Determinants of economic success in egg production in Germany – here: laying hens kept in aviaries or small-group housing systems

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Abstract

The European Union ban on conventional battery cages had far-reaching consequences for animal welfare and the economic success of egg production. The aim of this study was to identify the main influences on economic success of farms keeping laying hens in aviaries or small-group housing systems. The results confirmed the importance of productivity measures (i.e. conversion rate), whereas farm size was of consequence for small-group housing systems, only. Dependent on the housing system, management decisions (i.e. daily inspection time, feeding of self-mixed feed) accounted for a considerable part of economic effectiveness. Furthermore, the number of years of experience of the farmer with the housing system seemed to influence economic productivity. Positive effects of selling graded eggs (instead of bulk-ware) showed the relevance of market outlets on economic profitability. The study indicated that small-group housing systems might profit from selling their products directly to the consumer. The results show that decisions of politics and the retail sector as well as consumer choices have an influential effect on the economic success of egg production.

Keywords: *Laying hens, economic efficiency, market influences, management*

Zusammenfassung

Determinanten des wirtschaftlichen Erfolgs in der Eiproduktion in Deutschland – hier: in Volieren- oder Kleingruppenhaltungssystemen gehaltene Legehennen

Das EU-weite Verbot von konventioneller Käfighaltung hatte weitreichende Konsequenzen für das Tierwohl und die Wirtschaftsleistung in der Eiproduktion. Das Ziel dieser Studie war es, die Haupteinflüsse auf den wirtschaftlichen Erfolg in Betrieben mit Volieren- oder Kleingruppensystemen zu identifizieren. Die Ergebnisse bestätigten den Einfluss von Produktivitätskriterien (z. B. Futterverwertung) auf den wirtschaftlichen Erfolg, wogegen die Betriebsgröße nur bei der Kleingruppenhaltung eine Rolle spielte. Abhängig vom Haltungssystem bedingen Managemententscheidungen (z. B. tägliche Inspektionszeit, selbstgemischtes Futter) einen relevanten Teil des ökonomischen Erfolgs. Ebenso kann die Erfahrung des Landwirts mit dem Haltungssystem einen Einfluss haben. Positive Effekte durch den Verkauf von sortierten Eiern gegenüber Bulk-Ware zeigten die Relevanz von verschiedenen Absatzmärkten für den ökonomischen Erfolg. Alternativ zum Vertrieb im Einzelhandel könnte die Kleingruppenhaltung davon profitieren, die Eier direkt zu vermarkten. Die Ergebnisse dieser Studie lassen erkennen, dass Entscheidungen der Politik, des Einzelhandels und der Verbraucher den ökonomischen Erfolg der Eiproduktion beeinflussen.

Schlüsselwörter: *Legehennen, Wirtschaftlichkeit, Markteinflüsse, Management*

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1 Introduction

Mainly due to raised consumer awareness and resulting social and economic pressure from animal welfare groups and the retail industry, the farming methods of laying hens in the EU have undergone fundamental changes during the last 25 years, culminating in the political decision to ban housing in conventional cages, coming into effect in January 2012 (European Council, 1999). In Germany, laying hens are now predominantly kept in barns (floor housing or aviaries, respectively) as well as in free-range or organic systems. Currently, about 11 % of eggs are produced in enriched cages (MEG, 2015), so called 'small-group housing' (TierSchNutztV, 2006, last amended 2014), for which the legal basis is under debate. The alternative housing systems do not only pose new challenges regarding management strategies to ensure health and welfare of layers (Green et al., 2000; Tauson, 2005; Drake et al., 2010; Lambton et al., 2010), but also to achieve economic success. However, information on small group housing systems, being new and still under debate in Germany, are limited.

