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The adoption of technologies, management practices, and production systems in U.S. milk production

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Abstract

Adoption rates of 19 dairy technologies, management practices, and production systems (TMPPS) are estimated for the U.S. for 2005 and 2010 and, in cases where data are available, 1993 and 2000. Logit models are estimated to determine types of farms most likely to use each TMPPS. TMPPS experiencing the greatest increases in adoption have been automatic take-offs, the internet, breeding technologies, and USDA certified organic production; recombinant bovine somatotropin experienced a reduction in usage between 2005 and 2010. Factors influencing TMPPS usage include farm size, tenure, and diversification; farmer age and education; and region of the U.S. where the farm is located.

Keywords: Technology adoption; Breeding technology; Computerized technology; Production system

Background

Over the past two decades, the U.S. dairy industry has experienced significant structural change that has been accompanied by increases in the adoption of productivity-influencing technologies, management practices, and production systems (TMPPS). A number of factors can be attributed to changes in TMPPS usage by dairy farmers, including the capacity of some TMPPS to allow for realization of benefits associated with economies of size and/or improved efficiency, as well as changing consumer tastes and preferences for milk produced under specific production systems. The research presented in this paper adds to past literature on dairy technology adoption by analyzing the drivers that have influenced the use of TMPPS in the U.S. dairy industry, estimating new 2010 aggregate adoption estimates for these TMPPS, and analyzing the adoption diffusion of these TMPPS over the past two decades.

There have been large changes in numbers of dairy farms, total milk production, and milk production per cow in the U.S. over the past 20-years. From 1991 to 2010, total milk production increased by 30%, the number of farms decreased by 66%, and milk production on a per-cow basis increased by 42%, showing significant changes in the industry structure and productivity over the period. Clearly, average farm size increased along with cow productivity. A major contributor to this structural change has been the adoption of TMPPS that have allowed for greater economies of size and increased cow productivity.

Farmers generally adopt a TMPPS if it serves to increase farm profit and fits within the farm's resource constraints. In deciding whether to adopt a TMPPS, the farmer must consider whether it would change output quantity, output price, and/or cost of production. For example, use of recombinant bovine somatotropin (rbST) serves to increase milk produced per cow, but in areas where non-rbST premium milk prices are provided, a lower effective price per unit is received for milk produced under the technology. Furthermore, adoption would serve to alter production costs. In addition to the costs and returns associated with a TMPPS, farmers must consider whether adoption can occur given land, labor, capital, and credit constraints. For example, adoption of a pasture-based system may not fit within the farm's resource constraints if insufficient land is available for grazing or the land is in a higher-value use.

A number of studies have addressed factors influencing the adoption of various combinations of TMPPS in dairy production, most using limited dependent variable models to assess factors influencing usage. Table 1 describes each TMPPS and provides a brief summary of previous work for each. The most recent comprehensive study addressing TMPPS usage in U.S. dairy production was Khanal et al. (2010). The present study differs from theirs in several important ways. First, they analyzed 11 TMPPS; we analyze a fuller set, 19. Second, their analysis used mean comparison tests to compare usage on the basis of five farm and farmer demographic drivers, while we use multivariate analysis (logit) to analyze usage with 16 drivers, including farm, farmer demographic, and regional variables. Thus, we were able to fully account for the influence of adoption drivers used in the logit regression models. Third, their analysis focused on adoption drivers in 2000 and 2005 while ours focuses on the more recent 2010 data. Fourth, our analysis uses the full set of USDA Agricultural Resource Management Survey (ARMS) and Farm Costs and Returns Survey (FCRS) data, dairy versions, since 1993 to examine aggregate adoption over a 17-year period. Though this period is not sufficient to examine full diffusion of most technologies from introduction to equilibrium, it provides insight into TMPPS use patterns over an extensive period of diffusion.

The analysis of technology adoption and its determinants in agriculture has a rich history. In an early classic analysis of the technology adoption process, Griliches (1957) examined the diffusion of hybrid corn in the U.S., showing that technology diffusion followed an S-shaped, logistic curve from introduction to equilibrium. This shape implies that adoption diffusion starts off rather slowly, speeds up, and eventually levels out. He further showed strong influences of region on adoption rates, suggesting that identical adoption diffusion curves do not exist under all conditions. Cochrane (1958) discussed the agricultural treadmill, addressing how early technology adopters generally benefit the most economically, with late adopters being forced to either adopt or exit production. The analysis of technology adoption in agriculture increased throughout the 1960s and 1970s. By 1985, Feder et al. (1985) had reviewed the extensive literature on technology adoption in developing countries, discussing the major adoption drivers. The literature addressing technology adoption in agriculture has expanded since then, with a large body of work conducted on adoption determinants, the extent of which will not be fully discussed here. A substantial amount of this work has dealt with the U.S. dairy industry, much of which is discussed within this paper with respect to each of the TMPPS.

Table 1 Technologies, management practices, and production systems analyzed in the study

TMPPS	Description
Computerized and/or Automated Technologies	
Computerized feed delivery system	Provides specific feed ration to an individual or group of cows, depending upon cow's lactation phase. Typically used with total mixed ration designed to meet the animal's full nutritional needs.
Computerized milking system	At least compiles computerized milking data from milker, but may also refer to an automatic milking system or fully automated robotic system. Data provided useful for making individual cow decisions (Gillespie et al., 2009a).
On-farm computer to manage Dairy Records	Provides not only convenient way for farmers to keep farm records, but also facilitates analysis of the records.
Accessing the internet for dairy Information	May yield information on prices, input and output markets, and other useful data. Larger dairy farmers more prone to adopt technology and hold off-farm jobs have had greater internet experience (Grisham and Gillespie, 2008).
Automatic take-offs for milking units	Ensure cows are not under- or over-milked (resulting in increased mastitis incidence). Senses end of milk flow, shutting off milking unit vacuum and releasing it from the cow. Results in increased labor productivity and comfort.
Holding pen with an udder Washer	Facilitates automatic washing of cow teats prior to cow entering the milking parlor.
Breeding and/or Biological Technologies	
Artificial insemination	Involves artificially introducing semen into cow after collection from bull and processing. Introduced in the 1940s. Realized quick diffusion as a means to introduce superior genetics and eliminate transfer of venereal diseases (Foote, 1996), increase economic advantage (Barber, 1983), and avoid the need for farmers to deal with bulls. Khanal and Gillespie (2013) found higher profitability and lower costs with artificial insemination.
Sexed semen	Once collected from the bull, sperm separated into female X-bearing and male Y-bearing sperm cells prior to artificially inseminating. Advantage is ability to produce calves of desired sex (DeVries et al., 2008), though lower conception rates have been of concern (Wiegel, 2004).
Embryo transfer	Involves flushing embryos from a donor cow and transferring them to a recipient cow that is usually less valuable.
Recombinant bovine somatotropin	Released for commercial use in 1994 and expected to increase milk yield by about 10 lbs/day. Adoption and effect on farm profitability extensively studied (e.g., McBride et al., 2004; Tauer, 2009; Gillespie et al., 2010), with most finding no significant impact of use on farm cost and/or profitability. Modest adoption, partly due to negative consumer reactions to its use.
Management Practices	
Regular veterinary services	Promotes improved herd health and feed efficiency, with the objective of increasing production efficiency.
Use of a nutritionist to design feed mixes or purchase feed	Improves herd health and efficiency, with objective of increasing production efficiency. May help in curbing excretion of specific nutrients that are of environmental concern.
Keeping individual cow Production Records	Provides information on performance of each animal, assisting farmer in breeding, culling, and other decisions to increase production efficiency.
Forward purchasing of inputs	Involves contracting with an input supplier prior to purchase to ensure steady supply of inputs at a specified price, reducing risk.
Negotiating price discounts for dairy inputs	Facilitates procurement of lower-cost inputs. Generally more useful for larger operations that can purchase inputs in bulk. 32% of U.S. farms used forward contracts in 1994, with cash crop farmers using them more extensively than dairy farmers (Mishra and Perry, 1999).
Production systems	
Milk cows three or more times per day	Facilitates efficient parlor usage and increased cow productivity. Third milking increases milk production per cow 6% to 19% (Amos et al., 1985; DePeters et al., 1985). Additional yield similar across cows regardless of cow productivity (Erdman and Varner, 1995). Reduced reproductive

Table 1 Technologies, management practices, and production systems analyzed in the study *(Continued)*

	efficiency may result as cow spends more time being milked (Gisi et al., 1986).
Use of a dairy parlor	Compared to stanchion milking systems, use of a parlor generally reduces milking labor costs and is more cost-efficient for larger herds (Tauer 1998). Various configurations include swing, herringbone, parallel, side opening, polygon, carousel, flat barn. Cows enter stalls for milking, usually on raised platforms, and are released after milking.
Pasture-based milk production	Refers to extensive use of pasture for cow's forage needs. Provision of ≥50% of the cow's forage ration from pasture during the grazing months (Gillespie et al., 2009b). Generally produces less milk per cow, but at lower cost per cow. Some consumers willing to pay premium prices for milk from pasture-based operations. No significant differences found in profitability between pasture-based and similar-scale conventional milk production (Gillespie et al., 2009b).
USDA certified organic milk production	Has increased over past decade in response to consumer demand. Requires use of organically-grown feed and no growth promotants or antibiotics. U.S. organic milk production costs shown to be \$5 - \$8/cwt higher than for conventional milk (McBride and Greene, 2009). No significant differences in technical efficiency found between U.S. organic and non-organic dairy farms (Mayen et al., 2010).
Controlling the breeding and/or calving season	Refers to practice of synchronizing breeding, calving, lactation, and dry seasons in dairy herd. Most often used in pasture-based operations to exploit optimal pasture conditions throughout year, but also other advantages (Turner and Skele, 2007).

