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Grazing Adoption in Dairy Farming: A Multivariate Sample-Selection Approach

Henning Schaak and Oliver Musshoff

Milk production methods and pasture usage have gained increasing attention in recent years. This paper studies possible influences on the decision to adopt grazing practices as well as on the extent of these practices. German dairy farms were analyzed using a multivariate sample-selection model. Results indicate that specialized farms and farms with greater pasture acreage per cow are more likely to adopt grazing practices; farms with larger herds are less likely to adopt. For farmers utilizing grazing, length of daily pasture access depends on production-related variables, while the annual period depends only on farm specialization.

Key words: dairy production, grazing practices, maximum likelihood, multivariate sample-selection model

Introduction

The traditional farm management practice of grazing dairy cows on pasture has gained increased attention in social and political discourse.[1] Many stakeholders prefer grazing-based milk production systems, and some consumer groups exhibit a higher willingness to pay for milk from grazing cows (Ellis et al., 2009; Hellberg-Bahr, Steffen, and Spiller, 2012). This consumer preference is driven by perceived advantages for animal welfare and other benefits derived from grazing (Weinrich et al., 2014). Grazing can indeed have positive effects on the welfare of cows (von Keyserlingk et al., 2009). Grazing-based milk production is also discussed with respect to pasture-conservation issues, since grazing is seen as an important means of preserving pastures (Plachter and Hampicke, 2010), particularly those with high natural value (Matzdorf, Reutter, and Hübner, 2010; Bundesamt für Naturschutz, 2014) and intensively managed pastures (Weigelt et al., 2009).

Dairy processors in Europe have acknowledged this consumer preference by marketing grazing-based milk separately. From the perspective of a single farm, the economic viability of grazing practices depends on the chosen management style, on-farm conditions, and input costs (Peyraud et al., 2010; Thomet et al., 2011; Kiefer, Bahrs, and Over, 2013; Knaus, 2016). Despite the potential advantages, grazing has been declining in Europe (Reijs et al., 2013). Due to this gap between societal demands and actual developments in agriculture, agriculture policy has addressed future development of pasture use. For example, an industry agreement supported by policy measures was recently introduced in northern Germany (Grünlandzentrum, 2015).

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[1] We use "grazing" to refer to management practices that allow the herd access to pasture and the opportunity to graze there and does not differentiate among different grazing systems. For practically oriented definitions of different grazing systems, see for example Hodgson (1990) or Blanchet, Moechnig, and DeJong-Hughes (2000).

There is a need to improve understanding of the decisions made regarding adoption and usage extent of grazing practices. The existing literature is limited with respect to farmers' adoption of grazing practices. Using farm-level survey data, Foltz and Lang (2005) found a negative impact of renting land for grazing usage (which they interpret as a proxy for the share of distant acreage) and a positive impact of education on the adoption probability of grazing practices. In a contingent valuation setting that allowed for uncertainty in the decision, Kim, Gillespie, and Paudel (2008) found that both previous experience with grazing practices and the debt-to-asset ratio had a positive effect on willingness to adopt grazing practices. Recently, Jensen et al. (2015) studied farmers' willingness to adopt grazing practices and the potential extent of those practices by using a triple-hurdle model based on a hypothetical grazing program. They found that nonmonetary factors—such as education, current practices, and farm location—were associated with program participation. These studies primarily examined hypothetical adoption decisions in cattle rather than dairy production and used data from the United States.

Focusing on pasture management practices on Irish dairy farms, Kelly et al. (2015) found that the intention to implement a practice is strongly determined by individual farmers' beliefs. McDonald et al. (2016) studied the adoption of different grazing-related production technologies among Irish entrant dairy farmers and found that the farmers' beliefs regarding a technology had a substantial influence on the actual decision whether to use that particular technology. These Irish studies focused on specific management aspects rather than the adoption of grazing itself. This approach appears reasonable in their context, since up to 100% of Irish cows already graze pasture (Reijs et al., 2013).

In contrast, milk production in Germany is rather heterogeneous, and not all farms allow pasture access (Reijs et al., 2013; Lassen et al., 2014, 2015). We must consider the overall decision to adopt grazing practices rather than just particular aspects, but analyzing the overall adoption decision alone would be insufficient because daily pasture access can vary from a few hours per day on a single plot to intensive, rotational systems with full-day access. Additionally, the length of the annual grazing period may vary across farms with similar conditions. Furthermore, daily pasture access and length of the annual grazing period are also used to evaluate farms participating in dairy processors' pasture milk programs. To date, the overall decision to adopt grazing practices and the actual extent of these practices have not been studied simultaneously (in general) or in Germany, in particular.