Literature on influences on economic efficiency in egg production is sparse. Current research mainly focuses on productivity of the hens (e.g. Tauson, 2002; Singh et al., 2009; Guo et al., 2012; Freire and Cowling, 2013). However, variables like laying performance, feed conversion rate and mortality can only in part explain how to secure profits or avoid losses in egg production. Considerable variance between farms with similar housing systems, e.g. regarding mortality or laying performance, indicate that productivity is not primarily influenced by the housing system but by the quality of the management (e.g. Aerni et al., 2005). However, improving the management typically involves higher costs, e.g. for personnel, layer house modifications or feed components. Therefore, in regard to economic success it is important whether these investments pay off through higher returns, to at least achieve a balanced overall result in the long term.

Another major influence on economic profitability is found in market outlets. These can partly be influenced by the farmers themselves, e.g. the decision to sell eggs by direct marketing or to sell bulk-ware to wholesale industry. In these decisions costs for extra equipment, labour, etc. have to be weighed against higher returns. Nevertheless, factors beyond the reach of the farms play an important role as well. Market resolutions, such as the delisting of cage eggs by large parts of the retail industry in several European countries (European Commision, 2003) affect returns attainable for produced eggs and, therefore, the economic productiveness.

The aim of this study was to take an observational approach to identify the main influencing factors on the economic success of egg producers in Germany. However, it can be assumed that kind and impact of influencing factors vary with the housing systems. Therefore, two important housing systems for laying hens in Germany were assessed. One of these systems was 'small-group housing', because it was supposed to replace conventional cages. Secondly, aviary systems were investigated as they are the most common housing system for large laying hen flocks in Germany. We intended to identify main influences, which impact economic success regardless of individual farm conditions. As the most important influences on profitability can be assigned to the thematic clusters (blocks) animal associated productivity, direct and indirect farm management, a focus of the investigation was to identify the relative importance of these blocks and if possible to identify the driving factors within these groups. In order to identify block importance and single variable importance for a number of different indicators of economic success, simultaneously, a multivariate, multifactorial analysis tool was needed, which could yield not only single variable but also block importance (for the Results see Section 3.2). The only method to do so (to our knowledge) is the "Multiblock Redundancy Analysis" (Bougeard et al., 2012).

The study intended to perform an observational description of the main influences on economic success, as little is known about small group housing systems in Germany. Furthermore, we intended to identify strategies a farmer could use to compensate for potential disadvantages inherent in a housing system itself or for disadvantages through circumstances beyond the farm. Therefore, the results of the analyses were discussed from the point of view of farmers with a small-group housing system on the one hand and with an aviary system on the other hand.

2 Methods

2.1 Data collection and variable selection

The study presented was part of a collaborative project, where members of various scientific fields participated: Contributions came from animal health and behavior groups, as well as agricultural technologists, economic experts, and epidemiologists. The aim of this project was to deduce management recommendations for laying hens kept in small-group housing or aviary systems based on data collected in a cross-sectional study.

The project eligibility criteria were a minimal farm size of 2,000 hens, specifications considering the design of equipment in aviary systems, the willingness to answer questionnaires, to record and transmit productivity data and to grant access to the layer houses for health and hygiene assessment, behavioural observations as well as air measurements. These criteria were applied by all study teams and on all farms. Egg producers in Germany were contacted either directly or by advertisement. When farms showed their willingness to participate, they were visited a first time to assess whether or not they fulfilled the eligibility criteria. Those farms that did were later visited again by the different project partners for data collection. As this data collection was very extensive and therefore highly time consuming and cost-intensive as well as requiring trained personnel and specialized equipment, the number of participating farms was limited to 70. Due to the limited sample size, this study was restricted to identifying the most important influencing factors, despite having access to a large amount of information on the farms.

