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Research Article

Estimation of Parametric Single Index Ordered Logit Model on Milk Yields

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Abstract

This article aims to determine some important factors affecting the milk yield of Holstein Friesian cows and introduce the use of single index ordered logit model in milk yield studies. Considering the three-level ordered structure of the dependent variable of milk yield, a single index ordered logit model is applied to the data set. The data set used in this study is consisted of the 305-day milk records of the Holstein Friesian cows that calved between 2001-2011 years. 14487 records, obtained from 1840 herds belonging to the members of Cattle Breeders Association in Isparta province, Turkey, are analyzed. The direct effects of the variables: parity, lactation length, first year of calving and calving season on milk yield are investigated and comprehensive interpretations are presented. Results show that the cows having longer lactation lengths produce more milk than the cows having middle lactation lengths. The highest amount of milk yield is produced by the cows calving for the first time in their middle ages and in autumn season. The amount of milk obtained after a birth occurring in spring season is higher than the one reached after a birth in summer. Cow being on its 1st parity decreases the milk yield compared to the 6th parity. This result is consistent with the finding in literature in that cows reach their highest amount of milk on their 4th parities.

Keywords: *Milk yield, Holstein Friesian, Lactation, Single index ordered logit model*

Süt Veriminde Parametrik Tek İndeks Sıralı Lojit Model Tahmini

Öz

Bu makale, Holstein Friesian ineklerinin süt verimini etkileyen bazı önemli faktörleri belirlemek ve süt verimi çalışmalarında tek indeks sıralı lojit modelin kullanımını tanıtmayı amaçlamaktadır. Süt verimi bağımlı değişkeninin üç düzeyli sıralı yapısını göz önünde bulundurarak, veri setine tek indeks sıralı lojit model uygulanmıştır. Bu çalışmada kullanılan veriler 2001-2011 yılları arasında buzağılayan Holstein Friesian ineklerinin 305 günlük süt kayıtlarından oluşmaktadır. Isparta ilinde bulunan Sığır Yetiştiricileri Birliği üyelerine ait 1840 sürüden elde edilen 14487 kayıt analiz edilmiştir. Parite, laktasyon süresi, ilk buzağılama yılı ve buzağılama mevsimi değişkenlerinin süt verimi üzerindeki doğrudan etkileri araştırılmış ve sonuçların ayrıntılı yorumlarına yer verilmiştir. Sonuçlar daha uzun laktasyon süresine sahip olan ineklerin, orta laktasyon süresine sahip olan ineklerden daha fazla süt ürettiğini göstermektedir. Orta yaşlarında ve sonbahar mevsiminde ilk kez buzağılayan inekler en yüksek düzeyde süt üretmektedir. İlkbahar mevsiminde meydana gelen bir doğumdan sonra elde edilen süt miktarı, yazın doğumdan sonra ulaşılan miktardan daha yüksektir. 1. paritesindeki ineklerin süt verimi 6. pariteye göre azalır. Bu sonuç, ineklerdeki en yüksek süt miktarının 4. paritede elde edildiği yönündeki literatürde yer alan bulguyla tutarlıdır..

Anahtar sözcükler: *Süt verimi, Holstein Friesian, Laktasyon, Tek indeks sıralı lojit model*

INTRODUCTION

One of the most important mistakes made in statistical studies is to construct a model without considering the data structure, statistical assumptions and variable type used. If the concerned (dependent) variable is categorical with two or more levels, using a classical linear regression model is inappropriate due to various assumption violations. In this case, an alternative and more appropriate approach is to use models involving categorical dependent variables and taking into account the ordered or nominal structure of the dependent variables. In this paper, the introduction and interpretation of the Single Index Ordered Logit Model (SIOLM) are mainly dealt with in milk yield estimation of

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Holstein Friesian cows. In the literature, although there are some binary logistic regression applications in the related area, a study using SIOLM in milk yield estimation is not included in this degree especially in terms of interpretation. Hence, we believe that the introduction of the use of the method and especially the odds ratio interpretations will be a good reference for the researchers in the area as the model is also a flexible model which can be reconstructed with new variables for further research. The advantage of the ordered model is that it also provides probabilities related to the dependent variable. In this study, differing from the former models that have been used in the area, the prediction probabilities of milk yield on the variables first year of calving, parity, lactation length and calving season are provided through the model estimated. Furthermore, the significance tests of the levels of those variables are also performed so that necessary improvements on the conditions affecting the milk yield related to those levels can be established. It is known that only logistic regression models are able to calculate odds ratio scores and give comparable interpretations.