As noted above, dairy processors have started marketing grazing-based milk products separately. In order to allow the milk to be traceable, they have established special pasture milk programs. Farmers' program participation is regularly financially compensated. To the best of our knowledge, the question of whether these programs provide an incentive to increase grazing extent has not yet been studied. Knowledge about the potential effects would provide insights into whether these programs merely sustain or actually promote grazing practices.

This paper studies the grazing adoption decision as well as the actual extent of grazing in German dairy farming. To identify the influence of farm characteristics and socioeconomic factors on these decisions, we differentiate farmers' decision-making process into two steps. First, the farmer decides whether to apply grazing practices. If this general decision is made in favor of grazing, the farmer has to decide upon the length of the annual grazing period and daily pasture access in a second step. The prior adoption decision can be conceptualized as a selection rule and the length of the yearly and daily grazing extent act as variables that are only observed when the selection rule results in adoption.

Typically, the Heckman Model, also known as the Tobit II Model (Heckman, 1979; Amemiya, 1985), is applied in settings like this. As this model only allows one outcome variable to be estimated, this traditional approach is not feasible in the present setting, where the extent is differentiated in two dimensions. Instead, we apply a modification of the multivariate sample-selection model (MSSM) introduced by Yen (2005). Using data from German dairy farmers, this paper studies the general adoption decision and a conditional decision on the usage extent of grazing practices and identifies possible influences of farm-specific and socioeconomic variables.

The approach used in this paper is novel in several ways. In the context of grazing, most prior studies have focused on binary adoption decisions. With respect to dairy production, this paper is the first to simultaneously consider the grazing adoption decision as well as the actual extent of grazing. It is also the first to consider the extent in a two-dimensional manner and account for participation in pasture milk programs. To the best of our knowledge, this paper represents the first application of a multivariate sample-selection approach in the context of animal production. Finally, we introduce a modification of the MSSM, which allows for the maximum likelihood (ML) estimation of larger sets of complementary outcome variables without requiring simulation techniques.

Methodology

As mentioned previously, our research question requires a suitable sample-selection model for a multivariate case. Several approaches for estimating such censored systems exist (see Heien and Wesseils, 1990; Shonkwiler and Yen, 1999; Yen, 2005; Tauchmann, 2010). These approaches are predominantly based on two-step procedures (see Tauchmann, 2005, 2010, for discussions). One exception is the MSSM, introduced by Yen (2005), which is based on a set of equations in which each outcome variable is linked to a binary selection rule. This model can be analyzed using a single ML estimation. Given the computational demands of such full-information ML approaches, the MSSM is not widely applied in the literature (Tauchmann, 2010). This paper not only studies a general adoption decision but also a conditional decision on the usage extent of the outcome variables. Therefore, we modify the original MSSM for a simpler case in which only one selection rule exists. This selection rule (or equation) is applied to all outcome variables. Thus, if the selection rule applies, we observe a positive value for all outcome variables. In the following, we present the general modified model, following the elaborations for the original MSSM (Yen, 2005).

Consider the following model for m outcome variables of interest and T observations:

$$(1)\quad \begin{aligned} \log(y_{it}) &= \mathbf{x}_t'\boldsymbol{\beta}_{it} + v_{it} \text{ if } \mathbf{z}_t'\boldsymbol{\alpha} + u_t > 0 \\ y_{it} &= 0 \text{ if } \mathbf{z}_t'\boldsymbol{\alpha} + u_t \leq 0 \\ i &= 1, \ldots, m \\ t &= 1, \ldots, T \end{aligned}$$

where y_i represents the ith variable of interest, $\mathbf{z}$ and $\mathbf{x}$ are vectors containing the independent variables,[2] $\boldsymbol{\beta}$ and $\boldsymbol{\alpha}$ are the corresponding parameter vectors, and v_i represents random normal and u random standard normal errors.[3] Furthermore, $\mathbf{S} \equiv diag[\sigma_1, \ldots, \sigma_m]$, where $\sigma_1, \ldots, \sigma_m$ are the standard deviations of $\mathbf{v} \equiv [v_1, \ldots, v_m]$. $\mathbf{R}_{vv} = [\rho_{ij}^{vv}]$ is the $m \times m$ correlation matrix of the elements of $\mathbf{v}$, and $\mathbf{R}_{vu} = [\rho_i^{vu}]$ is the $m \times 1$ correlation matrix of the elements of $\mathbf{v}$ and u. The model assumes that the error-term vector $[u, \mathbf{v}'] \equiv [u, v_1, \ldots. v_m]$ follows a $(m+1)$-variate normal distribution with a mean of 0 and the following covariance matrix:

$$(2)\quad \boldsymbol{\Sigma} = \begin{bmatrix} \boldsymbol{\Sigma}_{11} & \boldsymbol{\Sigma}_{12} \\ \boldsymbol{\Sigma}_{21} & \boldsymbol{\Sigma}_{22} \end{bmatrix}.$$

The elements of $\boldsymbol{\Sigma}$ are $\boldsymbol{\Sigma}_{11} = 1$, $\boldsymbol{\Sigma}_{21} = \boldsymbol{\Sigma}_{12}' = \mathrm{E}(\mathbf{v}u) = \mathbf{S}'\mathbf{R}_{vu}$, and $\boldsymbol{\Sigma}_{22} = \mathrm{E}(\mathbf{v}\mathbf{v}') = \mathbf{S}'\mathbf{R}_{vv}\mathbf{S}$.

To construct the likelihood function, we must distinguish between observations where $\mathbf{z}'\boldsymbol{\alpha} + u > 0$ (the selection rule applies and the outcome variables are observed) and observations where $\mathbf{z}'\boldsymbol{\alpha} +$

[2] To improve readability, we omit observation subscripts for the remainder of the paper.

[3] The log transformation of y_i allows for potential negative outcomes on the right-hand side, implied by the normal error assumption. Alternative specifications relying on truncated error distributions are possible but inconvenient in the multivariate case (Yen, 2005).

$u \leq 0$ (the selection rule does not apply and $y_i = 0$ for all i). To obtain the likelihood contribution of the former cases, let $\mathbf{v} \equiv [\log(y_i) - \mathbf{x}'\boldsymbol{\beta}_\mathbf{i}]$ and $r = \mathbf{z}'\alpha$. The marginal probability density function (PDF) of $\mathbf{v} \sim N(0, \boldsymbol{\Sigma}_{22})$ is denoted as $g(\mathbf{v})$, and the conditional PDF of $u|\mathbf{v} \sim N(\mu_{u|\mathbf{v}}, \boldsymbol{\Sigma}_{u|\mathbf{v}})$ as $h(u|\mathbf{v})$. Here, $\mu_{u|\mathbf{v}} = \boldsymbol{\Sigma}_{12}\boldsymbol{\Sigma}_{22}^{-1}\mathbf{v}$ and $\boldsymbol{\Sigma}_{u|\mathbf{v}} = \boldsymbol{\Sigma}_{11} - \boldsymbol{\Sigma}_{12}\boldsymbol{\Sigma}_{22}^{-1}\boldsymbol{\Sigma}_{21} = 1 - \boldsymbol{\Sigma}_{12}\boldsymbol{\Sigma}_{22}^{-1}\boldsymbol{\Sigma}_{21}$. This allows us to calculate the likelihood contribution of the positive observations by

$$L_1 = g(\mathbf{v}) \prod_{j=1}^{m} y_j^{-1} \int_{\mathbf{u} > -\mathbf{r}} h(u|\mathbf{v}) d\mathbf{u} = g(\mathbf{v}) \prod_{j=1}^{m} y_j^{-1} \phi(r + \mu_{u|\mathbf{v}}; \boldsymbol{\Sigma}_{u|\mathbf{v}}). \tag{3}$$

The transformation from $[v_1, \ldots, v_m]'$ to $[y_1, \ldots, y_m]'$ requires the corresponding Jacobian (Johnson, Kotz, and Balakrishnan, 1994, pp. 14–15), given by $\prod_{j=1}^{m} y_j^{-1}$. $\phi(.)$ is a univariate normal cumulative distribution function (CDF) with a mean of 0, a variance of $\sum_{u|\mathbf{v}}$, and upper integration limits $r + \mu_{u|\mathbf{v}}$. For cases where the selection rule does not apply, the likelihood contribution reduces to the 0 regime of the ordinary probit model:

$$L_2 = \int_{u \leq -\mathbf{r}} f(u; \boldsymbol{\Sigma}_{11}) du = \phi(-r; \boldsymbol{\Sigma}_{11}), \tag{4}$$

where $f(u; \Sigma_{11})$ is the marginal PDF of $u \sim N(0, \Sigma_{11}) = N(0, 1)$.