For the purpose of data collection standard, operating procedures for health and behaviour assessment and measurements of hygienic conditions of air and housing equipment were determined (Dahoo et al., 2009). Three different questionnaires were used: The farm management questionnaire contained questions considering general farm management (light program, feed, hygiene, personnel etc.) and animal/herd characteristics (e.g. type of hybrid). Data were collected by trained observers in a personal interview. According to interobserver reliability analyses (for the method description see Ruddat et al., 2014; data not presented here) there was no indication of interviewer bias. The layer house equipment questionnaire included questions considering the size of the layer house as well as design, dimensions and conditions of housing equipment in the layer house. Measurements and observations were gathered by trained members of the project team during a visit to the farms. With the farm economics questionnaire productivity and other economic data (e.g. laying performance, returns for eggs, and feeding/personnel costs) were collected. Information was obtained by an economic expert in a personal meeting after depopulation. The questionnaires comprised over 1,000 questions in total, of which the qualitative ones were closed as well as semi-closed. All questionnaires were pilot tested on six farms and then modified to their final forms. The data were collected per farm and layer house, the latter representing the experimental unit. Additionally, a clinical scoring was conducted for each of 100 hens per layer house. The data from the farm management and layer house equipment questionnaires as well as the clinical scoring were kept in a SQL-database. The data of the farm economics questionnaire were digitized in Microsoft Excel™.

Due to the high number of investigated variables a process of variable selection was applied to ensure the final statistical models. Dependent variables were selected that measured different stages of economic profitability by including returns or costs as well as both combined (KTBL, 2012). To be able to differentiate between primary cost-driving factors and those affecting returns, direct costs and returns per egg were identified as suitable outcome variables besides net total per egg, which corresponds to the balance of revenues and total costs per egg (or margin or returns per egg) and reflects the overall economic success (Figure 1d). The returns per egg comprise the total revenues for the eggs, slaughtered hens and dry manure. The total costs contain the indirect costs (fixed costs) and the immediately attributable direct costs (variable costs). The fixed costs contain the costs for labour and machinery, building and capital, whereas the direct costs comprise the costs for pullets, feed, veterinarian costs, energy, water, marketing and packaging and other direct costs per egg. The endpoints and all factors, which may be associated with these endpoints, were checked for plausibility. In case of inconsistencies the data collectors were contacted to eliminate the problems. Furthermore, basic descriptive analyses were conducted yielding contingency tables and measures of central tendency and variation.

Variable selection included the removal of one dataset with missing mortality, as the methods used require complete datasets. Furthermore, to avoid sparse data problems, such as convergence problems of models and representativeness, variables with less than five observations in a category were transformed, i.e. dichotomized, if possible, or not considered for further analysis. Furthermore, variables were checked for strong multi-collinearity by investigating

