0.001
Education	-0.045	0.036	0.017	0.018	-0.050	0.113	-0.003	0.011
Ranching income	0.002	0.014	0.013	0.012	-0.040	0.075	-0.002	0.009
Internal fences	0.004	0.040	0.017	0.037	0.001	0.073	0.012	0.022
Ranch size	0.174**	0.071	0.245***	0.078	-0.174	0.290	-0.086	0.058
Distance	-0.001	0.001	0.000	0.001	-0.002	0.003	0.000	0.001
LCC I&II	-0.001**	0.001	-0.001***	0.001	-0.001	0.003	0.001	0.000
Slope less than 3%	0.000	0.001	-0.001*	0.000	-0.000	0.001	0.000	0.000

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 8 SEM estimates for intensity choices

VARIABLES	(1) Current intensity for adopters	(2)	(3) Desirable intensity for adopters	(4)	(5) Future intensity for non-adopters	(6)
Number of adopters known	1.537		0.367		-2.106	
Perceived neighborhood adoption		0.866		0.142		-2.172
Labor	-0.158	-0.092	-0.114	-0.147*	0.016	0.004
Operating years	0.012*	0.012**	0.003	0.004	-0.008	-0.008
Education	0.015	0.039	0.058	0.071	0.147	-0.042
Ranching income	-0.196	-0.149	-0.113	-0.108	-0.076	-0.178
Ranch size	0.199	0.065	-0.127	-0.157	0.147	-0.583
Distance	0.002	0.004	0.000	0.000	0.005	0.010
LCC I&II	-0.002	-0.002	-0.003	-0.003	0.001	-0.001
Slope less than 3%	0.004	0.004	0.005	0.005*	-0.007	-0.006
	# adopters known	Perceived neighborhood adoption	# adopters known	Perceived neighborhood adoption	# adopters known	Perceived neighborhood adoption
Current number for adopters	0.025	0.142				
Desirable number for adopters			0.081	-0.011		
Future number of non-adopters					-0.031	-0.084
Rotational grazing share in county	0.439*	0.618**	0.554**	0.688**	0.588**	0.628**
Observations	439	429	386	377	226	218

Note: *** p<0.01, ** p<0.05, * p<0.1