In this paper, in accordance with Feder et al. (1985), we use the term, "aggregate adoption" to refer to the portion of U.S. producers using each TMPPS. Adoption diffusion, on the other hand, refers to the "process of spread of a new (TMPPS)" (Feder et al., 1985), in our case throughout the U.S.

Technologies, management practices, and production systems in the U.S. dairy production

We categorize the major TMPPS used in U.S. dairy production as computerized and/or automated technologies, breeding and/or biological technologies, management practices, and production systems. Each TMPPS analyzed in this study is described and discussed in Table 1. Computerized and/or automated technologies refer to technologies that utilize computer hardware and software to enhance the efficient use of resources and/or provide information to the farmer. These technologies included in our analysis are *Computerized Feed Delivery System, Computerized Milking System, On-farm Computer to Manage Dairy Records, Accessing the Internet for Dairy Information, Automatic Take-offs for Milking Units,* and *Holding Pen with an Udder Washer*. Breeding and/or biological technologies refer to biological advances that result in greater reproductive and/or production efficiency. These technologies included in our analysis are *Artificial Insemination, Sexed Semen, Embryo Transfer,* and *rbST*.

Management practices refer to methods farmers use to impact productivity, with or without the use of a specific technology. Management practices included in our analysis are *Regularly Scheduled Veterinary Services, Use of a Nutritionist to Design Feed Mixes or Purchase Feed, Keeping Individual Cow Production Records, Forward Purchasing of Inputs,* and *Negotiating Price Discounts for Dairy Inputs*. Production systems differ if switching from one to another involves a fundamental change in the way the farm is managed on a daily basis. Production systems included in our analysis are *Milk Cows Three or More Times per Day, Use of a Dairy Parlor, Pasture-based Milk Production, Organic Milk Production,* and *Controlling the Breeding and/or Calving Season.* Note that use of our selected TMPPS does not necessarily increase production or efficiency. For example, pasture-based systems generally require more land and less variable input per unit of milk relative to conventional systems, while producing less milk per cow. Pruitt et al. (2012) similarly categorized TMPPS for U.S. cow-calf farms, without separating the technologies into subcategories.

Methods

Similar to the exposition provided by Pruitt et al. (2012), economic theory suggests the farmer maximizes expected utility associated with the adoption of TMPPS as:

$$\max_{i} EU(\pi|\mathrm{m}) \tag{1}$$

where $i \in \{0,1\}$ with 0 indicating non-adoption and 1 indicating adoption. The $EU(.)$ operator indicates expected utility; π is profit, where $\pi = R_i - C_i$ (revenue less cost); and m are farm and farmer characteristics that impact adoption.

The logit model, which assumes a logistic distribution, is a limited dependent variable model that is appropriate for analyzing decisions where there is a yes/no (1–0) outcome, such as whether farmers adopt a TMPPS. Using the logit model (Greene, 2000, p.814).

$$Prob\ (TMPPS = 1|x) = \frac{e^{x'\beta}}{1+e^{x'\beta}} = \Lambda(x'\beta) \tag{2}$$

Parameters β reflect the impacts of changes in x on the probability of adopting the *TMPPS* and Λ(.) indicates the logistic cumulative distribution function. Two assumptions in a logit analysis examining TMPPS adoption are that producers are either adopters or non-adopters and that a TMPPS is well-defined. In actuality, in some cases producers may be partial-adopters, for example using rbST on a subset of the animals on the farm. We do not have information on percentages of production on a farm covered by each TMPPS, so our analysis addresses whether the TMPPS was adopted for any portion of the farm's production. For the second assumption, it is recognized that for some TMPPS, i.e. a computerized milking system, a range of technologies may fit under that particular category. Due to data limitations, we cannot further subdivide the category, but analyze whether the producer adopted any TMPPS that falls under that category.

Using the logit model, β parameters cannot be directly interpreted other than for sign, thus creating the need for measures that can be used to explain the magnitude of an independent variable's influence over adoption. The marginal effect for a continuous variable using the logit model is calculated as in Greene (2000, p.816):

$$\frac{\partial E[y|x]}{\partial x} = \Lambda(\beta'\mathrm{x})\ [1-\Lambda(\beta'\mathrm{x})]\beta \tag{3}$$

Marginal effects for dummy variables are calculated as shown in Greene (2000, p. 817). The McFadden R^2 is used as an indicator of goodness of fit for the models. Independent variables included in the models consist of farm structure, demographic, and regional variables, as follow.

Independent variables

Farm structure variables

Farm size is measured as the number of cows in the operation, *Cows*, and the number of *Acres* on the farm. *Cows* is the average number of milk cows on the operation during the year, divided by 100 for ease of interpretation of marginal effects. As the number of cows increases, it is expected that adoption of TMPPS with associated size economies, such as computerized feed delivery systems, will increase. TMPPS that have been considered to be scale-neutral, such as rbST, have also been found to be more extensively used by larger-scale producers (McBride et al., 2004). *Acres* is a farm size measure that considers the extent of the land base. *Acres* is defined as total acres operated, including both owned and leased land, less farmland leased to others, divided by 100 for ease of interpretation of marginal effects.

The portion of farmland owned by the operator, *Owned*, allows for consideration of the impacts of land tenancy on TMPPS usage. Feder et al. (1985) discuss differential impacts of land tenancy on TMPPS usage, depending on the nature of the TMPPS. TMPPS that require substantial labor and investments in real estate assets (i.e., building improvements) would be expected to have lower usage by renters. *Specialization,* (Value of Production from Dairy) ÷ (Value of Total Farm Production), is expected to positively impact the use of TMPPS that reduce risk and/or require greater management. Greater specialization (lower diversification) generally exposes producers to more risk, increasing the attractiveness of TMPPS such as forward pricing.

Variables Organic Milk Production and Pasture-based Milk Production Systems differ in resource usage and, in some cases, output than their "conventional" counterparts, thus their inclusion as independent variables. The expected impact of these systems on adoption varies by TMPPS. For instance, since rbST is prohibited for USDA certified organic dairies and the marginal value product of its use would unlikely exceed the marginal factor cost for pasture-based production, expected signs for these systems would be negative for rbST. Observation suggests that USDA certified organic and pasture-based systems tend to be less technology-intensive in general. On the other hand, use of controlled breeding seasons would be expected to increase with either of these systems and good record-keeping is required for USDA certified organic production.

Farmer demographic variables

Two farmer demographic variables are included, farmer *Age* (the farmer's age divided by 10 for ease of interpretation of marginal effects) and whether the farmer holds a four-year *College* degree. Older farmers have generally been lower users of TMPPS for which they are unlikely to realize a full stream of benefits prior to retirement, or which change their management requirements, such as rbST (McBride et al., 2004). Farmers with more education are expected to be greater users of advanced TMPPS, as found by McBride et al. (2004) and Ward et al. (2008).

Regions

Nine U.S. production regions are included: *West* (Arizona-AZ, Colorado-CO, Idaho-ID, New Mexico-NM), *Pacific* (California-CA, Oregon-OR, Washington-WA), *Southeast* (Florida-FL, Georgia-GA), *Corn Belt* (Illinois-IL, Indiana-IN, Iowa-IA, Missouri-MO, Ohio-OH), *Northern Plains* (Kansas-KS), *Appalachia* (Kentucky-KY, Tennessee-TN, Virginia-VA), *Northeast* (Maine-ME, New York-NY, Pennsylvania-PA, Vermont-VT), *Lake States* (Michigan-MI, Minnesota-MN, Wisconsin-WI), and *Southern Plains* (Texas-TX). These regions differ in dairy industry structure, with the *Northeast* and *Lake States* traditionally being the largest dairy regions and the *West* and *Pacific* regions experiencing more recent growth. The base region in our models is the *Lake States.*

Comparing 2005 and 2010 aggregate adoption rates

Aggregate adoption rates of 19 TMPPS for 2005 and 2010 are compared using pair-wise 2-tailed *t*-tests utilizing the delete-a-group jackknife estimation procedure. The delete-a-group jackknife estimation procedure is used because the ARMS data are collected via a complex survey design with both an area and list frame, rather than a model-based random sample most commonly used for statistical analysis. Dubman (2000) explains how to estimate *t*-tests utilizing this procedure with ARMS data. These tests allow for determination of whether there were significant differences in aggregate adoption rates in 2005 versus 2010 and, thus, whether significant adoption diffusion occurred over the 5-year period for each TMPPS. For 12 of the TMPPS, Khanal et al. (2010) conducted similar analysis for 2000 and 2005. We included their aggregate adoption rates in our graphical analysis in order to present an extended perspective of diffusion. Additional aggregate adoption estimates are made for 1993 and 2000 in cases where data are available, allowing for further investigation of diffusion (to be discussed in greater detail in the next section). In addition to reporting percentages of farms using TMPPS, we also examine percentages of the total milk quantity produced by farmers using each of the TMPPS in 2005 and 2010.

