Journal of Agricultural and Applied Economics, 44,2(May 2012):203–222

Adoption of Technology, Management Practices, and Production Systems by U.S. Beef Cow-Calf Producers

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Using USDA's Agricultural Resource Management Survey data, factors leading to the adoption of technology, management practices, and production systems by U.S. beef cow-calf producers are analyzed. Binary logit regression models are used to determine impacts of vertical integration; region of the U.S.; farm size, diversification, and tenure; and demographics on adoption decisions. Significant differences were found in adoption rates by region of the U.S., degree of vertical integration, and size of operation, suggesting the presence of economies of size and vertical economies of scope. Results also indicate high degrees of complementarity among technologies, management practices, and production systems.

Key Words: cattle, cow-calf, management practices, production systems, technology adoption

JEL Classifications: D21, Q12, Q16

A variety of technologies, management practices, and production systems (TMPPS) have been available for adoption by U.S. cow-calf producers, most for extended periods such that few are truly "new." Some have been recommended by extension services and/or the USDA, with advisement usually focused on profitability/productivity and, in some cases, natural resource conservation. We analyze the adoption of 12 widely available cow-calf TMPPS, categorizing them into four groups: production technologies, services, production systems, and recordkeeping and information technologies. A better understanding of TMPPS adoption provides research and extension personnel with information as to how to improve program targeting and researchers and stakeholders with insights leading to a better understanding of national industry structure trends and differences among regions, segments, and enterprises.

The objectives of this study are to determine the factors leading to TMPPS adoption in the U.S. cow-calf sector and to determine the degree of complementarity of adoption among

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The views expressed here are those of the authors and may not be attributed to the Economic Research Service or the U.S. Department of Agriculture.

The authors gratefully acknowledge the helpful comments and suggestions from editor Mary Marchant and anonymous reviewers.

these TMPPS. We draw on data from the 2008 Phase III cow-calf version of the USDA Agricultural Resource Management Survey (ARMS). This study builds on cow-calf TMPPS adoption studies such as Gillespie, Kim, and Paudel (2007), Popp, Faminow, and Parsch (1999), and Ward et al. (2008) by expanding their state-level analyses to the national level and exploring complementarity among TMPPS. We begin by discussing each TMPPS, proceed by discussing previous TMPPS adoption studies and our analytical framework, and then provide the results and discussion.

Cow-Calf Production Technologies, Management Practices, and Production Systems

The TMPPS we consider include implants and/or ionophores, artificial insemination, embryo transfer and/or sexed semen, regularly scheduled veterinary services, use of a nutritionist, forage testing, rotational grazing, use of a calving season, animal identification, individual cow/calf recordkeeping, computer recordkeeping, and Internet use. These TMPPS were chosen based on their current or potential importance to the cow-calf sector and inclusion in the 2008 ARMS cow-calf survey. Some are likely technically interdependent (i.e., embryo transfer and artificial insemination), whereas others may not be (i.e., ionophores and rotational grazing), where technical interdependence refers to the adoption of one TMPPS impacting the marginal productivity of another. The large number of TMPPS allows us to explore tendencies of adopters of one TMPPS to adopt all others irrespective of technical interdependence. The 12 TMPPS examined in this study are described subsequently under the categories of technologies, services, production systems, and recordkeeping and information technologies.

Technologies

The use of *ionophores and growth-promoting implants* in the cattle industry can increase feed efficiency and average daily gains (Horn, 2006; Lawrence and Ibarburu, 2007). Ionophore use in the cow-calf segment has not been determined, but in 1999, ionophores were used in 93% of U.S. feedlots (U.S. Department of Agriculture, Animal and Plant Health Inspection Service [USDA-APHIS], 2000). Use of ionophores by cow-calf producers assists in replacement heifers reaching puberty earlier (Purvis and Whittier, 1996; Sprott et al., 1988). Growth-promoting implants were used on 12% of cow-calf operations in 2008, down from 27% in 1992–1993 (USDA-APHIS, 2009b). Although ionophore use aids in reaching puberty earlier, use of growth-promoting implants in replacement heifers is generally discouraged as a result of the potential to adversely impact conception rates (Staigmiller, Bellows, and Short, 1983).

Use of advanced breeding technologies such as artificial insemination, embryo transplants, and sexed semen has been limited in the U.S. beef cow-calf segment. Introduced to the U.S. in 1938, artificial insemination was developed primarily for genetic improvement and the elimination of venereal diseases (Foote, 1996). Studies have investigated adoption patterns for the U.S. hog industry (Gillespie, Davis, and Rahelizatovo, 2004) and the Indian buffalo industry (Saini, Sohal, and Singh, 1979). Compared with artificial insemination, embryo transplant technology is relatively new. Advantages are calves from genetically superior cows and marketing opportunities through the sale of offspring and embryos (Grimes, 2008), but it requires significant capital investment in facilities (Funk, 2006). Sexed semen technology, developed in the late 1980s, involves the separation of sperm into male and female sperm cells and then using artificial insemination. A disadvantage of sexed semen has been relatively low conception rates. Herd size and ability to use artificial insemination are factors expected to influence sexed semen adoption by beef cow-calf producers (Franks, Telford, and Beard, 2003). Rees et al. (2010) investigated the impact of production risk and human, social, and natural capital on the adoption of reproductive technology with results indicating that human capital impacts the decision to adopt and the intensity of use of reproductive technology.

Services

Regularly scheduled visits by veterinarians help cow-calf operators identify potential disease problems and design strategies to mitigate health risks. Half of beef cow-calf producers contacted a veterinarian in 2007–2008 with roughly one-third consulting a veterinarian for disease diagnosis, treatment, or prevention (USDA-APHIS, 2009a). Producers may consult with a nutritionist to design beef cow-calf rations or to purchase feed. This practice, combined with regular testing of forage quality for digestibility and/or protein content, can ensure the herd's nutritional requirements are met and unnecessary supplementation is reduced.

Production Systems

A best management practice (Louisiana State University Agricultural Center, 2002), rotational grazing involves fencing off multiple paddocks in a pasture and moving animals among them for efficient forage use. Capital investment involves fencing and watering equipment, and labor is required for rotating animals (Gillespie et al., 2008). The ARMS question on rotational grazing is nonspecific as to whether the system is management-intensive and whether movement of animals is frequent or occasional. Use of a defined calving season can aid the operation in at least two ways: 1) increasing uniformity and number of calves to market; and 2) determining the herd's reproductive efficiency. Open cows do not provide calves for sale, and synchronizing breeding/calving seasons helps in determining the period the cow has been open. Identifying cattle as belonging to the operation or for individual animal records allows for registration with animal identification systems, assistance in identifying stolen animals, and better recordkeeping.