The likelihood function of the model is the product of the likelihood contributions described for the two cases (equations 3 and 4). Yen (2005) points out that the MSSM can be reduced to either a set of ordinary sample-selection models (Heckman, 1979; Amemiya, 1985) or to a set of two-part models (Cragg, 1971) by imposing restrictions on the correlation coefficients. The modified model presented above allows for analogous model specifications. The original MSSM requires the calculation of m-dimensional normal CDFs, which can require computationally burdensome simulations (Yen, 2005). The modified model laid out here only requires the calculation of univariate normal CDFs. Thus, the model can potentially also be used to analyze larger sets of complementary variables with a common selection equation.

To get a better understanding of the effects of the explanatory variables, it is possible to calculate the marginal effects of the variables. The marginal probability of positive observations for all y_i is

$$P(y_i > 0) = \phi(\mathbf{z}'\boldsymbol{\alpha}) \tag{5}$$

and the conditional mean of y_i is given by (Yen and Rosinski, 2008)

$$E(y_i | y_i > 0) = \exp(\mathbf{x}'\boldsymbol{\beta}_i + \sigma_i^2/2)\phi(\mathbf{z}'\boldsymbol{\alpha} + \rho_i^{vu}\sigma_i)/\phi(\mathbf{z}'\boldsymbol{\alpha}). \tag{6}$$

Combining equations (5) and (6) gives the unconditional mean of y_i as

$$E(y_i) = \exp(\mathbf{x}'\boldsymbol{\beta}_i + \sigma_i^2/2)\phi(\mathbf{z}'\boldsymbol{\alpha} + \rho_i^{vu}\sigma_i). \tag{7}$$

In equations (4)–(7), $\phi(.)$ denotes univariate standard normal CDFs.

Partially differentiating equations (4)–(7) allows us to calculate the marginal effects of the explanatory variables. The marginal effects at the means are calculated by averaging the individual marginal effects of the sample (Bilgic and Yen, 2015). Standard errors can be obtained using the delta method (Oehlert, 1992).

Data and Model Specification

The data were collected using an online survey conducted in 2016. The sample contains data from 279 German farmers. Participants were contacted via newsletters of consulting collectives, professional associations, and a magazine specializing in milk production. Farmers who do not keep dairy cows were excluded from the survey.

Table 1. Descriptive Statistics ($N = 279$)

Variable	Unit	Mean	SD	German Mean
Herd size	no. of cows	89.68	93.97	61.00[a]
Milk yield	kg/year	7,958.00	1,527.25	7,628.00[a]
Arable land	ha	63.14	129.36	58.09[b]
Pasture land	ha	55.88	59.18	21.06[b]
Thereof: grazing land	ha	34.19	40.60	n/a
Grazing area/cow	ha/cow	0.51	0.47	n/a
Farming as main source of income	yes	90.32%		42.92%[b]
Farming system: organic	yes	19.71%		6.30%[c]
Gender: female	yes	11.47%		8.00%[d]
Age	years	46.13	10.65	n/a
Higher education	yes	20.43%		n/a
Agricultural training	yes	94.98%		n/a
Specialized farm	yes	36.20%		n/a
Grazing milk program participation	yes	14.70%		n/a

Sources: [a]BLE (2017); [b]Destatis (2017) [c]Destatis (2014); [d]Gurrath (2011).

Table 1 presents descriptive statistics of the farmers and their dairy production systems. If data were available, the table also shows the respective German averages. Of the sampled farmers, 11.5% were female, a higher share than in the German average (Gurrath, 2011). The farmers were between 22 and 83 years old. On average, surveyed farmers managed twice as much land as the average German farmer (Destatis, 2017). For the majority, farming was the main source of income. Most farmers had received a formal agricultural education, ranging from an apprenticeship to a university degree. One-fifth of farmers had received a university degree (not restricted to agricultural sciences). One-fifth of farms were organic. On average, pasture accounted for slightly less than 50% of the farms' total area. Of this pasture, farmers considered, on average, 62% feasible for grazing. The average herd size of surveyed farmers was 55% larger than the German average (BLE, 2017). On average, the farmers held 0.5 ha of grazing land per cow.[4] Average yearly milk yield of the farms was around 300 kg above the German average of 7,628 kg (BLE, 2017). At the time of sampling, around 15% of the farmers were participating in a pasture milk program through their dairy processor. 36% of the farms specialized in milk production. The most frequent secondary operation was crop production.