There are various studies about milk productivity in the literature. In some of the former studies in the related area, İşçi et al.[1] and Aytekin et al.[2], investigated the factors affecting the milk yield (recorded as a continuous variable) of Holstein Friesians using path analysis. Ristevski et al.[3] examined the correlations between ultrasound measurement of thickness of fat over the tuber ischiadicum, body condition scoring and the risk of lameness developing in Holstein Friesians using correlation analysis. Öner et al.[4], investigated the polymorphisms in seven genes related to reproductive traits in dairy heifers. They employed mixed effect logistic regression in their analysis. Solano et al.[5] examined the correlation between lying behaviour and lameness in Canadian Holstein Friesians. Koçak and Ekiz [6] studied the factors affecting the milk yield and lactation curve of Holstein cows using Wood equation in the analysis of the lactation curve. In the study of Tahtalı et al.[7], the factors affecting the milk yield were determined using path analysis. In the study carried out by Verma et al.[8], the effect of various genetic and non-genetic factors on milk yield and milk constituent traits in Murrah buffaloes were investigated using 176 Murrah buffaloes over a period of 10 years. Inspired by this work, using some of the variables and variable categorization in the study, we modeled 305-day milk yield data of the Holstein Friesian cows that calved between 2001-2011 years in Isparta province in Turkey for determining the most significance factors and also their levels using the SIOLM.

MATERIAL and METHODS

Material of this study consisted of the 305-day milk record of the Holstein Friesian cows that calved between 2001-2011 years. 14487 records, obtained from 1840 herds belonging to the members of Cattle Breeders Association in Isparta province, Turkey, are analyzed. In statistical analysis, determining the true model according to the structure of the variables in the data set used is a crucial point to be taken into consideration. Categorical dependent variables with more than two levels should be analyzed by using the models given in *Table 1* by considering the model assumptions for constructing an efficient statistical model with minimum error [9]. The data collected are used to determine the important factor levels affecting the milk yield of Holstein Friesians. SIOLM is used for analyzing the data, which is one of the most popular single index models. In the phase of estimating the SIOLM, definitions of the dependent and independent variables, variable levels and base categories are given in *Table 2*. To account for differences among herds, milk yield for each cow is categorized as low, middle and high based on herdmate deviations [10] and lactation length (middle and high) and first calving year (low, middle and high) are classified on the basis of expert opinion (Çiğdem Takma).

Due to the non-separable nature of the dependent variable, data that is measured with an ordinal scale cannot easily be modelled with the classical regression. Another alternative to be taken into consideration here is Multinomial Logit Model (MLM). However, such models fail since they do not consider the ordered structure of the dependent variable and consequently do not use the available information fully [11].

Table 1. *Multilevel dependent variable models*

Model	Type of the Dependent Variable	Model Assumptions
Multinomial Logit	Nominal	*Only the characteristics of individuals are required *Strict assumption of Independence of Irrelevant Alternative (IIA) has to be satisfied
Multinomial Probit	Nominal	*Only the characteristics of individuals are required *No other assumption is necessary including IIA
Ordered Logit	Ordered	*Only the characteristics of individuals are required *Parallel Slopes Assumption (PSA) is required
Ordered Probit	Ordered	*Only the characteristics of individuals are required *Parallel Slopes Assumption (PSA) is required
Nested Logit	Nested Nominal Design	*Inclusive Value (IV) is required to be positive
Conditional Logit	Nominal	*Characteristics of the choice and individuals are both required