Data

Data for analyses conducted in this study are primarily from the 2005 and 2010 ARMS, dairy version, conducted by the USDA National Agricultural Statistics Service (NASS) and Economic Research Service (ERS). The ARMS is conducted annually to collect economic information on U.S. farms. Every year, enterprises are selected for more in-depth surveying so that enterprise cost of production, input usage, and production systems can be estimated. The dairy enterprise was surveyed in detail in 1993 (FCRS), 2000, 2005, and 2010 (ARMS). Logit TMPPS adoption models used only 2010 data while aggregate adoption rates were estimated using all available years. We tried pooling 2005 and 2010 data for the logit analyses in a manner similar to Gillespie et al. (2010), but were not able to satisfy the likelihood ratio index poolability test as discussed in Pesaran et al. (1999). We found that interaction terms would be required for the discrete variable indicating year with all other independent variables. The implication was that independent variables had differential effects on the dependent variable, depending upon year. This resulted in multicollinearity, convergence problems in some cases, and minimal additional insight, leading us to use only 2010 data for the logit analyses. To ensure that only commercial operations were surveyed, the operation must have milked at least 10 cows at any time during the year. States covered include those listed above in the *Regions* subsection; KS and CO were surveyed in 2010 only. The

ARMS collects information on costs and returns at both whole-farm and dairy enterprise levels, TMPPS usage, and farm and household characteristics.

Sample farms for ARMS are selected from a list maintained by NASS. Using stratified sampling, each farm represents other "like" farms in the population. The dataset contains expansion factors (weights) to allow for extrapolation to the U.S. dairy population of the states where the survey was conducted. These states represent 90% of the U.S. dairy farm population of farms with 10 or more cows. Data were collected consistently in both 2005 and 2010 (hand enumeration using a complex sampling scheme and broad national coverage), so results from both years can be compared. The 2005 (2010) data include 1,814 (1,915) observations, respectively. For several TMPPS, adoption estimates may be made from the 2000 ARMS dairy survey and the 1993 Farm Costs and Returns Survey (FCRS), both of which were conducted using similar methods and, thus, are comparable to the 2005 and 2010 ARMS. The 2000 ARMS dairy survey included 870 observations from the same states as those in the 2005 ARMS with the exception of ME and OR. The 1993 dairy FCRS included 695 observations. These data do not link the same farms; each year's data is a separate cross-section representing the dairy farm population for that year. For several TMPPS, particularly those in the Computerized and/or Automated Technologies category, it is acknowledged that advances have been made over the past two decades; for example, up-to-date computerized milking systems may look different from those installed in 1993. Thus, interpretation of results for those TMPPS must be made with that realization.

Consistent with Dubman (2000), the delete-a-group jackknife procedure with 30 replicates is used for deriving statistical estimates. For more information as to why this procedure is used to estimate standard errors using the ARMS data derived from a complex survey design, see the report by the National Research Council, Panel to Review USDA's Agricultural Resource Management Survey (2008).

Results and discussion

Computerized and/or automated technologies

Aggregate adoption rates for computerized and/or automated technologies are shown in Figure 1. In 2010, computerized feed delivery systems were used by 8.7% of farmers compared with 7.1% in 2005, but the difference was not statistically significant (Table 2). This is compared with estimated usage rates of 8.1% in 2000 (Khanal et al., 2010) and 6.3% in 1993 (Short, 2000), showing rather tepid diffusion response over the 1993–2010 period. The percentage of milk produced by farms using computerized feed delivery systems increased from 28.2% in 2005 to 37.7% in 2010 (Table 2). For 2010, an additional 100 cows or 100 acres increased usage by 0.7 or 0.3 percentage points, respectively (Table 3). A farmer owning 100% versus 0% of his or her land decreased usage by 2.9 percentage points. Increasing the percentage of farm returns from dairy by 1% increased usage by 0.12 percentage points. Two of the regional variables were significant: Southeastern and Southern Plains producers were less likely to have adopted than Lake States farmers. Overall, while percentages of farmers using computerized feed delivery systems changed little over the past two decades, the percentage of milk produced by farms using this technology increased, explained by increasing numbers of larger-scale farms using it, as supported by our results. Though significance of regions

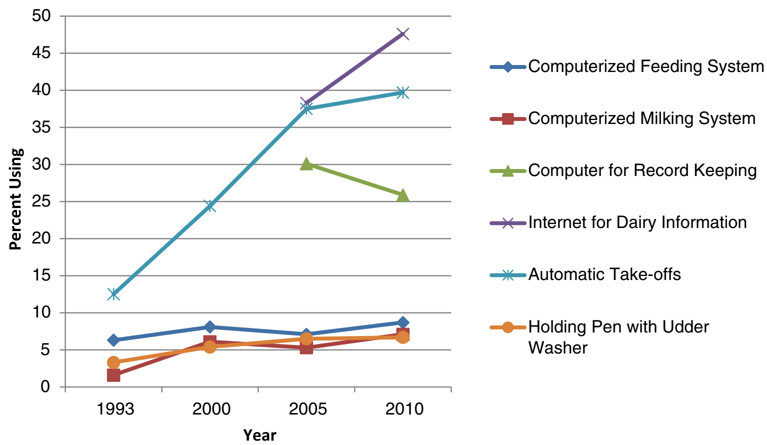

Figure 1 Percentage of U.S. Dairy Farms Using Computerized and/or Automated Technologies. Source: USDA ARMS and FCRS Dairy Surveys.

is found for most TMPPS and shown in Table 3, in the interest of space, these results are not discussed further in the text.

The aggregate adoption rate for computerized milking systems increased from 5.3% in 2005 to 7.1% in 2010. These adoption rates are compared with the estimated aggregate adoption rates of 6.1% in 2000 (Khanal et al., 2010) and 1.6% in 1993 (Short, 2000), showing limited diffusion after 2000. The percentage of milk produced by farms using computerized milking systems was 22.8% and 24.2% in 2005 and 2010, respectively. Usage was greater on farms with more acreage, where a higher percentage of the land was owned by the farmer, and that were more heavily specialized in dairy. In 2010, holding a college degree increased usage by 5.6 percentage points. USDA certified organic farmers had usage rates that were 2.3 percentage points lower than those of non-organic farmers. Overall, computerized milking systems experienced modest diffusion over the past decade. Adoption drivers included specialization in dairy and the farmer's education level.

In 2010, the aggregate adoption rate of on-farm computers for record-keeping was 25.9% of farmers compared with 30.1% in 2005, but the difference was not statistically significant. The percentage of milk produced by farmers using an on-farm computer for record-keeping increased from 66.1% in 2005 to 73.1% in 2010. Larger-scale farmers and those holding college degrees were the greater users. Though use of on-farm computers for record-keeping does not appear to have increased from 2005 to 2010, use by larger-scale, more highly-educated producers producing greater percentages of the milk in 2010 suggests greater diffusion in the near future.

The percentage of farms using the internet for collecting dairy information increased from 38.2% in 2005 to 47.6% in 2010. The percentage of milk produced by farmers using the internet for dairy information increased from 63.6% in 2005 to 79.9% in 2010. In 2010, large-scale, specialized, and educated farmers were the greater users. Considering (1) larger farms run by more highly educated farmers are increasing in number, and (2) internet usage is generally diffusing throughout the general population, significant future diffusion is expected.