Recordkeeping and Information Technology

Maintaining individual beef cow-calf records allows producers to 1) track whether cows are rebred; 2) determine average calf weaning weights; and 3) sometimes receive premiums when using alternative marketing outlets such as strategic alliances. Such records facilitate the provision of information for the Beef Quality Assurance program. Ward et al. (2008) found Oklahoma producers to identify individually 8% of cows and 21% of calves in their records. Furthermore, use of an on-farm computer to manage beef cow/calf records can increase recordkeeping flexibility. Ward et al. (2008) found that 63% of Oklahoma cow-calf producers kept records by hand only. Finally, the Internet has increased producer opportunities to consult with university, government, private firms, and other operators to learn about research, products, and market information.

Previous Studies Addressing Technologies, Management Practices, and Production Systems Adoption in the Livestock Sector

Most U.S. cow-calf sector TMPPS adoption studies have focused on individual states, not the entire U.S. (Gillespie, Kim, and Paudel, 2007; Johnson et al., 2010; Popp, Faminow, and Parsch, 1999; Ward et al., 2008; Wozniak, 1984, 1993; Young and Shumway, 1991). Factors leading to TMPPS adoption by cow-calf operators would not, theoretically, be expected to vary by region because the fundamental goal of converting forage to beef is consistent across regions. However, regional differences may be found, reflecting the heterogeneous input quality present in the U.S. stemming from variation in climate, forage types, soil types, and price differences that cow-calf operators experience by region. Additional adoption variability may result from differences in cow-calf operators' income dependency on the cow-calf enterprise.

Economies of size or scale are often present when TMPPS are adopted (Feder, Just, and Zilberman, 1985). With the majority of cow-calf operations fewer than 50 cows and these farms accounting for nearly 30% of all U.S. beef cows (U.S. Department of Agriculture, National Agricultural Statistics Service [USDA-NASS], 2009), recommended TMPPS can be less cost-effective to implement as a result of insufficient farm size. This phenomenon of lacking sufficient size for cost-effective adoption of TMPPS also extends to the backgrounding and stocker phases (Johnson et al., 2010; Popp, Faminow, and Parsch, 1999).

Approximately 14% of all U.S. beef cattle operations exist for a reason other than as a primary or supplemental source of income (USDA-APHIS, 2011). In such cases, the primary goal of cow-calf producers is land conservation or lifestyle factors associated with ranching (Basarir and Gillespie, 2006; Young and Shumway, 1991), which may partially explain producer reluctance to exploit economies of size and adopt TMPPS. Other factors influencing TMPPS adoption in livestock production have included human capital, often measured by education, age, or years of experience (Johnson et al., 2010; Ward et al., 2008); the economic importance of the enterprise to the household (Ward et al., 2008); land tenure (Gillespie, Kim, and Paudel, 2007); and vertical integration with other segments (Gillespie, Davis, and Rahelizatovo, 2004).

An issue that has received less attention than "who is adopting" has been the complementary nature of TMPPS adoption. Although studies have recognized technical interdependence among limited numbers of TMPPS, little work has examined the general tendency of adopters of one TMPPS to adopt others irrespective of technical interdependence. We address this issue, finding strong tendencies of producers to adopt multiple TMPPS.

Data and Methods

The cow-calf producer will adopt a TMPPS if the expected utility associated with adoption exceeds the expected utility associated with nonadoption:

$$(1)\qquad \max_{i} EU(\pi|\boldsymbol{d})$$

subject to: $i \in \{0, 1\}$ and $\pi = R_i - C_i$. $EU(.)$ is the expected utility operator; zero and one represent nonadoption and adoption states, respectively; R represents revenue; C represents costs of production; and $\boldsymbol{d}$ represents producer and farm characteristics. Although the producer's expected utility function is unobservable, adoption ($i = 1$) or nonadoption ($i = 0$) is observable. Adoption would be dependent on profit associated with a TMPPS as well as additional producer and farm characteristics that may influence the adoption decision such as managerial ability, region, farm size, and other factors to be discussed further in the proceeding sections.

Because adoption of a TMPPS is treated as a (0, 1) decision (adoption or nonadoption) in this study, the logit model, which assumes a logistic distribution, is used (Greene, 2008):

$$(2)\qquad Prob(T = 1|x) = e^{x'}\beta \Big/ \left(1 + e^{x'}\beta\right) = \Lambda(x'\beta).$$

The set of parameters β reflects the impact of changes in x on the probability of adopting T. Predicted values for the dependent variable are of the range (0, 1), so in our case, the logit models the probability of adoption. Using the logit model, estimated parameter signs for each independent variable indicate the direction of effect: a positive sign indicates the independent variable has a positive influence on adoption and vice versa. The odds ratio, θ, provides a measure of the magnitude of the impact of an independent variable on adoption, and, for a dummy variable, is the ratio of the probability of the dependent variable being one (adopted) vs. zero (not adopted):

$$(3)\qquad \theta = \frac{odds_{T=\mathbf{1}}}{odds_{T=\mathbf{0}}}.$$

For a continuous variable, θ is the ratio of the probability of the dependent variable being one vs. zero when the independent variable increases by one unit. The marginal effect is the estimated change in the probability of adoption when the independent variable increases by one unit, as discussed in Greene (2008, pp. 815–817) for both continuous and dummy variables. Although we estimate and report both odds ratios and marginal effects, our discussion of results centers mostly on odds ratios.

We use the degree of concordance as a measure of predictive power for our models. A pair of observations is concordant if the observation with the higher (lower) actual value is also the observation with the higher (lower) predicted mean value. Discordance occurs when the higher (lower) actual value is the observation with the lower (higher) predicted mean value. A tie occurs when the pair is neither concordant nor discordant. Thus, if for observation one, i = one and for observation two, i = zero, concordance would indicate the predicted probability of adoption would be greater for observation one than for observation two. The McFadden R^2 is also a useful measure of goodness of fit for the logit model (Greene, 2008). Adoption rates for the 12 TMPPS dependent variables explored in our research are shown in Table 1.

Independent Variables

Independent variables, their definitions, and weighted means are shown in Table 2. They fall into one of four broad categories: region; vertical integration; farm size, diversification, and tenure; and demographics. The ARMS data set is representative of agricultural producers but differs from the 2007 Census of Agriculture (USDA-NASS, 2009). In our study, the average number of cows on an operation is 102 compared with 43 in the Census of Agriculture. However, ARMS only interviewed cow-calf operators with a minimum of 20 beef cows. Using 2007 Census of Agriculture data, the average is 83 beef cows per farm when ignoring operations with fewer than 20 beef cows. The difference in age between the ARMS data set and the Census of Agriculture was small at 60 and 58, respectively.