Table 2. Variables in the model	
Dependent Variable: Milk Yield 1000-4000 kg (Low) 4001-7000 kg (Middle) 7001+ kg (High)	
Lactation Length (day) 100-200 (Middle) 201-305 (High) (Base category)	**Parity (P)** P1 P2 P3 P4 P5 P6 (Base category)
First Calving Year (month) <23 Low 24-27 Middle >28 High (Base category)	**Calving Season** Winter Spring Summer Autumn (Base category)

The estimation of SIOLM is made using STATA 7.0 package program. The direct effects of the variables: parity, lactation length, first year of calving and calving season on milk yield are investigated. In order to assess the model quality in SIOLM, Correct Classification Rate (CCR) is computed. Additionally, "odds ratio" values which can only be estimated by using logistic regression models are calculated by taking the exponential of the estimated b_k coefficients. These coefficients provide a comparative comparison of the effect degree of factor levels. The consistency of our finding is investigated by also comparing the results with the results of various studies.

Latent variable (Y^*) represents the quantities that are not directly measured but only inferred from the observed covariations among a set of variables [12]. The effects of some latent variables are determined by the following linear model [13,14].

$$Y^* = \sum_{k=1}^{K} \hat{b}_k X_k + \varepsilon \tag{1}$$

Here, estimated b_k and ε denote the estimated coefficients of the explanatory variables X_k and the error term, respectively. SIOLM can be obtained if the error term has mean "0" and variance $\pi^2/3$. In SIOLM, there is a certain ordering between the dependent variable-levels.

Considering that the dependent variable has J pieces of ordered categories, the relation between the observed levels and slopes could be given as follows.

$$\begin{aligned} Y_i &= 1, \quad Y^* \le \mu_1 \\ Y_i &= 2, \quad \mu_1 \le Y^* \le \mu_2 \\ Y_i &= 3, \quad \mu_2 \le Y^* \le \mu_3 \\ Y_i &= J, \quad \mu_{J-1} \le Y^*; \ (i = 1,2,\cdots,N) \end{aligned} \tag{2}$$

Here, μ represents the threshold parameter that distinguishes the unknown ordered categories. In SIOLM, the probability that the dependent variable belongs to the category "j" conditional to the explanatory variable is expressed as the following.

$$P(Y = j \backslash x_k) = F\left(\mu_j - \sum_{k=1}^{K} \hat{b}_k x_k\right) - F\left(\mu_{j-1} - \sum_{k=1}^{K} \hat{b}_k x_k\right) \tag{3}$$

In Eq. (3), F denotes the assumed distribution of the error term ε in the model. At the beginning of the analysis, it must be first checked whether the threshold parameters are statistically significant or not. If they are significant, it is determined whether the dependent variable has an ordered structure as it is assumed. The probability that the dependent variable y belongs to the category j or a lower category can be calculated using the following equation in SIOLM.

$$P(Y \le j) = P(Y^* \le \mu_j) = \frac{exp(\mu_j - \sum_{k=1}^{K} \hat{b}_k x_k)}{1 + exp(\mu_j - \sum_{k=1}^{K} \hat{b}_k x_k)} \tag{4}$$

The left side of Eq. (4) is called cumulative logit. SIOLM is achieved if the logistic distribution denoted by ψ is specifically chosen for F in Eq. (3). The probabilities that the dependent variable belongs to the relevant categories are given by Eq. (5), Eq. (6) and Eq. (7) [15,16].