In 2010, the aggregate adoption rate for automatic take-offs for milking units was 39.7% of farmers, compared with 37.5% in 2005, but the difference was not statistically

Table 2 Adoption rates of technologies, management practices, and production systems (TMPPS) on U.S. dairy farms

Technology, Management Practice, or Production System	% of Farms Adopting 2005	% of Farms Adopting 2010	% of Milk Produced Covered by TMPPS 2005	% of Milk Produced Covered by TMPPS 2010
Computerized and/or Automated Technologies				
Computerized Feed Delivery System	7.1	8.7	28.2[c]	37.7[d]
Computerized Milking System	5.3[a]	7.1[b]	22.8	24.2
On-farm Computer for Records	25.9	30.1	66.1[c]	73.1[d]
Internet for Dairy Information	38.2[a]	47.6[b]	63.6[c]	79.9[d]
Automatic Take-offs for Milking Units	37.5	39.7	72.9	77.0
Holding Pen with an Udder Washer	6.5	6.7	31.4	30.7
Breeding and/or Biological Technologies				
Artificial Insemination	81.5	80.1	88.9[c]	92.2[d]
Embryo Transfer and/or Sexed Semen	10.4[a]	17.8[b]	15.7[c]	24.3[d]
Recombinant Bovine Somatotropin	16.6[a]	8.5[b]	40.0[c]	16.6[d]
Management Practices				
Regularly Scheduled Veterinary Services	68.4	65.8	87.5	90.1
Nutritionist to Design Feed Mixes	71.6	72.6	87.8	90.0
Individual Cow Production Records	60.6	63.6	81.6	84.9
Forward Purchasing of Inputs	19.4	21.9	44.2[c]	53.1[d]
Negotiated Price Discounts for Inputs	34.5	36.2	60.0[c]	71.2[d]
Production Systems				
Milk Cows ≥3 Times per Day	7.0	9.4	30.4[c]	41.8[d]
Dairy Parlor	49.9	53.0	83.9[c]	89.3[d]
Pasture-based Milk Production	18.3	20.0	6.8	6.6
USDA Certified Organic Milk Production	1.6	8.6	0.7[c]	3.3[d]
Controlled Breeding and/or Calving Season	25.3	24.8	24.2	20.9

Superscripts [a] and [b] indicate that the estimates differ significantly at $P < 0.10$. Likewise, superscripts [c] and [d] indicate that the estimates differ significantly at $P < 0.10$.

significant. This is compared with estimated aggregate adoption rates of 24.4% in 2000 (Khanal et al., 2010) (which differed from the 2005 estimated at $P \leq 0.10$) and 12.5% in 1993 (Short, 2000). The percentage of milk produced by farms using automatic take-offs was 72.9% and 77.0% in 2005 and 2010, respectively. It appears that significant diffusion of the technology occurred up to 2005, with little additional diffusion thereafter.

Table 3 Logit results of farmer adoption of computerized/automated technology, 2010 (Standard errors in parenthesis)

Variable	Units	Computerized Feed Delivery System		Computerized Milking System		Computer to Manage Dairy Records	
		β	Marg Effect	β	Marg Effect	β	Marg Effect
Constant		−4.8220*** (0.8249)		−5.6313*** (0.9065)		−2.7211*** (0.6024)	
Farm Structure							
Cows	No./100	0.1220*** (0.0336)	0.0074*** (0.0020)	0.0214 (0.0195)	0.0010 (0.0010)	0.4062*** (0.1406)	0.0892*** (0.0330)
Acres	No./100	0.0515** (0.0225)	0.0031** (0.0010)	0.0791*** (0.0261)	0.0038*** (0.0010)	0.1081*** (0.0334)	0.0237*** (0.0070)
Owned	Portion	−0.4698* (0.2717)	−0.0285* (0.0162)	0.2866*** (0.1052)	0.0138*** (0.0050)	0.1438 (0.1046)	0.0316 (0.0231)
Specialized	Portion	1.9100** (0.7621)	0.1161** (0.0477)	2.0391** (0.8850)	0.0983** (0.0425)	0.7340 (0.6151)	0.1612 (0.1334)
Organic	0-1	−0.9541** (0.3986)	−0.0419*** (0.0154)	−0.5936* (0.3557)	−0.0231* (0.0131)	0.0266 (0.2031)	0.0059 (0.0449)
Pasture-based	0-1	−0.0877 (0.5212)	−0.0052 (0.0301)	−0.3445 (0.5208)	−0.0152 (0.0201)	−0.2756 (0.2593)	−0.0587 (0.0527)
Farmer Demographics							
Age	Yrs./10	0.1025 (0.1009)	0.0062 (0.0062)	0.1017 (0.1078)	0.0049 (0.0051)	0.0002 (0.0684)	0.0000 (0.0150)
College	0-1	0.5915* (0.3127)	0.0440 (0.0278)	0.8527*** (0.2893)	0.0559** (0.0239)	1.0507*** (0.2400)	0.2506*** (0.0580)
Regions							
West	0-1	0.4910 (0.4646)	0.0367 (0.0408)	0.0486 (0.4873)	0.0024 (0.0244)	0.7398* (0.3949)	0.1769* (0.0975)
Pacific	0-1	0.3543 (0.4289)	0.0247 (0.0334)	0.9872** (0.3992)	0.0715* (0.0391)	0.3691 (0.4413)	−0.0587 (0.0527)
Southeast	0-1	−0.9249* (0.5238)	−0.0385** (0.0161)	−3.6464 (2.2622)	−0.0513*** (0.0088)	0.1809 (0.3427)	0.0409* (0.0789)
Corn Belt	0-1	0.3359 (0.3528)	0.0225 (0.0250)	−0.0159 (0.3860)	−0.0008 (0.0185)	0.3226 (0.2174)	0.0732 (0.0501)
Northern Plains	0-1	−0.0263 (0.5652)	−0.0016 (0.0336)	−0.6097 (0.7224)	−0.0227 (0.0209)	0.3226 (0.2174)	−0.0277 (0.0849)
Appalachia	0-1	−0.1633 (0.3950)	−0.0093 (0.0215)	−0.0257 (0.3921)	−0.0012 (0.0186)	−0.2235 (0.2494)	−0.0472 (0.0511)
Northeast	0-1	−0.1040 (0.4136)	−0.0062 (0.0241)	0.0795 (0.4258)	0.0039 (0.0212)	−0.0914 (0.2640)	−0.0199 (0.0571)
Southern Plains	0-1	−2.0439** (1.0421)	−0.0586*** (0.0137)	−3.6757 (3.0604)		−0.6904 (0.4545)	−0.1317* (0.0754)
Diagnostics							
Pseudo R-square		0.1511		0.1266		0.1989	

Table 3 Logit results of farmer adoption of computerized/automated technology, 2010 (Standard errors in parenthesis) *(Continued)*

Variable	Units	Computerized Feed Delivery System		Computerized Milking System		Computer to Manage Dairy Records	
		β	Marg Effect	β	Marg Effect	β	Marg Effect
Constant		−1.3024*** (0.5003)		−1.8703*** (0.5522)		−4.4040*** (0.9720)	
Farm Structure							
Cows	No./100	0.2420** (0.0998)	0.0605** (0.0250)	0.3545* (0.1933)	0.0877* (0.0490)	0.0369* (0.0199)	0.0012* (0.0007)
Acres	No./100	0.0820*** (0.0293)	0.0205*** (0.0070)	0.1654*** (0.0421)	0.0409*** (0.0100)	0.0090 (0.0174)	0.0002 (0.0010)
Owned	Portion	0.0285 (0.1061)	0.0071 (0.0265)	0.1133 (0.1227)	0.0280 (0.0304)	0.0779 (0.1115)	0.0025 (0.0035)
Specialized	Portion	1.0941** (0.4581)	0.2733** (0.1145)	1.1199** (0.5113)	0.2769** (0.1250)	−0.5187 (0.6899)	−0.0168 (0.0227)
Organic	0-1	0.0297 (0.1730)	0.0074 (0.0432)	−0.6630*** (0.2012)	−0.1552*** (0.0439)	−0.6928 (0.4412)	−0.0174* (0.0096)
Pasture-based	0-1	−0.3330 (0.2134)	−0.0830 (0.0528)	−0.7728*** (0.2555)	−0.1821*** (0.0547)	−0.9543* (0.5126)	−0.0243** (0.0098)
Farmer Demographics							
Age	Yrs./10	−0.0318 (0.0701)	−0.0079 (0.0175)	−0.0911 (0.0686)	−0.0225 (0.0170)	0.2504*** (0.0951)	0.0810** (0.0350)
College	0-1	1.5028*** (0.2834)	0.3286*** (0.0485)	0.8154*** (0.2822)	0.2006*** (0.0666)	0.1055 (0.2457)	0.0035 (0.0085)
Regions							
West	0-1	0.1956 (0.3883)	0.0486 (0.0957)	−1.2902** (0.6198)	−0.2677*** (0.1018)	1.2892** (0.5237)	0.0766* (0.0460)
Pacific	0-1	−0.0166 (0.3635)	−0.0042 (0.0908)	1.2490*** (0.4616)	0.2944*** (0.0972)	3.6362*** (0.4186)	0.4907*** (0.0799)
Southeast	0-1	−0.4735 (0.3227)	−0.1170 (0.0779)	−1.5584*** (0.5061)	−0.3041*** (0.0749)	2.3456*** (0.4211)	0.2279*** (0.0668)
Corn Belt	0-1	−0.3144 (0.2014)	−0.0784 (0.0500)	−0.3053 (0.2074)	−0.0744 (0.0500)	−0.2714 (0.5588)	−0.0081 (0.0158)
Northern Plains	0-1	−0.1517 (0.4114)	−0.0379 (0.1027)	0.9535** (0.4754)	0.2304** (0.1046)	0.4631 (0.8462)	0.0186 (0.0408)
Appalachia	0-1	−0.7061*** (0.2290)	−0.1719*** (0.0531)	0.5523** (0.2214)	0.1372** (0.0541)	−0.0985 (0.5255)	−0.0031 (0.0159)
Northeast	0-1	−0.6250*** (0.2307)	−0.1548*** (0.0560)	−0.2459 (0.2386)	−0.0603 (0.0579)	0.0964 (0.5536)	0.0032 (0.0186)
Southern Plains	0-1	−0.6308 (0.4073)	−0.1542 (0.0950)	−1.6702*** (0.5661)	−0.3204*** (0.0789)	1.7811*** (0.5201)	0.1327** (0.0624)
Diagnostics							
Pseudo R-square		0.1223		0.1916		0.3086	