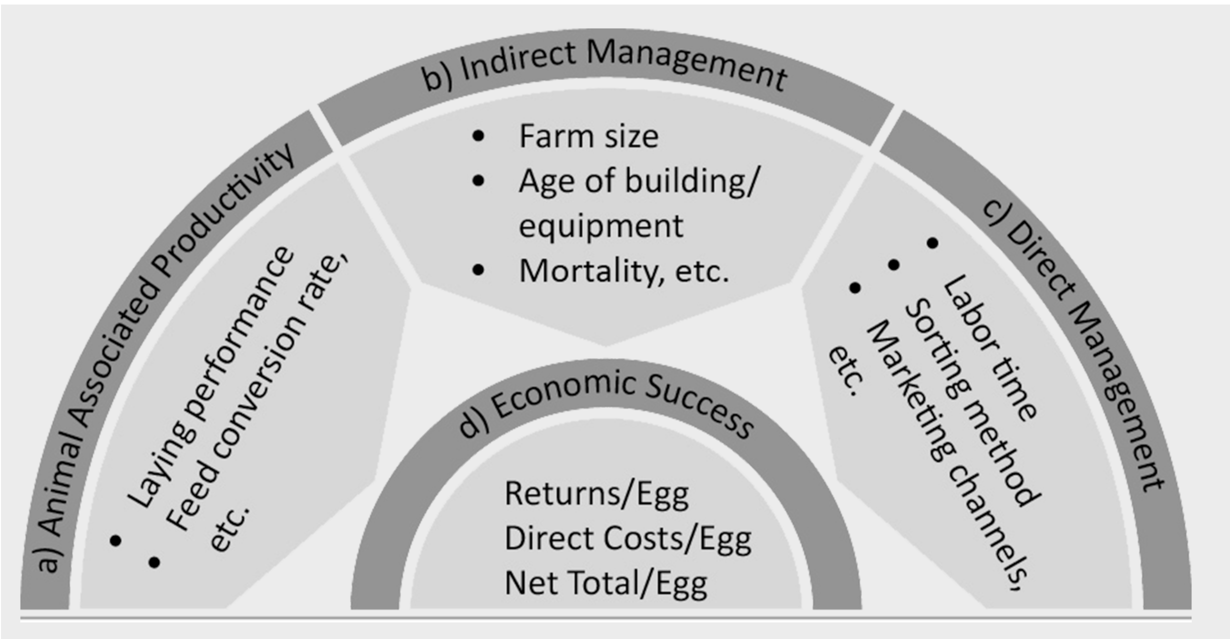

Figure 1
Relevant associations between groups (or blocks) of influences and the economic success of egg producing farms with small-group or aviary housing systems analyzed in this study

cross-tables and determining their variance inflation factors. The remaining potential influencing factors underwent a univariate one-factorial linear regression analysis (Neter et al., 1996) and only those being allowed in the final multiblock redundancy model, which had a p-value <0.15. This relaxed significance level was chosen at this level of variable selection in order to avoid losing confounded explanatory factor estimates.

2.2 Multiblock redundancy analysis

The method chosen for multivariate, multifactorial analysis was the multiblock redundancy analysis. For this method, sets of explanatory variables have to be grouped together in meaningful explanatory blocks and all outcomes have to be merged in one outcome block. The basic objective of this analytical method is to summarize each block by one latent variable. The latent variables then are constructed such that a criterion is maximized, which reflects the extent to which each latent variable (from the respective explanatory block) is linked to the latent variable of the outcome block. The solution to this maximization problem is derived from a matrix eigenanalysis. The multiblock redundancy analysis requires centered and scaled data in presence of variance heterogeneity.

After derivation of the latent variables, associations between the explanatory data and outcome are investigated. First, the degree of association between one explanatory block and the whole outcome block is computed based on the eigenanalysis. It is named block importance (BIP [%]) and considers the covariance between the latent variables of the explanatory block and the outcome block. To compute the block importance, the method allows a weighting of the explanatory blocks: Blocks can be equally weighted, weighted according to the number of variables included in each block or weighted due to practical reasons, such as biological considerations. In this study, the blocks were weighted equally.

Then, the association between one explanatory variable and the whole outcome block is assessed as variable importance (VIP [%]), which is based on the covariance of each specific explanatory variable with the whole outcome block and the loadings given by the eigenanalysis (see Bougeard et al., 2011;2012 for technical details).

Finally, the association between one explanatory variable and one specific outcome variable is calculated by ordinary least square regression, yielding regression coefficients for each association.

Due to the fact that this method employs principle component analysis to derive latent information, model fit can be adjusted by the number of dimensions used. For the study presented here, the cut-off for inertia was set to ≥80 %, indicating that with the given number of dimensions at least 80 % of the cumulative relative variance is explained by the latent variables. Goodness of fit of the models was assessed calculating the coefficient of determination for the total model as well as for each outcome variable. For this multiblock redundancy model two-sided 95 %-confidence intervals (CI) were computed for all these measures via bootstrap simulation with 400 steps (Carpenter and Bithell, 2000). The significance level of 5 % was chosen at this final level of analyses in order to identify the most important influences under the preselected explanatory variables. However, due to the explorative nature of this study, a multiplicity correction was omitted.

In this study explanatory variables were grouped in three blocks: The first contained "animal- associated productivity" variables such as laying performance, age at 50 % Laying Performance and feed conversion ratio (Figure 1a). The second block, "indirect management", was made up of those variables that also in some way reflected the management but could only be indirectly influenced (mortality) or could only be changed with great difficulty (farm size, age of barn/housing equipment; Figure 1b). A third block on the other hand was termed "direct management" (Figure 1c), as it included variables that could easily be influenced by management decisions (stocking density, feeding of self-mixed feeds, caretaking time/hen, selling eggs directly etc.). The variables included in the final multiblock redundancy analysis are listed in Table 2 for the aviary system and in Table 3 for the smallgroup housing system.