The USDA-Economic Research Service divides U.S. agriculture into nine farm resource regions: Northern Crescent, Eastern Uplands, Southern Seaboard, Mississippi Portal, Heartland, Prairie Gateway, Northern Great Plains, Basin Range, and Fruitful Rim (Figure 1, USDA ERS), each comprised of areas with similar agricultural enterprises and financial characteristics. Except for the Northern Crescent (for which there were no observations in the 2008 ARMS cow-calf survey), these regions are incorporated into our study, the base region being the Prairie Gateway. The Prairie Gateway is chosen as the base region as a result of this region containing states that account for more than one-third of all U.S. beef cows and these states also containing a large number of feedlots. Region is expected to significantly impact TMPPS adoption, because regions differ in agronomic characteristics and relative input and output prices. Regions have different average gross returns and average variable costs. Lower operating cost regions (based on data from the ARMS survey) were generally in the southern U.S.: $420.07 per cow in the Fruitful Rim, $468.10 per cow in the Southern Seaboard, and $469.32 per cow in the Mississippi Portal. The highest operating costs per cow were observed in the Heartland at $830.30,

Table 1. Adoption Rates of Selected Technologies, Management Practices, and Production Systems

Variable	Percentage of Farms Adopting	Percentage of Cows on Adopting Farms
Implants/ionophores	14.1	18.6
Artificial insemination	8.5	14.5
Embryo transfer/sexed semen	1.9	3.0
Veterinary services	22.5	31.9
Use of a Nutritionist	7.0	12.4
Forage testing	16.3	25.6
Rotational grazing	60.2	66.3
Calving season	61.4	71.4
Animal identification	80.1	86.5
Keeping individual animal records	45.8	51.1
Computer records	20.2	30.9
Internet	34.3	44.2

Source: 2008 USDA ARMS Cow-Calf Survey.

Table 2. Weighted Means and Description of Independent Variables

Variable	Description	Mean
	Region	
Prairie Gateway	Producer lives in this region (1 = yes, 0 = no)	0.263
Heartland	Producer lives in this region (1 = yes, 0 = no)	0.150
Great Plains	Producer lives in this region (1 = yes, 0 = no)	0.087
Fruitful Rim	Producer lives in this region (1 = yes, 0 = no)	0.066
Basin and Range	Producer lives in this region (1 = yes, 0 = no)	0.034
Mississippi Portal	Producer lives in this region (1 = yes, 0 = no)	0.038
Eastern Uplands	Producer lives in this region (1 = yes, 0 = no)	0.231
Southern Seaboard	Producer lives in this region (1 = yes, 0 = no)	0.131
	Vertical Integration	
Finisher	Producer retains animals through to slaughter weight (1 = yes, 0 = no)	0.090
Stocker	Producer backgrounds animals more than 60 days (1 = yes, 0 = no)	0.270
Backgrounder	Producer backgrounds animals 30–60 days (1 = yes, 0 = no)	0.226
Purebred	Producer is involved in the purebred breeding segment (1 = yes, 0 = no)	0.070
	Farm Size, Diversification, and Tenure	
Cows	Number of cows on the operation	101.893
Specialization	Portion of farm income generated by the beef enterprise	0.869
Off-farm work	Producer holds off-farm employment (1 = yes, 0 = no)	0.409
Farmland owned	Portion of farmland owned	0.740
	Demographic	
Age	Producer's age, years	59.927
College	Producer has completed a 4-year college degree (1 = yes, 0 = no)	0.260
Ten More Years	Producer expects to continue farming at least 10 more years (1 = yes, 0 = no)	0.545

Source: 2008 USDA ARMS Cow-Calf Survey.

reflecting differences in prices, resources, farm size, and use of production practices. McBride and Mathews (2011) showed regional differences in TMPPS adoption in the U.S. cow-calf sector.

Vertical Integration

Producers retaining calves postweaning can be expected to adopt TMPPS at different rates than those selling at weaning as a result of differences in resource sets needed to maintain each segment. Independent variables indicate producers who 1) background animals 30–60 days (Backgrounders); 2) background animals greater than 60 days (Stockers); and 3) retain animals to slaughter weight (Finishers). The upstream segment of purebred producers provides an input for the commercial cow-calf segment in purebred breeding stock and shows animals for youth competition. In the case of vertical economies of scope among beef segments, TMPPS adoption would increase with vertical integration.

Farm Size, Diversification, and Tenure

Larger cattle operations (more cows) have been greater adopters of capital, labor, and management-intensive TMPPS (Gillespie, Kim, and Paudel, 2007; Johnson et al., 2010; Ward et al., 2008). Specialization measures the portion of farm income generated by the beef enterprise and off-farm work indicates off-farm

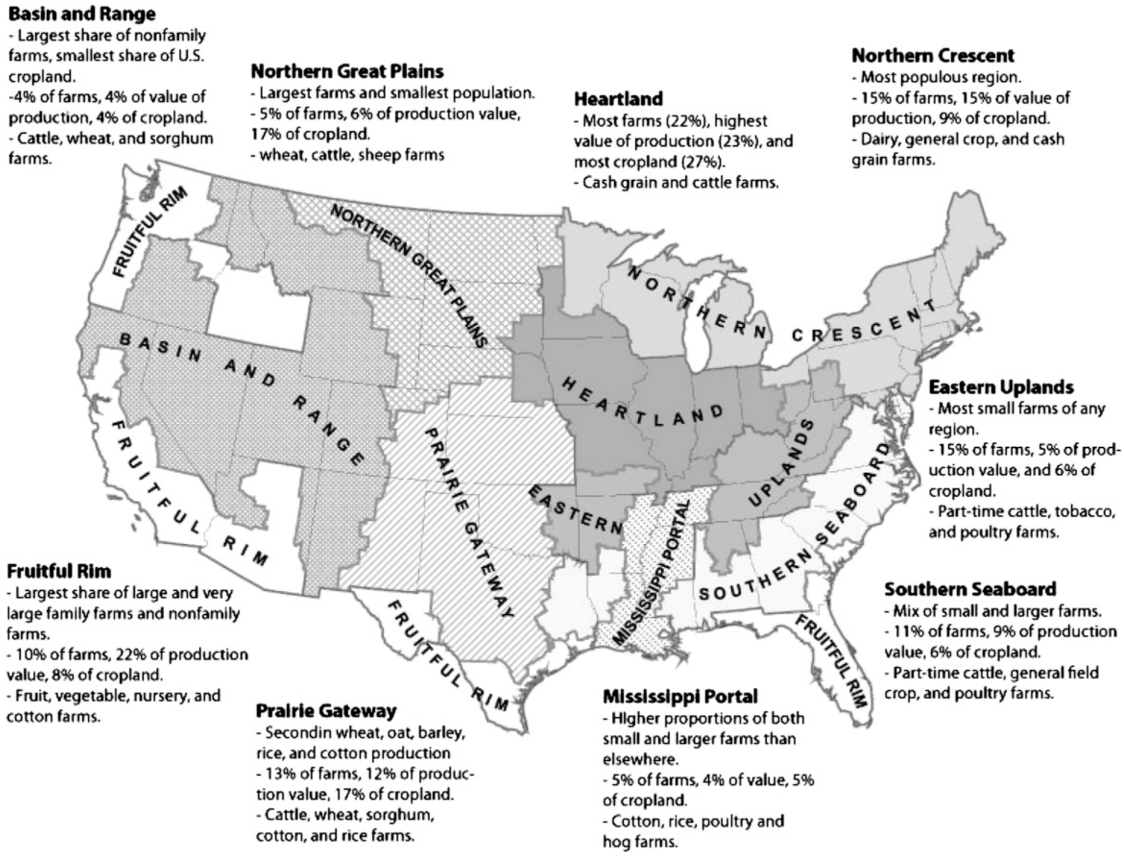

Figure 1. USDA Farm Resource Regions Used in the Agricultural Resource Management Survey (Source: USDA Economic Research Service)

employment is held. Ward et al. (2008) found higher percentages of household net income from the beef operation to be associated with the adoption of nine management practices. Higher percentages of farmland owned are expected to result in greater adoption of most TMPPS (Gillespie, Kim, and Paudel, 2007).