Note: *, **, and *** indicate significance at the P ≤0.10, P ≤0.05, and P ≤0.01 levels, respectively.

In 2010, large-scale, specialized, and educated farmers exhibited higher probability of using the technology. Furthermore, USDA certified organic or pasture-based operations had lower usage rates of 15.5 and 18.2 percentage points, respectively. Though diffusion was relatively stagnant between 2005 and 2010, increases in farm size and farmer education suggest modest diffusion in the near future.

In 2010, the aggregate adoption rate of holding pens with udder washers was 6.7% of farmers, compared with 6.5% in 2005, but the difference was not statistically significant. This is compared with estimated aggregate adoption of 5.4% in 2000 (Khanal et al., 2010) and 3.3% in 1993 (Short, 2000). The percentage of milk produced by farms using holding pens with udder washers was 31.4% and 30.7% in 2005 and 2010, respectively. In 2010, farmers with more cows were greater users and an additional 10 years of the farmer's age increased usage by 0.8 percentage points. USDA certified organic and pasture-based operations were lower users of this technology. Though diffusion of this technology has stagnated in recent years, increases in farm size and farmer education suggest modest diffusion in coming years.

Breeding and/or biological technologies

Aggregate adoption rates for breeding and/or biological technologies are shown in Figure 2 and logit results are shown in Table 4. In 2010, the aggregate adoption rate of artificial insemination was 80.1% of farmers, compared with 81.5% in 2005, but the difference was not statistically significant. Khanal et al. (2010) showed that in 2000, 64.3% of farmers used, as stated in the 2000 ARMS dairy survey, "genetic selection and breeding programs (embryo transplants, artificial insemination)." Since embryo transplants would rarely be used without artificial insemination, it is probable that all of these farms used artificial insemination, making this a reasonable estimate of the percentages of farms using the technology. Given that the 2000 and 2005 usage differed at $P \leq 0.10$, it appears that significant adoption diffusion occurred prior to 2005, but not thereafter. The percentage of milk produced by farms using artificial insemination increased from 88.9% in 2005 to 92.2% in 2010. Greater users of the technology in 2010 were large-scale, specialized, and educated farmers. On the other hand, operating a USDA certified organic or pasture-based operation reduced usage. Artificial insemination adoption may be nearing an equilibrium point since 90% of the milk produced is now covered by this technology.

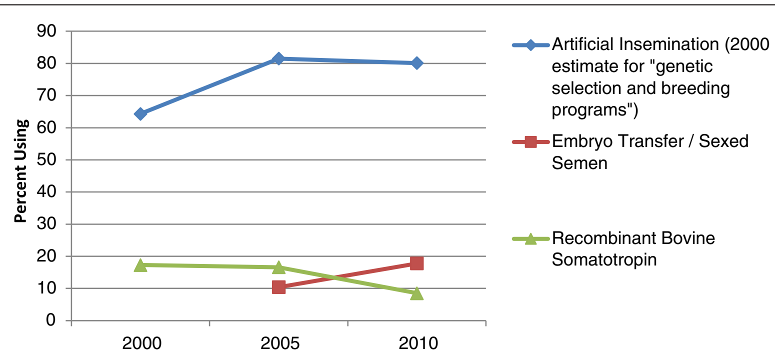

Figure 2 Percentage of U.S. Dairy Farms Using Breeding and/or Biological Technologies. Source: USDA ARMS and FCRS Dairy Surveys.

In 2010, the aggregate adoption rate of embryo transfer and/or sexed semen was 17.8% of farmers, compared with 10.4% in 2005, statistically different at $P \leq 0.05$. The percentage of milk produced by farms using embryo transfer and/or sexed semen technology increased from 15.7% to 24.3% from 2005 to 2010, respectively. In 2010, large-scale, young, and educated farmers were greater users of this technology, while USDA certified organic farmers were lower users. Strong increases are attributed primarily to the diffusion of sexed semen, with additional diffusion expected as farms become larger and more highly educated farmers enter the industry.

In 2010, the aggregate adoption rate of rbST was 8.5% of farmers compared with 16.6% in 2005, statistically different at $P \leq 0.01$. This is compared with an estimated aggregate adoption of 17.3% in 2000 (Khanal et al., 2010) and shows significant decline in the percentage of farms using rbST. This reduction is likely due to consumer concerns regarding rbST and resultant premiums for milk produced without the use of rbST. Past economic studies that have not shown increased profitability with rbST adoption also partially explain declining usage. Furthermore, to get the desired production response with rbST, greater management of feed inputs is needed. The percentage of milk produced by farms using rbST decreased from 40.0% in 2005 to 16.6% in 2010. For 2010, greater ownership of land increased rbST usage.

Management practices

Aggregate adoption rates for management practices are shown in Figure 3 and logit results are shown in Table 5. In 2010, the aggregate adoption rate for regularly scheduled veterinary services was 65.8% of farmers, compared with 68.4% in 2005, but the difference was not statistically significant. The percentages of milk produced by farms using regularly scheduled veterinary services were 87.5% and 90.1% in 2005 and 2010, respectively. In 2010, larger-scale and younger farmers were greater users, while certified organic and pasture-based farms were lower users. Increased numbers of larger-scale farms (greater use) along with increased numbers of certified organic farms (lower use) partially explain stagnant adoption.

In 2010, aggregate adoption of a nutritionist to design feed mixes was 72.6% of farmers, compared with 71.6% in 2005, but the difference was not statistically significant. This is compared with an estimated aggregate adoption rate of 66.9% in 2000 (Khanal et al., 2010). The percentage of milk produced by farmers using a nutritionist to design feed mixes was 87.8% and 90.0% in 2005 and 2010, respectively. In 2010, younger farmers and those who had more cows were greater users, while certified organic and pasture-based farmers had lower usage rates. Modest diffusion over the past decade may be partially explained by the opposing factors of increased farm size and increased certified organic production.

The 2010 aggregate adoption rate of individual cow production records was 63.6% of farmers compared with 60.6% in 2005, but the difference was not statistically significant. The percentage of milk produced by farmers keeping individual cow production records was 81.6% and 84.9% in 2005 and 2010, respectively. In 2010, large-scale, specialized, educated, and organic-certified farmers were greater users, while pasture-based farmers were lower users. Though rapid diffusion of this practice is not evident, it is generally considered by dairy farm management professionals to be an important component in increasing productivity. More larger and certified organic farms should result in greater diffusion.