$$P(Y = 1) = \Psi\left(\mu_1 - \sum_{k=1}^{K} \hat{b}_k x_k\right) = \frac{exp(\mu_1 - \sum_{k=1}^{K} \hat{b}_k x_k)}{1 + exp(\mu_1 - \sum_{k=1}^{K} \hat{b}_k x_k)} \tag{5}$$

$$\begin{aligned} P(Y = 2) &= \Psi\left(\mu_2 - \sum_{k=1}^{K} \hat{b}_k x_k\right) - \Psi\left(\mu_1 - \sum_{k=1}^{K} \hat{b}_k x_k\right) \\ &= \left[\frac{exp(\mu_2 - \sum_{k=1}^{K} \hat{b}_k x_k)}{1 + exp(\mu_2 - \sum_{k=1}^{K} \hat{b}_k x_k)}\right] - \left[\frac{exp(\mu_1 - \sum_{k=1}^{K} \hat{b}_k x_k)}{1 + exp(\mu_1 - \sum_{k=1}^{K} \hat{b}_k x_k)}\right] \end{aligned} \tag{6}$$

$$\begin{aligned} P(Y = J) &= 1 - \Psi\left(\mu_{J-1} - \sum_{k=1}^{K} \hat{b}_k x_k\right) \\ &= 1 - \left[\frac{exp(\mu_{J-1} - \sum_{k=1}^{K} \hat{b}_k x_k)}{1 + exp(\mu_{J-1} - \sum_{k=1}^{K} \hat{b}_k x_k)}\right] \end{aligned} \tag{7}$$

RESULTS

Single Index Ordered Logit Model results including the estimated coefficients of the variable levels of lactation length (middle), first calving year (low and middle), parity (P1, P2, P3, P4 and P5) and calving season (winter, spring and summer), their standard errors, Wald statistics, P-values and odds ratios are given in *Table 3*.

When *Table 3* is examined, it can be realized that the threshold parameters (μ_1) and (μ_2) are statistically significant with a level of 5% ($P \le 0.05$). The significance of the threshold parameter indicates that the dependent variable milk yield is ordered as it is assumed at the beginning of the study. Also, it appears that SIOLM is a suitable model for the data structure.

The linear combinations of the explanatory variables

Table 3. *Single index ordered logit model results*

Dependent Variable: Milk Yield 1:1000-4000, 2:4001-7000, 3: 7000+	Estimated b_k	Std. Error	Wald	P-value	Odds-Ratio
Lactation Length					
Middle (100-200)	**-2.679**	0.0574	2185.550	**0.000**	0.069
First Calving Year					
Low (<23)	**-0.231**	0.087	7.024	**0.008**	0.794
Middle (24-27)	**0.171**	0.042	16.665	**0.000**	1.186
Parity					
P1	**-0.561**	0.152	13.710	**0.000**	0.571
P2	-0.130	0.153	0.727	0.394	-
P3	0.070	0.156	0.199	0.656	-
P4	-0.062	0.163	0.146	0.702	-
P5	-0.026	0.178	0.022	0.882	-
Season					
Winter	**-0.443**	0.055	64.235	**0.000**	0.642
Spring	**-0.197**	0.053	13.935	**0.000**	0.821
Summer	**-0.264**	0.061	18.613	**0.000**	0.768
Threshold Parameters					
μ_1 = -2.447		0.154	251.416	**0.000***	
μ_2 = 2.019		0.154	172.724	**0.000***	
Model Validity					
Log likelihood = 1053.125; LR chi2(11) = 2710.703; Prob>chi2 = 0.000					

** Coefficient is statistically significant at a significance level of 5%*
Base Categories: *Lactation Length (High), First Calving Year (High), Parity (6), Season (Autumn)*

can be obtained by substituting the characteristics of each cow in the model equation given below. *Table 3* shows the model constructed using the estimated coefficients b_k.

$$\sum_{i=1}^{14487}\sum_{k=1}^{11}\hat{b}_k x_{ik} = (-2.679)xMiddle - (0.231) \; x\,Low + \cdots + (-0.264)xSummer \tag{8}$$

The following probability equations are obtained depending on the expression in Eq. (8) and formulations given by Eq. (5), Eq. (6) and Eq. (7). At the different levels of all the factors affecting the milk yield, the probabilities for the given categories of the milk yield can be calculated with the following equations.