Demographics

Operator human capital is measured by age and whether the producer has completed a 4-year college degree. Popp, Faminow, and Parsch (1999), Ward et al. (2008), and Wozniak (1984) found that higher education resulted in greater TMPPS adoption, although age has provided mixed results (Gillespie, Kim, and Paudel, 2007; Ward et al., 2008). Reasons for discrepancies in the impact of age on TMPPS adoption might include how long the TMPPS has been available, whether the TMPPS is capital- and/or labor-intensive, and different generational attitudes regarding the TMPPS. Age may have a nonlinear effect, which we attempt to capture through use of the variable 10 more years, indicating whether the producer expected to continue farming for at least 10 additional years. A TMPPS requiring a longer payback period to justify the initial investment (i.e., rotational grazing) would not be expected to be adopted by producers with shorter planning horizons.

Investigating the Complementary Nature of Technologies, Management Practices, and Production Systems

In addition to analyzing traditional factors influencing TMPPS adoption, of interest is the complementary nature of adoption of groups of

TMPPS. From a productivity standpoint, the question is one of factor interdependence: is the marginal productivity of one TMPPS increased or decreased by use of another TMPPS? From Beattie, Taylor, and Watts (2009, p. 36), if $y = f(z_1, z_2)$, where y denotes output and z_j input j (in our case TMPPS), then $\frac{\partial^2 y}{\partial z_1 \partial z_2} = f_{12} = f_{21} > 0$ if the inputs are technically complementary; $f_{12} = f_{21} =$ zero if technically independent; and $f_{12} = f_{21} < 0$ if technically competing. In addition to the marginal productivity of one TMPPS being increased or decreased by use of another TMPPS, the marginal cost of a second TMPPS could be increased or decreased. An example would be reduced marginal cost to the operator of using an additional TMPPS when cattle are already being processed through a working chute for vaccinations or artificial insemination. On the other hand, adopters of one TMPPS may adopt others simply because they are "technology adopters" irrespective of factor interdependence.

Studies have used a number of modeling procedures to consider joint adoption of TMPPS: the multinomial probit (Dorfman, 1996), the multivariate probit (Gillespie, Davis, and Rahelizatovo, 2004), and the count data regression model (Gale, 1998). By accounting for jointness in adoption, each has reduced estimation bias. In our case, almost all TMPPS are found to be complementary in nature, whether technically so or because adopters of one TMPPS are simply prone to also adopt others. With 12 TMPPS, multinomial probit or multivariate probit models would prove to be infeasible for modeling adoption, and the count data regression models assume all TMPPS to be of equal value or importance, which is not useful for our purposes. Thus, we follow the precedents of Gillespie, Kim, and Paudel (2007), Johnson et al. (2010), and Ward et al. (2008)and focus on results of the individual technologies, recognizing the limitations and those of alternative methods. Furthermore, we proceed in similar fashion as Khanal, Gillespie, and MacDonald (2010), who examined adoption rates of 10 TMPPS by dairy farmers who had 1) adopted and 2) not adopted each of the other nine TMPPS. We show significant differences in adoption rates of TMPPS by adoption and nonadoption of each of the other TMPPS, explicitly showing the complementary nature of adoption.

Data and Associated Estimation Considerations

Data from the 2008 cow-calf version of the Phase III ARMS were used for this analysis. Questions regarding costs, returns, products produced, input use, and the use of TMPPS were included in the questionnaire administered directly to cow-calf producers in 22 states in the U.S.: Alabama, Arkansas, California, Colorado, Florida, Georgia, Iowa, Kansas, Kentucky, Mississippi, Missouri, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Tennessee, Texas, Virginia, and Wyoming. Producers with at least 20 cows were selected for the survey from a list maintained by the USDA-NASS. Expansion factors or "weights" are included in the data set to allow for expansion of the sample to 96% of the targeted U.S. cow-calf producer population.

Logit regression and difference in means tests using farm-level ARMS data result from a complex survey design with both area and list frames. As such, the data do not represent a model-based random sample, which is commonly used in traditional econometric analyses. Thus, to make inferences to the population, we use the delete-a-group jackknifing procedure using 30 replicates for all models as recommended by USDA-NASS when estimating sample variance and estimating t-statistics. Further information on these procedures is found in the Panel to Review USDA's ARMS (2008) and Dubman (2000).

Results

U.S. regions were highly significant in explaining cow-calf TMPPS adoption (Table 3). Producers in the Midwest and western parts of the U.S. (Heartland, Great Plains, and Basin and Range) were generally greater TMPPS adopters, whereas Southeastern U.S. producers (Mississippi Portal, Eastern Uplands, and Southern Seaboard) were lower adopters. This reflects production differences by region, consistent with McBride and Mathews (2011).

Table 3. Logit Results of Technologies, Management Practices, and Production Systems, 2008

	Implants/Ionophores				Artificial Insemination				Embryo Transfer/Sexed Semen			
Variables	β	Standard Error	Marginal Effects	Odds Ratio	β	Standard Error	Marginal Effects	Odds Ratio	β	Standard Error	Marginal Effects	Odds Ratio
Intercept	0.085	0.580			–2.417***	0.937			–3.841***	1.142		
Heartland	0.723***	0.276	0.084	2.062	0.643**	0.326	0.040	1.901	0.316	1.011		
Great Plains	–0.460*	0.270	–0.038	0.632	0.750**	0.303	0.051	2.119	–0.707	0.620		
Fruitful Rim	–0.777	0.570			–1.041	0.685			–0.044	1.054		
Basin and Range	–0.162	0.336			0.853***	0.327	0.063	2.347	–0.466	0.712		
Mississippi Portal	–1.210*	0.626	–0.075	0.298	–0.468	0.717			–0.188	14.161		
Eastern Uplands	–0.794***	0.285	–0.064	0.452	–0.351	0.313			–0.728	0.862		
Southern Seaboard	–0.628*	0.348	–0.050	0.534	–0.635*	0.381	–0.027	0.530	0.267	0.671		
Finisher	0.116	0.231			0.875***	0.291	0.062	2.398	0.349	0.940		
Stocker	0.397*	0.211	0.022	1.488	0.624**	0.243	0.037	1.866	0.489	0.339		
Backgrounder	0.219	0.212			0.531***	0.198	0.031	1.701	–0.417	0.545		
Purebred	0.090	0.570			1.612***	0.420	0.082	5.025	2.646***	0.697	0.024	14.084
Cows	0.000	0.000			0.001**	0.000	0.000	1.001	0.000**	0.000	0.000	1.000
Specialization	–0.839***	0.268	–0.080	0.432	–0.005	0.214			–0.006	0.422		
Off-farm work	–0.060	0.174			0.103	0.247			0.304	0.411		
Farmland owned	–0.448	0.342			–0.415	0.266			0.278	0.391		
Age	–0.019**	0.008	–0.002	0.981	–0.016	0.012			–0.029	0.019		
College	0.267	0.229			1.236***	0.235	0.085	3.448	1.861***	0.444	0.030	6.410
Ten more years	–0.023	0.190			–0.014	0.248			–0.065	0.453		
Percent concordant	69.3				76.5				72.0			
Percent discordant	30.1				23.0				23.6			
Percent tied	0.6				0.5				4.3			
Likelihood ratio	32,057.6				31,393.4				10,686.8			
McFadden R^2	0.116				0.158				0.164			