Figure 1 illustrates the extent of grazing. The left side shows the distribution of average grazing days per year, and the right side shows the distribution of average grazing hours per day. In our sample, 68 farmers did not conduct any grazing activities. For the farmers who applied grazing, the herd had pasture access for 173.63 days per year (SD: 49.52) and 11.44 hours per day (SD: 5.95) on average.

In our analysis, the outcome variables were the number of days per year ("DpY") and hours per day ("HpD") of grazing access. We considered a number of factors as explanatory variables. Farm size can be an important determinant of the decision to adopt grazing practices (Jensen et al., 2015). Several variables can be used to represent the multiple dimensions of farm size (e.g., size of dairy herd, total acreage, or total number of workers). Naturally, these variables are strongly correlated.[5] To prevent multicollinearity issues, only the number of cows in the dairy herd ("herd size") was included as an explanatory variable. Related to farm size, Kristensen, Madsen, and Noe (2010) noted that, for their sample, a higher share of grazing farms than nongrazing farms held grazing acreage per cow above a certain threshold. Therefore, and to account for land endowment, the grazing-relevant land endowment was included as the available "grazing area/cow."

[4] 1 ha is equivalent to 2.47 acres.

[5] In the sample, correlations for the given examples ranged between 0.487 and 0.543.

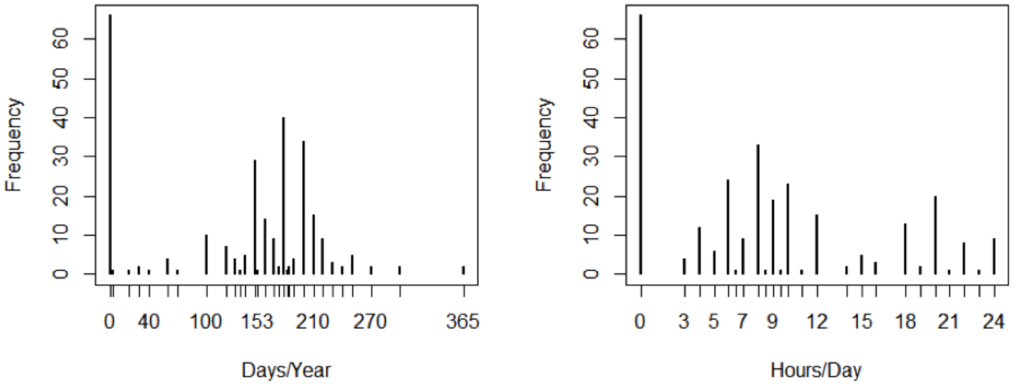

Figure 1. Distribution of Pasture Access (*N* = 279)

To account for farm management characteristics, dummy variables for whether the farm was specialized in milk production ("specialized farm") and/or was organically managed ("organic") were included. Grazing management requires specific management skills and intensive monitoring, not only of the herd but also of the pastures. This could result in restrictions for farms not specialized in dairy production. Although organic farming organizations typically require pasture access, they usually do not specify the mandatory grazing extent. Therefore it cannot be stringently assumed that an organic farm applies, *ceteris paribus*, more extensive grazing practices. Furthermore, we included "milk yield" (in kg/year) in the analysis. Higher milk yields require higher levels of concentrate intake, which, time-wise, are difficult to achieve in extensive grazing systems and limit possible forage intake. Finally, a dummy variable for "program participation" controlled whether participation in a pasture milk program influenced grazing extent. As discussed above, there is currently no knowledge about whether participation in pasture milk programs influences the grazing extent on individual farms. The variables "organic" and "program participation" were excluded from the selection equation since both variables require grazing on the farm.

Socioeconomic characteristics influence farmers' decision making (cf. Ondersteijn, Giesen, and Huirne, 2003) and are commonly considered in agricultural economics research. Therefore, farmers' age, gender, and whether farming was the main income source (i.e., "full-time farmer") were included in the analysis.