For the category 1000-4000 kg,

$$P(Y_i = \text{"}1000-4000\text{"}) = \frac{exp\left(-2.447-\sum_{k=1}^{11}\hat{b}_k x_{ik}\right)}{1+exp\left(-2.447-\sum_{k=1}^{11}\hat{b}_k x_{ik}\right)} \tag{9}$$

For the category 4001-7000 kg,

$$P(Y_i = \text{"}4001-7000\text{"}) = \left[\frac{exp\left(2.019-\sum_{k=1}^{11}\hat{b}_k x_{ik}\right)}{1+exp\left(2.019-\sum_{k=1}^{11}\hat{b}_k x_{ik}\right)}\right] - \left[\frac{exp\left(-2.447-\sum_{k=1}^{11}\hat{b}_k x_{ik}\right)}{1+exp\left(-2.447-\sum_{k=1}^{11}\hat{b}_k x_{ik}\right)}\right] \tag{10}$$

For the category 7000+ kg,

$$P(Y_i = \text{"}7001+\text{"}) = 1 - \left[\frac{exp\left(2.019-\sum_{k=1}^{11}\hat{b}_k x_{ik}\right)}{1+exp\left(2.019-\sum_{k=1}^{11}\hat{b}_k x_{ik}\right)}\right] \tag{11}$$

The second column of *Table 3* contains the estimated coefficients of the explanatory variables. In the fifth column, the p-values are given for testing the significance of the estimated model parameters. An estimated coefficient with a negative sign indicates that the corresponding variable affects the milk yield in a decreasing way and a positive coefficient means the variable makes the milk yield increase with respect to the base category displayed in *Table 2*. The odds ratios given in the last column of *Table 3* are interpreted only for statistically significant factors in the analysis. The patterns with arrows display the increase or decrease along the categories of the milk yield, which are presented in *Table 3*, with respect to the significant categories of the variables. Detailed interpretations of the results for all variables are given below.

$$\text{Middle (100-200)} \xrightarrow[\text{High (201-305) (base)}]{\text{(low) (middle) (high)}} \text{(-) effect on odds}$$

According to the model estimated, a middle lactation length (100-200) causes the milk yield to decrease compared to the long lactation length (201-305). In other words, the cows having longer lactation lengths produce more milk than the cows having middle lactation lengths.

The odds ratio for the middle lactation length is 0.069 which yields 14.5 when inverted. Hence, the probability that a cow having a high lactation length will produce middle or high amount of milk is 14.5 times higher than the probability that it will produce low amount of milk.

While a low first calving year (<23 month) seems to cause the milk yield to decrease compared to a high first calving year (>28 month), a middle first calving year (24-27 month) has an impact which increases the milk yield. Thus, it can be interpreted that the highest amount of milk yield is produced by the cows calving for the first time in their middle ages (24-27 month).

The odds ratio for low first calving years is calculated as 0.794. When we invert this odd ratio the result is 1.26. This means that when a cow has a high first calving year, the probability that the milk yield will be high is 1.26 times more likely than it will be low compared to low first calving year.

Low (<23) $\xrightarrow[\text{High (>28) (base)}]{\text{(low) (middle) (high)}}$ (-) effect on odds

The odds ratio that the first calving year in middle level is 1.186. This can be interpreted as the probability that the cows having middle first calving year will produce high amount of milk is 1.186 times greater than the ones having high first calving years. Thus, we can say that the ideal first calving years for cows to produce high amount of milk are the middle ages.

The odds ratio for Parity 1 (P1) is calculated as 0.571 which yields an odds value of 1.75 when inverted. This means that cow being on its 1st parity decreases the milk yield compared to the 6th parity.

Middle (24-27) $\xrightarrow[\text{High (>28) (base)}]{\text{(low) (middle) (high)}}$ (+) effect on odds

When calving seasons are considered, the highest amount of milk is seen in autumn season. The least amount of milk, on the other hand, is observed in winter season. The amount of milk obtained after a birth occurring in spring season is higher than the one reached after a birth in summer. The decrease in the milk yield in winter is approximately 1.68 (-0.443/-0.264) times higher than the decrease in summer season when compared to the amount of milk reached in autumn season. However, it is 2.25 (-0.443/-0.197) times higher when compared to spring season. Also, the decrease in the amount of milk yield obtained in summer season is 1.34 (-0.264/-0.197) times less than the amount that in spring compared to the autumn season.