Table 3. Continued

	Veterinary Services				Nutritionist				Forage Testing			
Variables	β	Standard Error	Marginal Effects	Odds Ratio	β	Standard Error	Marginal Effects	Odds Ratio	β	Standard Error	Marginal Effects	Odds Ratio
Intercept	–0.841	0.545			–0.550	0.668			–0.480	0.696		
Heartland	0.470*	0.264	0.083	1.600	0.278	0.312			–0.069	0.231		
Great Plains	0.998***	0.223	0.197	2.717	–0.126	0.290			0.237	0.396		
Fruitful Rim	–0.118	0.233			–0.523	0.567			–0.393	0.367		
Basin and Range	0.584*	0.311	0.109	1.792	–0.109	0.395			0.347	0.374		
Mississippi Portal	–0.945*	0.501	–0.114	0.388	–1.953*	1.007	–0.456	0.142	–0.892	0.603		
Eastern Uplands	–0.136	0.237			–0.853*	0.452	–0.033	0.434	–0.513	0.313		
Southern Seaboard	0.708**	0.279	–0.096	0.492	–1.245	0.786			–0.395	0.312		
Finisher	0.144	0.226			0.776***	0.228	0.050	2.174	0.583**	0.280	0.086	1.792
Stocker	0.255*	0.151	0.042	1.290	0.292	0.297			0.244	0.168		
Backgrounder	0.056	0.140			–0.201	0.251			0.269*	0.151	0.035	1.309
Purebred	0.988***	0.370	0.158	2.688	–0.263	0.541			0.340	0.382		
Cows	0.001*	0.000	0.000	1.001	0.001*	0.001	0.000	1.001	0.001***	0.000	0.000	1.001
Specialization	–0.468*	0.247	–0.075	0.627	–0.435	0.385			0.037	0.518		
Off-farm work	–0.018	0.181			–0.211	0.201			–0.324*	0.171	–0.040	0.723
Farmland owned	–0.029	0.147			0.177	0.310			–0.077	0.164		
Age	–0.008	0.007			–0.031***	0.009	–0.001	0.970	–0.023**	0.009	–0.003	0.978
College	0.530***	0.171	0.091	1.701	0.292	0.223			0.606***	0.199	0.084	1.831
Ten more years	–0.063	0.188			–0.078	0.286			–0.086	0.171		
Percent concordant	71.3				74.2				70.8			
Percent discordant	28.3				25.1				28.8			
Percent tied	0.4				0.7				0.5			
Likelihood ratio	28,504.8				17,847.1				21,180.6			
McFadden R^2	0.078				0.103				0.070			

Table 3. Continued

	Rotational Grazing				Calving Season				Animal Identification			
Variables	β	Standard Error	Marginal Effects	Odds Ratio	β	Standard Error	Marginal Effects	Odds Ratio	β	Standard Error	Marginal Effects	Odds Ratio
Intercept	–0.256	0.399			1.497**	0.718			2.520***	0.676		
Heartland	–0.119	0.237			1.244***	0.302	0.222	3.472	–0.531*	0.306	–0.074	0.588
Great Plains	0.236	0.268			3.273***	0.574	0.365	26.316	0.066	0.329		
Fruitful Rim	0.030	0.308			–0.300	0.364			–1.120*	0.291	–0.187	0.326
Basin and Range	0.891***	0.320	0.184	2.439	2.243***	0.806	0.288	9.434	4.469	9.496		
Mississippi Portal	–0.097	0.363			–0.920***	0.332	–0.221	0.399	–2.249***	0.362	–0.458	0.105
Eastern Uplands	0.094	0.186			–0.361**	0.169	–0.081	0.698	–0.985***	0.305	–0.145	0.373
Southern Seaboard	0.212	0.216			–0.667***	0.213	–0.156	0.513	–1.124***	0.325	–0.180	0.325
Finisher	–0.170	0.306			0.473*	0.268	0.095	1.605	0.581	0.438		
Stocker	0.039	0.169			0.112	0.191			0.201	0.200		
Backgrounder	0.072	0.118			0.039	0.168			–0.013	0.223		
Purebred	0.169	0.326			0.071	0.283			1.032	0.561		
Cows	0.001*	0.000	0.000	1.001	0.001***	0.000	0.000	1.001	0.002*	0.001	0.000	1.002
Specialization	0.176	0.159			0.012	0.686			–0.038	0.222		
Off-farm work	–0.054	0.141			–0.160	0.208			0.369	0.235		
Farmland owned	0.112	0.118			0.098	0.141			–0.243	0.156		
Age	0.000	0.006			–0.022**	0.010	–0.005	0.978	–0.015	0.009		
College	0.439**	0.174	0.101	1.550	0.338**	0.132	0.072	1.402	0.523**	0.223	0.058	1.686
Ten more years	0.416***	0.112	0.099	1.515	–0.143	0.156			0.204	0.236		
Percent concordant	61.4				78.5				78.7			
Percent discordant	38.1				21.3				21.0			
Percent tied	0.5				0.3				0.4			
Likelihood ratio	12,110.3				67,657.3				42,171.5			
McFadden R^2	0.027				0.150				0.125			