Calculations were done using the software package R (R Core Team, 2016). The ML estimation was carried out using the R package "maxLik" (Henningsen and Toomet, 2011). As mentioned previously, the model allows for alternative specifications with respect to the correlation of the error terms. To test for the appropriate specification, we estimated the model separately without restrictions and with the three possible alternative specifications: First, the selection equation error term and the variable error term were assumed to be uncorrelated. Second, the error terms of the variable equations were assumed to be uncorrelated, while correlation with the selection equation was possible. Last, all error terms were assumed to be independent. These specifications are similar to the model variants nested in the original MSSM (Yen, 2005). Likelihood-ratio tests rejected the specifications imposing restrictions on the correlations.

Results and Discussion

Table 2 presents the results of the ML estimation of the unrestricted model. Column 1 shows the estimated parameters for the selection equation. Columns 2 and 3 show the estimated parameters for the outcome variables ("DpY" and "HpD"). Most of the statistically significant estimated parameters for one explanatory variable showed the same effect direction for the dependent variables. Additionally, the estimated error-term correlations are presented. The results showed

Table 2. Parameter Estimates of the ML Estimation

Variable	Selection 1	Days per Year (DpY) 2	Hours per Day (HpD) 3
Constant	−0.04749	5.36041***	2.81545***
	(0.61100)	(0.28900)	(0.31249)
Farm characteristics			
Herd size	−0.00302***	−0.00025	0.00048
	(0.00107)	(0.00055)	(0.00065)
Milk yield	0.00003	0.00001	−0.00007**
	(0.00006)	(0.00003)	(0.00003)
Grazing area/cow	1.44500***	−0.10406	0.18318**
	(0.39038)	(0.07154)	(0.07696)
Organic	–	0.14548*	−0.01442
		(0.08816)	(0.09911)
Specialized farm	0.49318***	−0.23873***	−0.09822
	(0.18681)	(0.06874)	(0.07507)
Program participation	–	0.06274	−0.03165
		(0.07421)	(0.08803)
Socioeconomic variables			
Full-time farmer	0.30651	−0.06917	−0.00832
	(0.32194)	(0.10850)	(0.11629)
Gender	−0.33098	−0.04299	−0.15575
	(0.24944)	(0.10436)	(0.11529)
Age	0.00450	−0.00035	−0.00056
	(0.00787)	(0.00310)	(0.00339)
Error-term correlations			
DpY and HpD	0.30545***		
	(0.06521)		
Selection and DpY	−0.81214***		
	(0.05139)		
Selection and HpD	−0.35312***		
	(0.12035)		
N	279		
Log-likelihood	−881.8304		
AIC	1,825.661		

Notes: Standard errors in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.

a statistically significant positive correlation of the error terms of DpY and HpD, implying that potential unobserved factors have the same effect direction. Furthermore, there was a statistically significant negative correlation between the selection equation and DpY and between the selection equation and HpD. This implies that potential unobserved factors that positively influence the adoption decision have a negative impact on the grazing extent (in both dimensions). To show the robustness of the results, alternative model specifications are presented in Appendix A. In these specifications, the socioeconomic variables were either excluded in the selection equation or the outcome equations. We find that the results do not qualitatively change in the alternative specifications.

In what follows, we focus on marginal effects rather than on ordinary parameter estimates, as this allows for a more meaningful interpretation (Bilgic and Yen, 2015). Marginal effects are given at the variable level, so they represent the average change of the untransformed variables. The marginal effects can be calculated as conditional (the level of extent given adoption) and unconditional (the level of extent regardless adoption) on the adoption decision. Table 3 presents the marginal effects of the explanatory variables on adoption probability as well as the conditional and unconditional marginal effects. The standard errors of the marginal effects were calculated using the "deltamethod" function implemented in the R package "msm" (Jackson, 2011). Column 1 shows the marginal effects on the probability of grazing adoption. Columns 2 and 3 show the marginal effects on the conditional and unconditional levels of DpY and columns 4 and 5 show the marginal effects on HpD.

Herd size had a statistically significant negative effect on the probability of grazing adoption as well as on the unconditional levels of DpY and HpD. At the conditional level, milk yield had a statistically significant negative influence on HpD. Grazing area per cow had a statistically significant positive effect on adoption probability, DpY at the unconditional level, and HpD at both the unconditional and conditional levels. At the mean, an increase of 0.1 ha in grazing area per cow led to an 8.5% increase in the absolute adoption probability. This shows the importance of suitable grazing area for the adoption decision.