For plausibility checks and descriptive analysis data were imported to SAS 9.3 (SAS Institute Inc., 2012). Statistical procedures and associated interpretation tools concerning the multivariate, multifactorial analysis were performed using code programs in R (R Development Core Team, 2008). The code source was made available by Stéphanie Bougeard.

3 Results

3.1 Descriptive analysis

Of the originally 70 farms meeting the eligibility criteria, four withdrew their consent to participate for various reasons during the data collection process. Therefore, the sample consisted of 19 small-group housings and 47 aviaries, which were visited during the period from April 2010 to September 2012 by the different project partners. The depopulation on one farm with small-group housing fell outside the time period of the project, resulting in 18 small-groups included in the analysis of productivity and economic efficiency. Compared with data of the Federal Statistical Office (DeStatis extract from 01.12.2011) the farms in the sample population were a typical representation of German egg production regarding farms size, geographical distribution and housing technology.

The variables selected, based on hypotheses, are listed in Table 1, for aviaries and small-group housing systems, separately. A descriptive analysis of the outcome variables is shown there, too. An outlier could be identified for the minimum direct costs. This value belongs to a farmer, who was farming laying hens as a contractor, meaning that vaccinated laying hens, feedstuff as well as veterinary consultancy were provided by a third party. The farmer invested personnel and the layer house, only. His direct costs were energy, water, cleaning and disinfection and costs for marketing, only.

Table 1

Variables originally selected for analysis and **descriptive results** of those quantitative variables included in the **aviary** model (47 farms) and **small-group** model (18 farms), respectively. The grouping of variables in the respective groups (blocks) is also shown.

	Aviary					Small-Group				
	Mean	Median	SD	Min	Max	Mean	Median	SD	Min	Max
Block d: *Outcome Variables*										
Returns (Cent/Egg) [1]	10.60	10.48	3.38	2.20	17.56	9.64	8.54	3.66	4.53	17.69
Direct Costs (Cent/Egg) [1]	6.65	6.09	1.83	0.31	10.44	6.36	5.95	1.59	4.57	10.94
Net Total (Cent/Egg) [1]	0.93	0.76	1.64	-2.97	4.78	-0.14	0.26	2.04	-6.02	4.80
Explanatory Variables										
Block a: *Animal Associated Productivity*										
Laying Performance (Eggs/Hen and Year)	278.87	286.00	30.05	160.95	321.84	281.02	289.57	36.23	215.03	323.88
Age at 50 % Laying Performance (Weeks)	21.65	22.00	1.25	19.00	24.00	22.35	22.75	1.59	19.00	25.50
Feed Conversion Rate (g/Egg)	146.84	142.96	25.24	109.01	252.08	147.52	145.90	20.43	123.11	200.14
Breed	– [5]					– [5]				
Rearing System	– [2]					– [2]				
Block b: *Indirect Management*										
Mortality (%)	10.46 [5]	9.67	5.70	1.62	30.00	6.81	5.05	4.18	3.00	18.06
Farm Size (Number of Hens)	52596	22000	96850	2300	580000	71140	30780	105467	2500	342840
Injuries after Housing	– [2]					– [2]				
Mortality after Housing (%)	– [2]					– [2]				
Age of Layer House Equipment (Years)	2.53	2	3.06	0	11	1.47 [5]	1	1.26	0	4
Age of Layer House Building (Years)	21.25	20	18.74	0	56	17.58 [5]	22	16.24	0	43
Educational Level of Farm Manager	– [3]					– [3]				
Cannibalism	– [5]					– [3]				
Nest Pollution	– [3]					– [3]				
Incidences of Diseases	– [5]					– [5]				
Incidences of Red Fowl Mite	– [5]					– [5]				
Block c: *Direct Management*										
Economic Counselling	– [2]					– [2]				
Herd Controls/Day Housing	3.7	3	1.89	1	8	2.68 [5]	2	1.70	1	7
Self-mixed Feed	– [3]					– [3]				
Uses/Day of Egg Collection Belt	– [5]					– [n/a]				
Vaccination against Salmonella	– [3]					– [3]				
Collections/Day of Mislaid Eggs	1.66	1	0.92	1	5	N/A	N/A	N/A	N/A	N/A
Number of Feeding Phases	2.32	3	1.17	1	5	1.72	1	0.87	1	3
Frequency of Manure Belt Activity	– [3]					– [3]				
Sickbay	– [3]					– [3]				
Daily Inspection Time/Hen (s/Hen)	0.60	0.43	0.47	0.10	2.06	1.35 [5]	0.32	2.94	0.12	12
Nesting Site/Hen	– [2]					– [2]				
Stabling Roosters	– [3]					– [3]				
Molting	– [2]					– [2]				
Stocking Density (Hens/m^2)	10.55	9.50	3.29	6.10	20.60	11.38	11.11	1.17	8.60	13.9
Eggs Sold as "Grade A" (%)	64.31	93.00	44.32	0.00	100.00	73.01 [5]	93.00	39.23	0.00	100.00
Eggs Sold Unsorted (%)	– [4]					– [4]				
Eggs Sold by Direct Marketing (%)	13.47	0.00	23.84	0.00	98.00	22.68	6.09	34.32	0.00	100.00