Table 3. Continued

	Individual Animal Recordkeeping				Computer for Recordkeeping				Internet			
Variables	β	Standard Error	Marginal Effects	Odds Ratio	β	Standard Error	Marginal Effects	Odds Ratio	β	Standard Error	Marginal Effects	Odds Ratio
Intercept	0.116	0.508			–1.025*	0.575			0.703*	0.415		
Heartland	0.138	0.215			–0.109	0.300			–0.125	0.197		
Great Plains	0.814***	0.220	0.199	2.257	0.296	0.196			0.111	0.258		
Fruitful Rim	–0.356	0.364			–0.007	0.316			–0.061	0.335		
Basin and Range	0.676***	0.252	0.166	1.965	0.631***	0.216	0.112	1.880	0.477	0.313		
Mississippi Portal	–0.417	0.292			–0.366	0.449			–0.154	0.341		
Eastern Uplands	0.048	0.181			–0.256	0.217			–0.264	0.243		
Southern Seaboard	–0.089	0.211			–0.266	0.254			–0.314	0.224		
Finisher	0.370	0.226			0.430**	0.205	0.072	1.538	0.198	0.194		
Stocker	0.182	0.178			0.320**	0.158	0.050	1.377	0.196	0.148		
Backgrounder	0.366**	0.153	0.091	1.443	–0.050	0.187			0.076	0.169		
Purebred	1.033***	0.387	0.257	2.809	1.042***	0.340	0.157	2.833	0.468	0.423		
Cows	0.000	0.000			0.001***	0.000	0.000	1.001	0.001***	0.000	0.000	1.001
Specialization	0.025	0.152			0.314	0.191			0.027	0.218		
Off-farm work	0.027	0.167			0.118	0.190			0.218	0.152		
Farmland owned	–0.321**	0.143	–0.080	0.726	0.035	0.138			–0.112	0.143		
Age	–0.009	0.006			–0.023***	0.008	–0.003	0.978	–0.032***	0.005	–0.007	0.969
College	0.714***	0.167	0.177	2.041	0.853***	0.192	0.145	2.347	0.948***	0.156	0.220	2.577
Ten more years	–0.075	0.155			0.133	0.164			0.157	0.143		
Percent concordant	66.1				72.4				72.0			
Percent discordant	33.5				27.2				27.8			
Percent tied	0.4				0.3				0.3			
Likelihood ratio	26,599.0				30,442.0				42,451.7			
McFadden R^2	0.057				0.089				0.097			

Note: ***, **, and *, indicate significance at the 1%, 5%, and 10% levels, respectively, with jackknife standard errors and 29 degrees of freedom.

Larger farms, measured by cows, were greater adopters of TMPPS. Although none of the cow-calf TMPPS would require a large operation for successful implementation, none are completely scale-neutral, particularly considering a high percentage of cow-calf producer are very small (i.e., less than 50 cows). Cow-calf producers vertically integrating with downstream segments of cattle production generally increased the adoption of TMPPS. In no case was vertical integration with a downstream segment associated with a lower TMPPS adoption rate. Overall, farm size tied with college for the most influential factor explaining TMPPS adoption, significant in 10 of the 12 cases. Consistent with previous studies (e.g., Feder, Just, and Zilberman, 1985), older producers were less likely to adopt TMPPS.

Results by Technologies, Management Practices, and Production Systems

Technologies. Region, degree of vertical integration, and education were important in explaining adoption of implants/ionophores, artificial insemination, and embryo transfer/sexed semen. Implants/ionophores were adopted by 14.1% of U.S. cow-calf producers; adopters held 18.6% of the cows (Table 1). With the exception of the Heartland region, which had odds of 2.06 of adopting, relative to the Prairie Gateway, all regions that were significantly different from the Prairie Gateway (Mississippi Portal, Eastern Uplands, Great Plains, and Southern Seaboard) were less likely to adopt implant/ionophores. These results are not surprising if implants/ionophores are complementary with increased feeding of harvested forage, which is used less in the Southeastern U.S.

Stockers were more likely to adopt implants/ionophores relative to nonstockers, consistent with the focus on adding animal weight during the stocker phase. An odds ratio of 1.49 for stockers suggests this group is 1.49 times more likely to adopt ionophores/implants than producers who are solely cow-calf producers. Increased levels of on-farm specialization in beef, measured as the portion of farm income generated by the beef enterprise, reduced the likelihood of adoption of implants/ionophores. An increase in specialization in beef from 0–100% resulted in a 0.08 decrease in the probability of adoption. Likewise, producers who were 100% specialized in beef had odds of adopting that were 0.43 relative to cases where 0% was from beef production. Although at first glance these two measures of impact may seem inconsistent, one must consider that only 14.1% of farms adopted implants/ionophores, so a decrease in probability of adoption by 0.08 is roughly equivalent to an odds ratio of 0.43.

Adopters of artificial insemination held 14.5% of U.S. beef cows with 8.5% of cow-calf producers adopting this technology. This contrasts with 1) the dairy industry, where artificial insemination was adopted by 82% of producers who produced 89% of the milk in 2005 (Khanal, Gillespie, and MacDonald, 2010); and 2) the hog industry, where it was adopted by 12% of farrow-to-finish, 30% of farrow-to-feeder pig, and 77% of farrow-to-wean producers in 2004 (McBride and Key, 2007). Producers in the Heartland, Great Plains, and Basin Range regions were, respectively, 1.90, 2.12, and 2.35 times more likely to adopt than Prairie Gateway produces, whereas Southern Seaboard producers had odds of adopting of 0.53 relative to Prairie Gateway producers. Producers who added value to calves before sale (finishers, stockers, and backgrounders) were more likely to adopt artificial insemination. Purebred producers were 5.03 times more likely to adopt than those producers selling solely in the commercial market reflecting the desire to improve the genetic potential of animals sold. Larger-scale producers were more likely to adopt artificial insemination. Producers holding 4-year college degrees were 3.45 times more likely to adopt than nonholders, reflecting the management skills required for the technology.

Embryo transfer and/or sexed semen was adopted by 1.9% of U.S. cow-calf producers; adopters held 3.0% of the cows. This contrasts with the dairy industry, where in 2005, embryo transfer/sexed semen was adopted by 10% of producers who produced 16% of the milk (Khanal, Gillespie, and MacDonald, 2010). Like with artificial insemination, larger operations (more cows) were more likely to adopt this technology. Purebred producers were 14.08 times more likely to adopt this technology and college graduates were 6.41 times more likely to adopt than nongraduates.

Services. Vertical integration, farm size, diversification, and demographic variables were generally more important than regional variables in explaining the adoption of the use of veterinary services, nutritionists, and forage testing than region. Regularly scheduled veterinary services were used by 22.5% of U.S. cow-calf producers; users held 31.9% of the cows. Heartland, Great Plains, and Basin and Range producers were, respectively, 1.60, 2.72, and 1.79 times more likely to adopt than Prairie Gateway producers, whereas Mississippi Portal and Southern Seaboard producers had odds of 0.39 and 0.49, respectively, of adopting relative to Prairie Gateway producers. Stocker, purebred producers, larger producers, and those holding 4-year college degrees were more likely to adopt this service, whereas increased specialization in the beef enterprise lowered the probability of using regularly scheduled veterinary services.