P1 $\xrightarrow[\text{P6 (base)}]{\text{(low) (middle) (high)}}$ (-) effect on odds

When calving is in winter season, the odds ratio is calculated as 0.642 which is 1.56 when inverted. Therefore, when calving is in autumn season, the probability that the milk yield will be high is 1.56 times more likely compared to winter season.

Winter $\xrightarrow[\text{Autumn (base)}]{\text{(low) (middle) (high)}}$ (-) effect on odds

When calving occurs in spring season, the odds ratio is calculated as 0.821 whose inverse is 1.22. Thus, when calving occurs is autumn, the probability that the milk yield will be high is 1.22 times more likely than the case when calving occurs in spring.

Spring $\xrightarrow[\text{Autumn (base)}]{\text{(low) (middle) (high)}}$ (-) effect on odds

The odds ratio for the case of calving in summer is 0.768 which is inverted as 1.30. Hence, in the case when calving occurs in autumn, the probability that the milk yield will be high is 1.30 times more likely than the one obtained when calving occurs in summer season.

Summer $\xrightarrow[\text{Autumn (base)}]{\text{(low) (middle) (high)}}$ (-) effect on odds

The correct classification rate given in *Table 4* indicates the quality of the model. It measures the consistency between the actual and the predicted amount of milk yield estimated by the SIOLM model. It is seen that 77.9% of the cows have been correctly assigned to the related category by the model. This means that, by using this model, it is

Table 4. *Correct classification rate*

Actual	Predicted			
	1000-4000	**4001-7000**	**7001+**	**Total**
1000-4000	1236*	1500	0	2736
4001-7000	616	10061*	0	10677
7001+	23	1051	0*	1074
Total	1875	12612	0	14487

** Number of cows that have been correctly assigned to the related category by the model* possible to predict the milk yield of any animal, in terms of the first year of calving, lactation length, parity and calving season with a 77.9% level of success rate.

DISCUSSION

The classical linear methods give statistically incorrect results when the concerned dependent variable is categorical with more than two levels. This study is about the determination of the important factors affecting the milk yield of Holstein Friesian cows using SIOLM. The most important advantage of SIOLM compared to other models is that it is the only model that can be used when the dependent variable has an ordered structure. Using a SIOLM to determine the significant variables and variable levels affecting the 305-day milk yield of Holstein Friesians enabled us to test the significance of all the categories of the variables separately as well as their positive or negative effects on the milk yield. Another advantage of SIOLM is that it also enables the researcher calculate odds ratios. Therefore, we are also able to compare the effects of the categories with each other through the bilateral odds ratio values calculated among them.

The present study is concluded as milk yield is affected by all the factors concerned at different levels of importance. The probability that a cow having a high lactation length will produce middle or high amount of milk is 14.5 times higher than the probability that it will produce low amount of milk. This result is in accordance with the findings of Vijayakumar et al.[17] who recorded that Holstein cows reach the highest milk yield in greater lactation length periods. Additionally, Lateef et al.[18] stated that the maximum milk yield is obtained from the Holstein Friesian cows having the highest lactation lengths (greater than 400 days). When a cow has middle first calving year, the probability that the milk yield will be high is 1.186 times more likely than it will be low. That is cows having middle first calving years produce the most amount of milk. This result is partly supported by the findings of Eastham et al.[19] stating that lower ages of first calving cause more milk yield. Cow being on its 1st parity produces less milk compared to the one on its 6th parity. This finding is also supported by M'hamdi et al.[20] who show in a tabular form that milk yield increases as the first calving year increases. Finally, the most amount of milk is obtained in autumn season. When calving is in spring season, the probability that the milk yield will be high is 2.25 times more likely compared to winter season. This result is supported by one of the findings of Nalubwama et al.[21] which shows that Holstein cows that calved in wet seasons have higher milk production compared to those that calved in the dry seasons.

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