Table 4 Logit results of dairy farmer adoption of breeding and/or biological technologies, 2010 (Standard errors in parenthesis)

Variable	Units	Artificial Insemination		Embryo Transfer and/or Sexed Semen		Recombinant Bovine Somatotropin	
		β	Marg Effect	β	Marg Effect	β	Marg Effect
Constant		0.5505 (0.5881)		−1.1789** (0.5862)		−2.1980** (0.9552)	
Farm Structure							
Cows	No./100	0.0904** (0.0039)	0.0124 (0.0050)	−0.0080 (0.0137)	−0.0011 (0.0020)	0.0227 (0.0156)	0.0014 (0.0010)
Acres	No./100	−0.0026 (0.0203)	−0.0004 (0.0030)	0.0430*** (0.0150)	0.0058*** (0.0020)	0.0759*** (0.0258)	0.0047*** (0.0020)
Owned	Portion	0.0272 (0.0947)	0.0037 (0.0130)	0.1152 (0.1086)	0.0156 (0.0146)	0.2500** (0.1140)	0.0153** (0.0069)
Specialized	Portion	1.3565*** (0.5033)	0.1857*** (0.0704)	0.2655 (0.4738)	0.0359 (0.0642)	0.8526 (0.7443)	0.0523 (0.0458)
Organic	0-1	−1.0418*** (0.1950)	−0.1848*** (0.0378)	−1.7048*** (0.2730)	−0.1428*** (0.0189)		
Pasture-based	0-1	−0.6382*** (0.2245)	−0.0990*** (0.0385)	−0.2700 (0.3065)	−0.0345 (0.0367)	−0.5205 (0.4887)	−0.0280 (0.0224)
Farmer Demographics							
Age	Yrs./10	0.0585 (0.0842)	0.0080 (0.0116)	−0.1524* (0.0834)	−0.0206* (0.0112)	−0.2132 (0.1448)	−0.0131 (0.0089)
College	0-1	0.9075*** (0.2945)	0.0979*** (0.0243)	0.7171*** (0.2473)	0.1156** (0.0456)	0.3967 (0.3398)	0.0278 (0.0265)
Regions							
West	0-1	−1.3309*** (0.4031)	−0.2591*** (0.0948)	−0.5137 (0.3592)	−0.0584* (0.0351)	−3.1607*** (1.2306)	−0.0663*** (0.0104)
Pacific	0-1	−0.2934 (0.3836)	−0.0438 (0.0618)	0.1479 (0.3170)	0.0209 (0.0463)	−1.2464** (0.5305)	−0.0488*** (0.0142)
Southeast	0-1	−2.0875*** (0.3188)	−0.4461*** (0.0723)	−0.5125 (0.4233)	−0.0581 (0.0408)		
Corn Belt	0-1	−0.9362*** (0.2398)	−0.1550*** (0.0445)	−0.0845 (0.2577)	−0.0112 (0.0338)	−1.0171*** (0.3797)	−0.0481*** (0.0152)
Northern Plains	0-1	−0.6402 (0.4731)	−0.1066 (0.0917)	−0.2606 (0.4214)	−0.0323 (0.0481)	−0.7839 (0.5455)	−0.0349* (0.0179)
Appalachia	0-1	−1.9202*** (0.2434)	−0.3981*** (0.0543)	−0.1872 (0.2756)	−0.0239 (0.0337)	−2.2961*** (0.7466)	−0.0647*** (0.0115)
Northeast	0-1	−0.0168 (0.2927)	−0.0023 (0.0403)	0.0724 (0.2900)	0.0099 (0.0400)	−0.2535 (0.3408)	−0.0148 (0.0189)
Southern Plains	0-1	−2.5655*** (0.3651)	−0.5501*** (0.0733)	−1.7184** (0.6979)	−0.1319*** (0.0271)	−2.6556* (1.5891)	−0.0643*** (0.0126)
Diagnostics							
Pseudo R-square		0.1217		0.0459		0.0892	

Note: *, **, and *** indicate significance at the P ≤0.10, P ≤0.05, and P ≤0.01 levels, respectively.

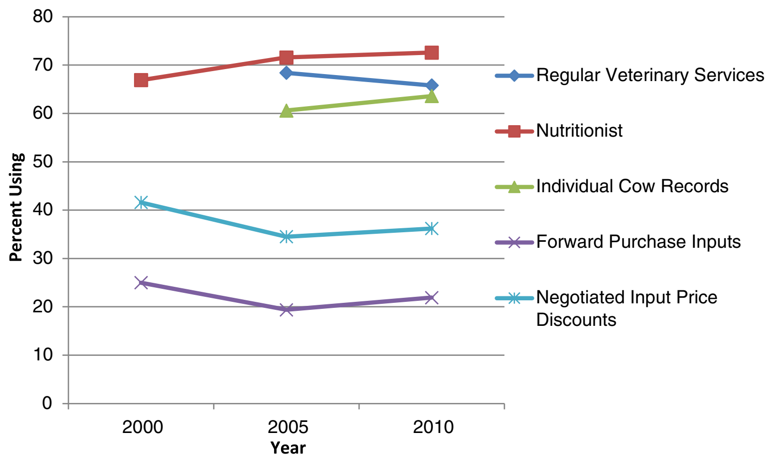

Figure 3 Percentage of Dairy Farms Using Selected Management Practices, U.S. Source: USDA ARMS and FCRS Dairy Surveys.

In 2010, 21.9% of farmers forward-purchased inputs, compared with 19.4% in 2005, but the difference was not statistically significant. This is compared with 25.0% of farmers forward purchasing inputs in 2000. The percentage of milk produced by farmers forward-purchasing inputs increased from 44.2% in 2005 to 53.1% in 2010. In 2010, farmers who were larger-scale, younger, educated, and those who owned greater percentages of their farmland were greater users, while certified organic and pasture-based producers were lower users. Though diffusion of this practice is not noticeable on a percentage-of-farms basis, modest diffusion is expected with the entry of larger-scale farms with more highly educated producers.

In 2010, 36.2% of farmers negotiated price discounts for inputs, compared with 34.5% in 2005, but the difference was not statistically significant. This is compared with 41.6% of farmers negotiating price discounts in 2000. The percentage of milk produced by farmers who negotiated for price discounts for inputs increased from 60.0% in 2005 to 71.2% in 2010. In 2010, larger-scale, younger, and educated farmers, and those who owned greater percentages of their farmland were greater users, while certified organic farmers were lower users. Implications for further diffusion of this management practice are similar to those for forward purchasing of inputs.

Production systems

Aggregate adoption rates for production systems are shown in Figure 4 and logit results are shown in Table 6. In 2010, 9.4% of farmers milked cows at least 3 times a day, compared with 7.0% in 2005, but the difference was not statistically significant. This is compared with 3.4% of farmers milking at least 3 times per day in 2000 (Khanal et al., 2010) (which differed from the 2005 estimate at $P \leq 0.10$) and 2.7% in 1993. Overall, the percentage of farmers milking cows at least 3 times daily has increased modestly over the past two decades. The percentage of milk produced by farms milking cows at least 3 times per day increased from 30.4% in 2005 to 41.8% in 2010. In 2010, larger-scale, specialized, and more educated farmers were greater users, while certified organic and pasture-based farmers were lower users. Though the differences in the percentage of farms using this system was not statistically significant over the period, 2005–2010, it

Table 5 Logit results for dairy farmer adoption of management practices, 2010 (Standard errors in parenthesis)

Variable	Units	Regular Veterinary Services		Nutritionist to Design Feed Mixes/Purchase		Keep Individual Cow Production Records		Forward Purchasing of Inputs		Negotiate Price Discounts for Inputs	
		β	Marg Effect	β	Marg Effect	β	Marg Effect	β	Marg Effect	β	Marg Effect
Constant		0.9779* (0.5619)		2.2682*** (0.5681)		−0.0730 (0.5371)		−0.9932 (0.6556)		−0.2132 (0.5356)	
Farm Structure											
Cows	No./100	0.3171** (0.1491)	0.0638** (0.0270)	0.1747* (0.0907)	0.0319** (0.0160)	0.1170 (0.0874)	0.0263 (0.0190)	0.0969** (0.0392)	0.0152** (0.0060)	0.2356*** (0.0616)	0.0555*** (0.0150)
Acres	No./100	0.0807*** (0.0290)	0.0162*** (0.0060)	0.0245 (0.0230)	0.0045 (0.0040)	0.0492** (0.0241)	0.0111** (0.0060)	0.0670*** (0.0218)	0.0110*** (0.0030)	0.0769*** (0.0235)	0.0181*** (0.0050)
Owned	Portion	0.1526 (0.0932)	0.0307 (0.0187)	0.0129 (0.1027)	0.0024 (0.0188)	0.1515* (0.0906)	0.0341* (0.0204)	0.1977* (0.1057)	0.0310* (0.0167)	0.1737* (0.0896)	0.0409* (0.0212)
Specialized	Portion	0.3708 (0.4797)	0.0745 (0.0971)	0.2184 (0.5011)	0.0399 (0.0915)	1.0345** (0.4783)	0.2329** (0.1084)	0.1089 (0.5634)	0.0171 (0.0883)	0.1536 (0.4778)	0.0362 (0.1125)
Organic	0-1	−0.7560*** (0.1825)	−0.1696*** (0.0437)	−0.8361*** (0.1802)	−0.1771*** (0.0403)	0.3477* (0.1894)	0.0744* (0.0390)	−0.6341*** (0.2225)	−0.0841*** (0.0265)	−0.6024*** (0.1830)	−0.1312*** (0.0376)
Pasture-based	0-1	−1.4377*** (0.2251)	−0.3250*** (0.0546)	−1.2251*** (0.2219)	−0.2590*** (0.0518)	−1.0914*** (0.2155)	−0.2599*** (0.0521)	−1.2014*** (0.2702)	−0.1504*** (0.0262)	−0.2873 (0.2310)	−0.0661 (0.0516)
Farmer Demographics											
Age	Yrs./10	−0.1978*** (0.0767)	−0.0398*** (0.0154)	−0.2680*** (0.0732)	−0.0489*** (0.0132)	−0.0994 (0.0690)	−0.0224 (0.0155)	−0.1863** (0.0793)	−0.0292** (0.0126)	−0.2208*** (0.0697)	−0.0520*** (0.0165)
College	0-1	0.1120 (0.2441)	0.0021 (0.0474)	0.1344 (0.2611)	0.0239 (0.0452)	0.6260** (0.3020)	0.1285** (0.0553)	0.9036*** (0.2394)	0.1709*** (0.0518)	0.5234** (0.2171)	0.1275** (0.0573)
Regions											
West	0-1	0.1626 (0.3951)	0.0315 (0.0746)	−0.1990 (0.3567)	−0.0381 (0.0707)	−0.4782 (0.3339)	−0.1139 (0.0824)	0.4811 (0.3260)	0.0861 (0.0781)	−0.0821 (0.3375)	−0.0192 (0.0781)
Pacific	0-1	0.1620 (0.3884)	0.0315 (0.0738)	−0.5675* (0.3451)	−0.1163 (0.0760)	0.3482 (0.3762)	0.0742 (0.0763)	0.2478 (0.3260)	0.0415 (0.0576)	−0.0817 (0.3208)	−0.0191 (0.0743)