A nutritionist to design cow-calf rations or to purchase feed was used by 7% of U.S. cow-calf producers; users held 12.4% of the cows. This contrasts with the dairy industry, where 72% of producers who produced 88% of the milk used a nutritionist in 2005 (Khanal, Gillespie, and MacDonald, 2010). Mississippi Portal and Eastern Upland producers were less likely than Prairie Gateway producers to use the services of a nutritionist. Year-round grazing in much of the Southeastern U.S. would generally lead to lower use of purchased or stored forages and feedstuffs, thus reducing the need to use a nutritionist. Finishers were 2.17 times more likely than cow-calf only producers to use a nutritionist. Larger producers were more likely and older producers less likely to use the services of a nutritionist.

Testing forage quality for digestibility and/or protein content was done by 16.3% of U.S. cow-calf producers; those operations testing held 25.6% of the cows. Finishers and backgrounders were, respectively, 1.79 and 1.31 times more likely to adopt than producers who were strictly cow-calf operators. Larger producers were more likely to adopt and producers holding 4-year college degrees were 1.83 times more likely to adopt forage testing. Producers holding off-farm jobs, relative to those who do not, were less likely to test forage quality, a result generally expected with TMPPS unless they are labor-saving such as herbicide-tolerant soybeans (Fernandez-Cornejo, Hendricks, and Mishra, 2005).

Production Systems. Regional, farm size, and demographic variables were the primary factors influencing the adoption of rotational grazing, calving season, and individual animal identification. A rotational grazing system was used by 60.2% of U.S. cow-calf producers; adopters held 66.3% of the cows. Basin and Range producers were 2.44 times more likely to use rotational grazing than Prairie Gateway producers. Larger producers were more likely to use rotational grazing. Holders of 4-year college degrees and producers who planned to continue their cow-calf enterprises for at least 10 more years were, respectively, 1.55 and 1.52 times more likely to adopt than nonholders and producers with shorter planning horizons. These results reflect the increased management associated with rotational grazing and the need to spread fixed costs of fencing and watering equipment over greater animal numbers and a longer time period to recoup the initial investment.

A calving season was used by 61.4% of U.S. cow-calf producers; these producers held 71.4% of the cows. Region was highly influential: Heartland, Great Plains, and Basin and Range producers were, respectively, 3.47, 26.32, and 9.43 times more likely to calve seasonally than Prairie Gateway producers, and Mississippi Portal, Eastern Upland, and Southern Seaboard producers had respective odds of 0.40, 0.70, and 0.51 relative to Prairie Gateway producers of calving seasonally. Climatic conditions partially explain different regional adoption rates. For instance, severe winter weather would encourage use of spring calving, consistent with our results for calving season adoption. Finishers were 1.61 times more likely to calve seasonally, and larger producers were more likely to do so. An additional year of age reduced the odds of calving seasonally by 0.02 and producers holding college degrees were 1.40 times more likely to calve seasonally.

Use of animal identification to identify cattle as belonging to an operation or for individual animal records was used by 80.1% of U.S. cow-calf producers who held 86.5% of the cows. Heartland, Fruitful Rim, Mississippi Portal, Eastern Upland, and Southern Seaboard producers had respective odds of adoption of 0.59, 0.33, 0.11, 0.37, and 0.33 relative to Prairie Gateway producers. Larger producers were more likely to use animal identification systems and holders of 4-year college degrees were 1.69 times more likely to use them than nonholders.

Recordkeeping and Information Technology. Vertical integration, farm size, diversification, and demographic variables were influential in explaining the adoption rates of individual animal recordkeeping, computer use for recordkeeping, and the Internet. Individual cow-calf recordkeeping was conducted by 45.8% of U.S. cow-calf producers; these producers held 51.5% of the cows. Great Plains and Basin and Range producers were, respectively, 2.26 and 1.97 times more likely to adopt the practice of keeping individual animal records than Prairie Gateway producers.

Because individual cow-calf records benefit not only the cow-calf, but also downstream segments, it is not surprising that backgrounders were 1.44 times more likely than nonbackgrounders to keep individual records. Producers whose cattle sales were 100% breeding stock were 2.81 times more likely to adopt than those whose sales were 100% commercial, consistent with the need to keep detailed breeding records. Those owning 100% of their farmland had odds of 0.73 of keeping individual records relative to those renting 100% of their farmland. Four-year college degree holders were more than twice as likely to keep individual records as nonholders. Land tenure negatively impacted the likelihood of keeping individual cow-calf records. Although lower adoption rates among landowners would be unexpected for land improvements, little previous literature or economic theory allowed for an *a priori* expectation on the impact of tenure on recordkeeping.

An on-farm computer for recordkeeping was used by 20.2% of U.S. cow-calf producers; these producers held 30.9% of the cows. Basin and Range producers were 1.88 times more likely to use a computer for recordkeeping than Prairie Gateway producers. Finishers and stockers were, respectively, 1.54 and 1.38 times more likely to use a computer for recordkeeping than nonfinishers and nonstockers, consistent with the additional benefits of recordkeeping systems when producing for multiple industry segments. Producers whose cattle sales were 100% breeding stock were 2.83 times more likely to use a computer for recordkeeping than those whose sales were 100% commercial. Larger producers were more likely to adopt use of an on-farm computer for recordkeeping. Each additional year of age reduced the odds of adopting by 0.02, and producers holding 4-year college degrees were 2.35 times more likely to adopt than nonholders.

Approximately 34.3% of U.S. cow-calf producers accessed the Internet for cow-calf information; these producers held 44.2% of the cows. Larger producers were more likely to use the Internet. Each additional year of age reduced the odds of internet use by 0.03, and holders of 4-year college degrees were 2.58 times more likely to use the Internet than nonholders.

Complementary Nature of Technologies, Management Practices, and Production Systems Adoption

Comparing the population of adopters of any of the TMPPS with the population of nonadopters of that same TMPPS (132 comparisons), the percentage of adopters who had adopted other TMPPS was significantly higher ($p \leq 0.10$) than the percentage of nonadopters who had adopted a second TMPPS in all but three cases: 1) embryo transfer/sexed semen adopter vs. nonadopter adoption rates of implants/ionophores; 2) rotational grazing adopter vs. nonadopter adoption rates of implants/ionophores; and 3) implant/ionophore adopter vs. nonadopter adoption rates of rotational grazing. Similar to Khanal, Gillespie, and MacDonald (2010), Table 4 shows percentages of adopters vs.