Unconditionally related to the adoption decision, organic farmers showed longer yearly grazing periods. This stems from the requirement of pasture access in organic farming programs. More interestingly, there were no statistically significant effects on the conditional level. Thus, the length of the grazing periods did not statistically significantly differ between conventional and organic farms, given that the farms use grazing. The farmers' age showed no statistically significant effect on grazing adoption or extent in the sample, which adds to the literature of mixed findings (e.g., Foltz and Lang, 2005, found no effect, while Kim, Gillespie, and Paudel, 2008, found a negative effect on the grazing adoption decision). Female farmers provided a statistically significantly shorter annual grazing period but longer daily access at the unconditional level. This could stem either from attitude differences between men and women or—as the share of female participants was rather small—from unobserved particularities of the female-led farms. There was no statistically significant effect of participation in a pasture milk program on grazing extent in either dimension. Thus, participation apparently creates no incentive for more grazing. Whether the farm represented the main source of income also had no statistically significant effect. Specialized farms were more likely to apply grazing, but given the decision, they showed a statistically significantly shorter grazing period. At the unconditional level, they also showed statistically significantly longer daily access.

The results allow for further interpretation. For DpY, the length of the annual grazing period depends on factors outside the farm rather than observed farm characteristics. For example, maximum grazing period length is limited by the length of the pasture growing period, which differs regionally. Also noteworthy is that grazing area per cow showed no statistically significant effect at the conditional level for DpY, while it was highly statistically significant for HpD. In contrast to the yearly period, the length of daily access was also influenced by production-related variables (e.g., milk yield and grazing area per cow). High milk yields are not achievable without supplementary feed concentrates. Thus, high milk yields restrict the use of intensive grazing systems (which usually require long daily access) since higher portions of grass intake on pasture limit the intake of feed concentrates. At the same time, intensive grazing systems require more pasture area per cow and longer daily access to provide enough fresh forage (Hodgson, 1990). Given the decision to adopt grazing, the annual grazing period only depends on whether the farm is specialized. In contrast, daily pasture access depends on production-related variables, which, in turn, depend on managerial decisions.

Table 3. Marginal effects of the ML-estimation ($N = 279$)

	Selection	Days per Year (DpY)		Hours per Day (HpD)	
	Probability	Conditional Level	Unconditional Level	Conditional Level	Unconditional Level
Variables	1	2	3	4	5
Continuous explanatory variables					
Herd size	−0.00226***	−0.04235	−0.42126***	0.00224	−0.02149***
	(0.00085)	(0.09497)	(0.10389)	(0.00721)	(0.00812)
Milk yield	0.00002	0.00008	0.00329	−0.00070**	−0.00034
	(0.00005)	(0.00510)	(0.00612)	(0.00035)	(0.00045)
Grazing area/cow	0.85626***	−17.72385	134.09745***	3.16544***	11.22084***
	(0.31194)	(12.40646)	(42.98703)	(0.84730)	(2.72174)
Age	0.00336	−0.05885	0.53471	−0.00166	0.03327
	(0.00629)	(0.53848)	(0.76411)	(0.03737)	(0.05544)
Binary explanatory variables					
Organic	–	24.77876	18.74194*	−0.15896	−0.12184
		(15.28870)	(9.76220)	(1.09121)	(0.69677)
Gender	−0.24751	−7.32299	−48.17679**	−2.04807	4.11205**
	(0.19931)	(18.09839)	(22.81417)	(1.26932)	(1.73760)
Full-time farmer	0.22922	−11.78132	30.57556	0.21520	2.51924
	(0.25726)	(18.81611)	(31.74714)	(1.28040)	(2.24132)
Program participation	–	10.69337	8.08816	−0.34889	−0.26743
		(12.87074)	(8.21828)	(0.96921)	(0.61887)
Specialized farm	0.36881**	−40.66097***	32.77906	−0.58874	3.33676**
	(0.14728)	(11.92191)	(18.03046)	(0.82647)	(1.30266)

Notes: Standard errors in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.