[1] outcome block of both models = All outcome variables were inserted in one block
Explanatory variables were excluded from the separate models due to:
[2] missing values,
[3] sparse data,
[4] collinearity,
[5] univariate preselection (therefore descriptive results are shown in grey color, only).
N/A = not applicable

Therefore, the farm was kept in the dataset. Table 1 also shows how influencing variables were grouped into the three influencing blocks and reasons, which precluded their insertion in the respective model. The main reason why variables were not included in the final models were sparse data (aviary: 6; small-group: 8) or insufficient p-values in the univariate analyses (aviary: 6; small-group: 8). The final aviary model included 13, the small-group model eight of the original influencing factors. The only remaining qualitative (dichotomized) variable was part of the aviary model, namely the feeding of self-mixed feed, which was practiced on 12 of the 47 farms. The results of the descriptive analysis of the quantitative variables included in the final models are shown in Table 1.

3.2 Multiblock redundancy analysis

The cut-off of 80 % inertia was exceeded by using two dimensions in both models, the one for smallgroup housing and the one for aviaries, already. For the smallgroup housing model the overall coefficient of determination was R^2 = 0.464; for the outcome returns (cent/egg) it was R^2 = 0.517, for direct costs (cent/egg) R^2 = 0.628 and for net total (cent/egg) R^2 = 0.247. For the aviary model the overall coefficient of determination was R^2 = 0.456; for the outcome returns (cent/egg) it was R^2 = 0.502, for direct costs (cent/egg) R^2 = 0.501 and for net total (cent/egg) R^2 = 0.364.

Small-Group Housing. Of the three blocks in the small-group model the one on animal-associated productivity had the highest relevance and explained 46.7 % (BIP, 95 %-CI: 34.8; 58.7) of the variability in the data. The two blocks containing management variables had about the same relevance with a BIP of 27.2 % (95 %-CI: 14.8; 39.7) for indirect and 26.0 % (95 %-CI: 11.4; 40.7) for direct management. Of the variables entered in the model, the feed conversion rate had by far the highest (significant) importance for the overall outcome, however, it was significantly associated with more returns and higher direct costs per egg, only (Table 3). The farm size showed the second most (significant) importance for the overall outcome, but it was significantly associated with a higher net total gained per egg, only.

Aviary. In aviaries the block "direct management" had the highest relevance for the overall economic success and explained 46.3 % (BIP, 95 %-CI: 36.0; 56.7) of the variability of

Table 2

Regression coefficients and relevance (VIP) of influences on returns, direct costs and net total per egg in **aviary housing systems** (n = 47) – estimated in the multiblock redundancy analysis.