Table 5 Logit results for dairy farmer adoption of management practices, 2010 (Standard errors in parenthesis) *(Continued)*

Southeast	0-1	−1.3025***	−0.3077***	−0.5115	−0.1048	0.2343	0.0507	−0.9940**	−0.1135***	−0.3641	−0.0815
		(0.3561)	(0.0841)	(0.3379)	(0.0746)	(0.3454)	(0.0721)	(0.3960)	(0.0327)	(0.3387)	(0.0718)
Corn Belt	0-1	−0.1350	−0.0277	−0.2997	−0.0574	−0.1171	−0.0267	0.0895	0.0143	−0.2650	−0.0610
		(0.2153)	(0.0447)	(0.2263)	(0.0447)	(0.2005)	(0.0460)	(0.2222)	(0.0359)	(0.2030)	(0.0459)
North Plains	0-1	−1.0329**	−0.2411**	−0.3279	−0.0647	0.0725	0.0161	0.7164*	0.1358	−0.4551	−0.1003
		(0.4103)	(0.1026)	(0.3884)	(0.0815)	(0.3611)	(0.0795)	(0.3945)	(0.0860)	(0.3930)	(0.0801)
Appalachia	0-1	−0.0493	−0.0100	−0.6199**	−0.1285**	−0.0926	−0.0211	0.1971	0.0326	0.1571	0.0376
		(0.2451)	(0.0501)	(0.2457)	(0.0546)	(0.2250)	(0.0518)	(0.2412)	(0.0415)	(0.2177)	(0.0526)
Northeast	0-1	0.2990	0.0583	0.3519	0.0616	−0.0007	−0.0002	−0.1123	−0.0173	−0.1129	−0.0264
		(0.2595)	(0.0488)	(0.2634)	(0.0441)	(0.2407)	(0.0542)	(0.2859)	(0.0433)	(0.2379)	(0.0553)
South Plains	0-1	−1.8523***	−0.4322***	−1.1208***	−0.2503***	−0.8597**	−0.2087**	−0.2819	−0.0406	−0.4848	−0.1064
		(0.4339)	(0.0898)	(0.3858)	(0.0939)	(0.3474)	(0.0848)	(0.4069)	(0.0539)	(0.3829)	(0.0775)
Diagnostics											
Pseudo R^2		0.1510		0.1141		0.0750		0.1214		0.1038	

Note: *, **, and *** indicate significance at the P ≤0.10, P ≤0.05, and P ≤0.01 levels, respectively.

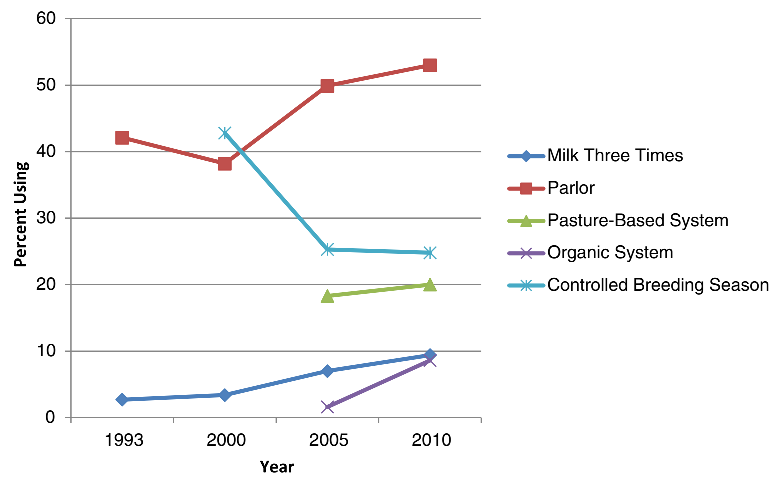

Figure 4 Percentage of Dairy Farms Using Selected Production Systems, U.S. Source: USDA ARMS and FCRS Dairy Surveys.

appears that over the past two decades, steady diffusion has continued with larger-scale, more highly educated producers entering the industry.

In 2010, the aggregate adoption rate of a milking parlor was 53.0% of farmers, compared with 49.9% in 2005, but the difference was not statistically significant. This is compared with an aggregate adoption rate of 38.2% in 2000 (Khanal et al., 2010) (which differed from the 2005 percentage at $P \leq 0.10$) and 42.1% in 1993 (Short 2000). Overall, the percentage of farms using parlors increased over the past two decades. The percentage of milk produced by farms under a parlor system increased from 83.9% to 89.3% from 2005 to 2010, respectively. In 2010, large-scale farmers and those who operated pasture-based operations were greater users. Though diffusion has been modest but steady over the past two decades, the striking increase in adoption with more cows suggests that new, larger entrants will be adopters.

Logit models were not estimated for pasture-based milk production or certified organic milk production because, while they are production systems, they are used as independent variables in the other TMPPS models and are, thus, considered TMPPS adoption drivers. We do, however, examine usage rates for these production systems. In 2010, 20.0% of operations were pasture-based, compared with 18.3% in 2005, but the difference was not statistically significant. Percentages of milk produced by farms under pasture-based systems were 6.8% and 6.6% in 2005 and 2010, respectively. Farmers in some markets may receive premiums for pasture-based milk, one of the reasons being that milk produced from pasture-based dairies may have lower somatic cell counts along with higher protein and butterfat components (Horner et al. 2012). Furthermore, USDA certified organic production, which requires cows to have access to pasture, has increased. These factors are likely the major drivers allowing aggregate adoption of pasture-based production to hold steady. Though pasture-based production has not shown significant diffusion in recent years, future consumer demand for milk produced under more "sustainable" systems could be a significant driver influencing its use in coming years.

In 2010, 8.6% of the operations were certified organic, compared with 1.6% in 2005, but the difference was not statistically significant, as the coefficients of variation for the estimates were relatively high for both years. The percentage of milk produced by farms using

Table 6 Logit results for dairy farmer adoption of production systems, 2010 (Standard errors in parenthesis)