Table 4. Weighted Means Estimates, Percentages of Technology Adopters and Nonadopters Adopting Other Technologies, Management Practices, and Production Systems, Reporting Those with 25 or More Percentage Point Differences, All Significant at $p \leq 0.10$, 2008

Technology, Management Practice, or Production System	Nonadoption (%)	Adoption (%)
Implants/ionophores		
Calving season	57.5	84.9
Artificial insemination		
Veterinary services	19.2	58.5
Forage testing	13.6	44.8
Calving season	58.4	93.8
Individual animal records	42.4	82.9
Computer for recordkeeping	17.2	52.2
Internet use	31.1	69.0
Embryo transfer/sexed semen		
Artificial insemination	6.9	87.0
Nutritionist	6.4	34.6
Forage testing	15.6	49.2
Calving season	60.7	95.7
Individual animal records	45.1	80.8
Computer for recordkeeping	19.4	61.9
Internet use	33.5	76.3
Veterinary services		
Calving season	55.8	80.8
Individual animal records	39.7	66.8
Nutritionist		
Veterinary services	19.3	65.1
Forage testing	13.6	52.6
Calving season	59.4	88.0
Forage testing		
Veterinary services	18.3	44.1
Rotational grazing	56.3	80.0
Calving season	57.4	82.1
Individual animal records	40.6	72.4
Computer for recordkeeping	15.9	42.4
Internet use	29.2	60.6
Animal identification		
Calving season	41.0	66.5
Individual animal records	16.8	53.0
Individual animal records		
Computer for recordkeeping	6.8	36.1
Internet use	22.4	48.5
Computer for recordkeeping		
Individual animal records	36.7	81.8
Internet use	23.4	77.6
Internet use		
Individual animal records	35.9	64.7
Computer for recordkeeping	6.9	45.7

Note: All differences in means are estimated using jackknife standard errors with 29 degrees of freedom.

nonadopters who had adopted other TMPPS when the percentage of adoption was at least 25 percentage points greater, a total of 33 cases.

Particularly noteworthy are: 1) embryo transfer/sexed semen adopters had adoption rates of artificial insemination that were 80.1

percentage points higher than embryo transfer/sexed semen nonadopters; 2) embryo transfer/sexed semen adopters had adoption rates of internet use that were 42.8 percentage points higher than embryo transfer/sexed semen nonadopters; 3) producers hiring a nutritionist had adoption rates of veterinary services that were 45.8 percentage points higher than nutritionist nonusers; 4) producers using a computer for recordkeeping had individual animal records adoption rates that were 45.1 percentage points higher than those not using a computer for recordkeeping; and 5) producers using a computer for recordkeeping had adoption rates of the Internet that were 54.2 percentage points higher than those not using a computer for recordkeeping. The evidence overwhelmingly suggests significant complementary relationships among TMPPS.

From the results, one cannot discern whether the technologies are technically complementary, that use of one TMPPS increases the marginal productivity of another TMPPS. Complementary adoption may occur because some producers tend to be simply "TMPPS adopters," whereas others are not. A few examples of TMPPS combinations, however, that would be expected to be technically complementary would include artificial insemination and embryo transfer/sexed semen, computerized recordkeeping and individual animal records, and animal identification and individual animal records. Examples of combinations that are complementary in adoption, but it is questionable whether they are technically complementary, might include rotational grazing and implants/ionophores, animal identification and calving season, and embryo transfer/sexed semen and forage testing.

Conclusions

In U.S. beef cow-calf production, there are wide ranges of 1) use of TMPPS; 2) sizes of operations; and 3) segments in which farmers are involved. These factors, along with the highly segmented nature of the beef industry (Outlaw, Anderson, and Padberg, 1997), result in significant heterogeneity in TMPPS adoption. Our analyses of TMPPS adoption lead to some striking conclusions.

Strong TMPPS adoption differences exist by region, partially reflecting the different resource sets and relative prices of inputs and outputs by region. The greater TMPPS adopters are generally in the Western and Midwestern U.S., whereas the lower adopters are generally in the Southeastern U.S. Regional differences for some TMPPS such as calving season are explained by climate differences, whereas others such as recordkeeping are less easily explained. Such differences may be the result of complementarity of adoption with other TMPPS or regional differences in producer goal structures, but further work on the reasons would be of interest. These regional differences likely contrast with the hog and broiler industries in which standardized production practices and confinement housing reduce climatic and agronomic impacts.

Size matters in adopting TMPPS in the cow-calf segment, because larger producers were more likely to adopt TMPPS in 10 of the 12 cases. Although one may argue that some TMPPS such as computer use are generally scale-neutral, examination of adoption patterns does not lead to that conclusion. In most TMPPS cases, the fixed investment of capital, labor, or learning leads to greater adoption among larger-scale operators, particularly considering that many of the small-scale producers are very small. Some in this data set have 20–50 cows and the beef cow-calf industry, as a whole, includes many producers with fewer than 20 cows, a farm size where even more dramatic differences might be expected. These results provide substantive evidence of economies of size in TMPPS adoption.

Education matters in adopting TMPPS in the cow-calf segment: producers with college degrees were more likely to adopt 10 of the 12 TMPPS. Higher education generally enhances the ability to process information and provides exposure to TMPPS, encouraging adoption. Age is also important with older producers less likely to adopt, even in cases in which the TMPPS has long been recommended such as a calving season. This may reflect a tendency of retired people who do not depend on the cow-calf enterprise for their livelihood to enter cow-calf production.

Vertically integrating into an upstream or downstream segment increases TMPPS adoption: finishers, stockers, backgrounders, and purebred producers were all greater adopters. These results provide evidence of potential vertical economies of scope throughout the supply chain in the adoption of TMPPS, particularly through the increased efficiency in which information can be transferred among segments. This finding underscores the continued importance of extension programming such as calf-to-carcass programs in which producers receive carcass information on finished cattle and are exposed to downstream segments of the U.S. beef industry.

Cow-calf producers are lower adopters of selected TMPPS than dairy and hog producers, as seen in the adoption rates of breeding technologies and the use of a nutritionist. This is symptomatic of the less vertically coordinated, land-based cow-calf enterprise that involves a lower investment in fixed assets that are specific to the enterprise and lesser economies of size. Basarir and Gillespie's (2006) finding of goal structure differences between dairy and cow-calf producers likely further explains TMPPS adoption differences.

Adoption of TMPPS is overwhelmingly complementary: of 132 pairs of the 12 TMPPS, adopters of one TMPPS had higher adoption rates than nonadopters of other TMPPS for all but three cases. Although we cannot formally test technical complementarity for each of these TMPPS pairs vs. the alternative that there is a tendency for some producers to be technology adopters regardless of the nature of the TMPPS technical relationship, we suspect that both phenomena exist to some degree for each pair. The implication is that, in examining the impact of the adoption of a particular TMPPS on productivity measures such as profitability, weaning weight, or others, careful attention needs to be paid to separating the effects of TMPPS. In addition, selection bias can be of significant concern if adopters tend to be more productive whether or not they adopt a specific TMPPS. If the complementary nature of TMPPS, as found in our results, cannot be ascribed purely to the technical interdependence of the TMPPS, then that would provide evidence for selection bias in measuring the impact of TMPPS adoption on productivity.

Most TMPPS examined in this study require relatively low investment costs and are more labor- or management-intensive, making them available to most producers even if economies of size or scope cannot be fully exploited. However, as Ward et al. (2008) state, reaching a narrowly defined target group (less educated, smaller producers) with educational programming continues to be an issue. Education and farm size have been dominant factors explaining TMPPS adoption throughout the literature. As the average age of U.S. cow-calf producers continues to increase, the next wave of producers will be more educated, providing new challenges and opportunities for extension educators as new TMPPS continue to be developed.

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