Influencing Factors	Regression Coefficients [Two Sided 95 %-CI]			VIP in % [Two Sided 95 %-CI]
	Returns / Egg	Net Total / Egg	Direct Costs / Egg	
Laying Performance (/ Hen Housed and Year)	-0.137 [-0.397; 0.122]	0.282 [-0.152; 0.716]	-0.328 [-0.58; -0.075]	2.4 [0; 6.6]
Age at 50 % Laying Performance (Week)	0.137 [-0.142; 0.417]	-0.469 [-1.133; 0.195]	0.45 [-0.011; 0.911]	4.7 [0; 11]
Feed Conversion Rate (g/Egg)	0.445 [-0.021; 0.911]	-0.828 [-1.493; -0.164]	1.008 [0.5; 1.515]	22.7 [7.8; 37.7]
Farm Size (Number of Hens)	-0.162 [-0.347; 0.023]	-0.061 [-0.304; 0.181]	-0.13 [-0.297; 0.037]	0.3 [0; 1.9]
Age of Layer House Equipment (Years)	0.342 [0.093; 0.592]	0.526 [0.131; 0.922]	0.016 [-0.197; 0.229]	2.4 [0; 8.3]
Age of Layer House Building (Years)	-0.137 [-0.409; 0.135]	-0.185 [-0.505; 0.135]	-0.023 [-0.253; 0.207]	0.3 [0; 1.8]
Herd Inspections / Day	-0.045 [-0.64; 0.55]	0.381 [-0.183; 0.945]	-0.296 [-0.766; 0.174]	2.4 [0; 10.4]
Self-Mixed Feed	0.393 [-0.062; 0.847]	0.594 [-0.115; 1.303]	0.025 [-0.413; 0.463]	7.6 [0; 20.3]
Collections / Day of Mislaid Eggs	0.465 [-0.002; 0.933]	0.154 [-0.558; 0.867]	0.388 [-0.052; 0.828]	9.6 [0; 24.1]
Daily Inspection Time / Hen	0.339 [-0.209; 0.887]	-0.23 [-1.159; 0.7]	0.506 [0.015; 0.996]	8 [0; 21.9]
No. of Feeding Phases	-0.239 [-0.618; 0.14]	-0.189 [-0.756; 0.379]	-0.128 [-0.486; 0.229]	2.4 [0; 9.4]
Stocking Density (Hens/m²)	-0.271 [-0.698; 0.156]	0 [-0.767; 0.768]	-0.285 [-0.631; 0.062]	3.7 [0; 9.9]
Pct. of Eggs Sold as "Grade A"	0.846 [0.265; 1.426]	0.739 [0.016; 1.463]	0.406 [-0.049; 0.861]	30.2 [6.4; 54]
Pct. of Eggs Sold by Direct Marketing	0.163 [-0.414; 0.74]	0.523 [-0.516; 1.563]	-0.17 [-0.637; 0.298]	3.2 [0; 16.2]

VIP = Variable Importance – Relevance of the Influencing Factor
CI = Confidence Interval

Table 3
Regression coefficients and relevance (VIP) of influences on returns, direct costs and net total per egg in **small-group housing systems** (n = 18) – estimated in the multiblock redundancy analysis.