Variable	Units	Milk Cows ≥3 Times/Day		Use of a Dairy Parlor		Control Breeding and/or Calving Season	
		β	Marg Effect	β	Marg Effect	β	Marg Effect
Constant		−6.8569*** (1.3940)		−2.9046*** (0.7228)		1.2252** (0.5979)	
Farm Structure							
Cows	No./100	0.1168*** (0.0427)	0.0053** (0.0020)	3.2069*** (0.4211)	0.6800*** (0.0610)	−0.0097 (0.0135)	−0.0017 (0.0020)
Acres	No./100	0.0853*** (0.0261)	0.0039*** (0.0010)	0.0358 (0.0516)	0.0076 (0.0110)	−0.0229 (0.0166)	−0.0041 (0.0030)
Owned	Portion	0.3359*** (0.1154)	0.0152*** (0.0051)	−0.1253 (0.0974)	−0.0266 (0.0207)	−0.3062* (0.1670)	−0.0545* (0.0296)
Specialized	Portion	4.5926*** (1.3418)	0.2084*** (0.0617)	−0.7025 (0.6383)	−0.1490 (0.1336)	−0.2972 (0.4909)	−0.0529 (0.0873)
Organic	0-1	−2.6073*** (0.9107)	−0.0542*** (0.0114)	0.1841 (0.2108)	0.0378 (0.0421)	0.5651*** (0.1937)	0.1126*** (0.0400)
Pasture-based	0-1	−1.2610 (0.7799)	−0.0425** (0.0170)	0.5428** (0.2322)	0.1072*** (0.0418)	0.7396*** (0.2317)	0.1463*** (0.0502)
Farmer Demographics							
Age	Yrs./10	0.0159 (0.1527)	0.0007 (0.0069)	0.0482 (0.0987)	0.0102 (0.0210)	0.0424 (0.0694)	0.0075 (0.0123)
College	0-1	1.1874*** (0.2842)	0.0838*** (0.0277)	0.0248 (0.3723)	0.0052 (0.0783)	0.2968 (0.2374)	0.0560 (0.0472)
Regions							
West	0-1	0.0407 (0.4535)	0.0019 (0.0213)			0.5220* (0.3079)	0.1048 (0.0668)
Pacific	0-1	−1.1548** (0.5672)	−0.0341*** (0.0119)			0.3633 (0.2941)	0.0701 (0.0601)
Southeast	0-1	−2.3947*** (0.5348)	−0.0442*** (0.0087)			1.6935*** (0.3116)	0.3884*** (0.0713)
Corn Belt	0-1	−0.8453** (0.3685)	−0.0306** (0.0126)	2.0361*** (0.2759)	0.3186*** (0.0367)	0.4468** (0.2277)	0.0855* (0.0450)
North Plains	0-1	−0.0042 (0.5353)	−0.0002 (0.0242)			1.3877*** (0.3852)	0.3141*** (0.0936)
Appalachia	0-1	−0.9534** (0.3915)	−0.0299*** (0.0101)	3.2609*** (0.3809)	0.3231*** (0.0361)	0.9836*** (0.2441)	0.2114*** (0.0561)
Northeast	0-1	−0.5939 (0.3898)	−0.0242 (0.0148)	−0.1933 (0.2540)	−0.0415 (0.0555)	−0.1774 (0.2772)	−0.0309 (0.0472)
South Plains	0-1	−1.5348** (0.7694)	−0.0382*** (0.0115)			0.9363*** (0.3637)	0.2015** (0.0870)
Diagnostics							
Pseudo R^2		0.2374		0.3665		0.0569	

Note: *, **, and *** indicate significance at the P ≤0.10, P ≤0.05, and P ≤0.01 levels, respectively.

a certified organic system increased from 0.7% in 2005 to 3.3% in 2010. Further diffusion of certified organic milk production will likely be driven by consumer demand.

In 2010, 24.8% of the farmers controlled their breeding and/or calving seasons, compared with 25.3% in 2005, but the difference was not statistically significant. This is compared with 42.8% of farmers controlling breeding seasons in 2000. The percentages of milk produced by farms controlling breeding and/or calving seasons were 24.2% and 20.9% in 2005 and 2010, respectively. In 2010, small-scale and certified organic farmers, and those who operated pasture-based systems were greater users. Though use of this system appears to be declining, future usage may depend partially on the usage of pasture-based and certified organic systems.

Adoption relationships among TMPPS

Previous research has established that adopters of most TMPPS are also adopters of most of the others, with Khanal et al. (2010) and Pruitt et al. (2012) showing this result for the U.S. dairy and cow-calf industries, respectively. Our research supports these findings, showing that most TMPPS are technically complementary or, at the very least, adopters of one TMPPS are prone to also adopt most others. We used the Fisher exact test (Zar, 1984, p. 390) to determine whether usage among TMPPS was correlated and, in cases where correlation was found, the Cramer coefficient (Zar, 1984, p. 322) to determine whether a complementary or substitute relationship existed among each of the TMPPS. These analyses were conducted using the 2010 ARMS dairy data with the provided weights. Results showed that adoption of all TMPPS was positively correlated with the adoption of all other TMPPS with the exception of: (1) use of a certified organic system was negatively correlated with all other TMPPS except for use of a breeding season and a pasture-based system; (2) use of a pasture-based system was negatively correlated with all other TMPPS except for uses of a breeding season and a certified organic system; (3) use of a breeding season was negatively correlated with veterinary services, use of a nutritionist, forward purchasing of inputs, three-times daily milking, a holding pen with an udder washer, and rbST; (4) use of artificial insemination was negatively correlated with uses of a certified organic system, a pasture-based system, and a parlor; and (5) no relationships were found between artificial insemination and breeding season, parlor and embryo transfer / sexed semen, and rbST and holding pen with an udder washer. Overall, results show striking support for previous findings suggesting that TMPPS adopters tend to be adopters of other TMPPS except for cases of alternative systems such as certified organic and pasture-based production.

Conclusions

Aggregate adoption rates of most major productivity-enhancing TMPPS have increased over the past couple of decades. Of the computerized and/or automated technologies, automatic take-offs have experienced the highest adoption diffusion rates, moving from 13% to 40% aggregate adoption from 1993 to 2010, though diffusion appears to have slowed during 2005–2010. Most of the other technologies in this category have experienced relatively slow adoption diffusion, with all but a computer for record-keeping and internet use for dairy information having aggregate adoption rates less than 10% throughout the period of study. It is noted, however, that for three of these technologies, percentages of milk produced covered by the technologies greatly exceeds percentages of farms using them, suggesting greater usage among larger farms. This is further supported by logit results showing farm size to be positively associated with usage of the six technologies in this category. Furthermore, farms more heavily specialized in milk production and farmers with college degrees were the more likely users of these technologies while certified organic and pasture-based farms were generally the less likely users.

Of the three breeding and/or biological technologies, only artificial insemination held steady during the 2005–2010 period: 80-82% of farms used it and 89-91% of gross value of milk production was covered by the technology. Its aggregate adoption increased relative to 2000. This technology is likely approaching a "ceiling" or equilibrium value, a result that should not be surprising given the rapid early adoption of this technology in the 1940s and its relatively high current usage. Newer technologies, such as embryo transfer / sexed semen and rbST have experienced significant diffusion, with the former increasing both in usage and percentage of production coverage by about 70% during 2005–2010. This is likely attributed primarily to sexed semen, a relatively new technology that has been expected to experience significant diffusion (DeVries et al., 2008). On the other hand, after initially modest diffusion following its commercial release in 1994, rbST usage decreased from 2005 to 2010, with a 49% reduction in farms using it. This rather dramatic decrease is likely explained by negative consumer reactions to milk produced using the technology, premiums in some cases being paid for milk not produced using rbST, and small or nonexistent impacts of rbST use on farm profitability (Tauer 2009; Gillespie et al., 2010). For each of the breeding and/or biological technologies, usage was concentrated among larger-scale operations, as indicated by the higher percentages of milk production covered by the technologies relative to percentages of farms using them, and significant *Cows* or *Acres* coefficients in the logit models. Certified organic farms were less likely to use any of these technologies (they are barred from using rbST), and more highly educated producers were more extensive users of the breeding technologies.

Each of the dairy management practices had relatively steady aggregate adoption rates during 2005–2010; percentages of farms using the practices did not differ significantly for the two years. Figure 3 illustrates a relatively steady aggregate adoption since 2005. Larger farms were greater users, as indicated by the higher percentages of milk production covered by the management practices relative to percentages of farms adopting, and significant *Cows* or *Acres* coefficients in the logit models. Increased percentages of owned land and the farmer holding a college degree increased usage, while older farmers were generally lower users of management practices. Certified organic and pasture-based producers were lower users of the management practices, with the exception of certified organic producers keeping individual cow production records, as expected due to the stringent requirements of USDA certified organic production.

Several trends can be seen in the selection of dairy systems. As farms have increased in size and dairy farming has become more intensive (versus extensive) in nature, higher percentages of farms have adopted parlor systems and are milking cows at least three times a day. In the face of these trends, however, percentages of farms producing under pasture-based systems have remained steady and certified organic dairy production has increased. This suggests that U.S. dairy production is becoming more diverse in its use of production systems, more intensive on the one hand and more likely certified organic and/or pasture-based on the other. Larger, more specialized farms operated by farmers with college degrees were more likely to milk cows at least three times a day, and larger farms were more likely to utilize a dairy parlor. Certified organic and pasture-based operations were more likely to control breeding and/or calving seasons.

It is worthwhile to point out the major impact that education had on TMPPS use. *College* was significant with a positive sign for 11 of the 17 TMPPS for which logit models were estimated. Numbers of percentage points by which usage by college degree-holding farmers exceeded that by non-degree holders ranged from six (computerized milking system) to 33 (accessing the internet for dairy information). College was particularly important for adopting computerized and/or automated technologies and breeding and/or biological technologies, underscoring the importance of training in adopting productivity-enhancing technology.

In order for many extension economists to serve their full dairy clientele, they need to be knowledgeable about the available TMPPS in terms of costs and benefits associated with each one of them. Further research should continue to focus on the advantages and disadvantages of each of these TMPPS systems under different production environments, as well as their associated costs and benefits.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
JG conducted the logic analyses and figures and drafted the manuscript. RN conducted the difference in means analysis and assisted with drafting the manuscript. IS assisted with drafting the manuscript. All authors read and approved the final manuscript.

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