Conclusion

Various stakeholders have developed an interest in pasture usage in dairy production, creating a need for a better understanding of the influences on the adoption and extent of grazing practices in dairy production. This paper studied relevant factors using a modified version of the MSSM to analyze data on German farmers. The results indicate that a key influence on adoption is grazing area per cow. Specialized dairy farmers are on average more likely to apply grazing practices. Also, the extent of pasture suitable for grazing increases the adoption probability, while larger herds decrease the probability. Conditional on the adoption decision, the length of the annual grazing period only statistically significantly depends on the farm specialization, while the length of daily pasture access is influenced by production-related variables such as milk yield. As the length of the annual grazing period appears to be more dependent on factors exogenous of the farm, this should be considered in discussions regarding the minimum length of the access period in pasture milk programs or organic certification standards. Participation in a pasture milk program does not statistically significantly affect the extent of the grazing practices; therefore, the requirements of such programs may need to be re-evaluated if these programs aim to actually extend the application of grazing on a larger scale. Further, as farmers receive an expense allowance for program participation, the absence of a participation effect on grazing extent may indicate the presence of a freeloader effect.

Developing pasture usage for grazing must also viewed in the context of structural changes in German agriculture. Farms often grow in larger steps. In case of such growth steps, providing sufficient pastureland for grazing is more challenging than providing additional space in stables. The legal situation regarding converting arable land to pastures represents an additional hurdle for those farms, as the temporary conversion of arable land to pasture faces uncertain changes in policy regulations and potential permanent changes to the legal status of converted land. In contrast to growth-oriented farms (given that pasture-based dairy products remain or extend their relevance as a market segment), grazing-based production may become an important specialization for farmers not willing or not able to grow their production. This may also require a re-evaluation of current pasture milk programs in order to sufficiently compensate participants.

The approach applied in this paper has some limitations. Although long daily pasture access is required for intensive grazing management systems, differences in the actual grazing management of the farm could not be taken into account. Furthermore, regional differences, such as length of the growing period or altitude above sea level, were also not accounted for. With respect to grazing programs, we did not address possible effects of the participation opportunity, such as a switch to grazing practices. There are various possible directions for further research. A natural extension of the model would be to explicitly include the specific grazing system applied on the farm. For example, the approach presented in this paper could be extended toward a hierarchical selection process, consisting of multiple decision steps. Still, a distinct definition of individual grazing systems is challenging due to the need for farm-specific adaptions. Also, farmers may dynamically switch approaches throughout the year. As complex data like this would be difficult to obtain, experimental approaches may provide a helpful framework since they allow for distinct definitions of grazing systems in a controlled environment. Such a framework could also be used to further analyze the effects of pasture milk programs.

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Appendix A: Alternative Model Specifications

	Alternative Specification 1			Alternative Specification 2		
Variable	**Selection**	**Days per Year (DpY)**	**Hours per Day (HpD)**	**Selection**	**Days per Year (DpY)**	**Hours per Day (HpD)**
Constant	0.348	5.184***	2.825***	0.410	5.086***	2.768***
	(0.556)	(0.268)	(0.312)	(0.664)	(0.227)	(0.268)
Farm characteristics						
Herd size	−0.003***	−0.001**	0.001	−0.003***	−0.001**	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Milk yield	−0.000	0.000	−0.000*	−0.000	0.000	−0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Grazing area/cow	2.023***	0.043	0.173**	2.088***	0.042	0.179**
	(0.417)	(0.066)	(0.078)	(0.413)	(0.066)	(0.078)
Organic	–	0.183**	0.009	–	0.191**	0.014
		(0.087)	(0.100)		(0.086)	(0.100)
Specialized farm	0.512**	−0.140**	−0.109	0.537**	−0.160**	−0.133*
	(0.217)	(0.065)	(0.077)	(0.217)	(0.062)	(0.075)
Program participation	–	0.126	−0.028	–	0.137*	−0.030
		(0.077)	(0.089)		(0.077)	(0.089)
Socioeconomic variables						
Full-time farmer	–	−0.118	−0.034	−0.221	–	–
		(0.100)	(0.117)	(0.335)		
Gender	–	−0.084	−0.186	−0.437*	–	–
		(0.100)	(0.114)	(0.260)		
Age	–	−0.001	−0.001	−0.001	–	–
		(0.003)	(0.003)	(0.008)		
Error-term correlations						
DpY and HpD	0.226***			0.233***		
	(0.071)			(0.071)		
Selection and DpY	0.110			0.085		
	(0.149)			(0.149)		
Selection and HpD	−0.501***			−0.534***		
	(0.096)			(0.089)		
N	279			279		
Log-likelihood	−892.579			−893.115		
AIC	1,841.158			1,836.230		

Notes: Standard errors in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.