Influencing Factors	Regression Coefficients [Two Sided 95 %-CI] Returns / Egg	Net Total / Egg	Direct Costs / Egg	VIP in % [Two Sided 95 %-CI]
Laying Performance (/ Hen Housed and Year)	-0.290 [-0.828; 0.248]	-0.366 [-1.307; 0.575]	-0.248 [-0.692; 0.196]	3.2 [0; 20.4]
Age at 50 % Laying Performance (Week)	0.172 [-0.101; 0.445]	0.124 [-0.331; 0.579]	0.171 [-0.093; 0.436]	2.7 [0; 10.4]
Feed Conversion Rate (g/Egg)	0.832 [0.158; 1.506]	0.659 [-0.890; 2.208]	0.814 [0.336; 1.292]	55.7 [27.4; 84.1]
Mortality (%)	0.181 [-0.141; 0.504]	-0.083 [-0.627; 0.461]	0.237 [-0.162; 0.635]	5.6 [0; 20.4]
Farm Size (Number of Hens)	0.023 [-0.319; 0.365]	0.565 [0.027; 1.102]	-0.120 [-0.474; 0.235]	12.1 [0.6; 23.6]
Number of Feeding Phases	-0.055 [-0.571; 0.461]	0.518 [-0.401; 1.437]	-0.200 [-0.660; 0.260]	14.6 [0; 33.7]
Stocking Density (Hens/m² incl. Nest)	-0.100 [-0.503; 0.302]	-0.011 [-0.543; 0.520]	-0.116 [-0.393; 0.162]	0.8 [0; 10.4]
Pct. of Eggs Sold by Direct Marketing	0.374 [-0.479; 1.226]	0.560 [-0.458; 1.577]	0.297 [-0.201; 0.795]	5.3 [0; 31.9]

VIP = Variable Importance – Relevance of the Influencing Factor
CI = Confidence Interval

the data. Whereas the block with variables on animal-associated productivity explained another 37.8 % (BIP, 95 %-CI: 27.8; 47.8), the block reflecting the indirect management was significantly of less relevance (BIP = 15.9 %; 95 %-CI: 5.5; 26.3). Regarding the total outcome block the percentage of eggs sold as "Grade A" as well as the feed conversion rate showed the highest importance. When considering the individual associations between outcomes and influencing factors, additional influencing factors became significant as well (Table 2). The age of layer house equipment and the percentage of eggs sold a "Grade A" were significantly associated with more returns and a higher net total per egg, respectively. The daily inspection time per hen was significantly associated with higher direct costs per egg. The feed conversion rate was significantly associated with a lower net total and higher direct costs per eggs.

4 Discussion

4.1 Quality assurance of statistical analyses

As this study was to identify the predominant determinants of economic success in egg production in Germany the most suitable information to describe productivity was to be used. Literature mainly uses laying performance, feed conversion ratio and mortality when describing the productivity of laying hens on herd or farm level (Figure 1a) and utilizes this productivity to draw conclusions as to the economic efficiency of the different housing systems (e.g. LayWel, 2006a; Singh et al., 2009; Sosnowka-Czajka et al., 2010; Freire and Cowling, 2013). However, to equate the productivity of the hens with the economic success of the farm would mean neglecting other influences on the overall economic profitability. Therefore, additional to productivity parameters (Figure 1a) other factors were included as potential explanatory variables, whose influence might not be immediately evident, but which were considered nevertheless to have an indirect effect on the economic outcome, e.g. farm size (Damme, 2008; Thobe and Haxsen, 2014; Figure 1b). Some variables were suspected to have an ambiguous influence insofar as they are cost intensive, but might lead to higher returns (e.g. control time/hen). A third criterion to include an explanatory factor was its reflection of market influences (Figure 1c; e.g. whether eggs were sold graded or in bulk; Thobe and Haxsen, 2014) and therefore being subject to direct management decisions.

The fact that several variables had to be excluded from the analysis as their variability was insufficient or they did not reach the required p-value in the univariate selection process, might partly be due to the sample size. However, it may also reflect the uniformity of conditions of laying hen housing found in the field, especially in certain areas such as genotypes (Kjaer and Sorensen, 2002; van Hierden et al., 2002), the occurrence of red fowl mites (Green et al., 2000; LayWel, 2006b) or the (nearly nonexistent) installation of separated sickbays. As the minimum direct cost (Table 1) for aviaries was a valid value, it may be concluded that farming laying hens as a contractor represents a farming concept, which is rare but known in Germany. For farmers in Germany this concept may provide an incentive, because they have to cope with extremely fluctuating egg prices. As the maximum acceptable stocking density is 18 hens/m² in aviaries with more than one level and 12.5 hens/m² in small group housing systems, the stocking density was exceeded over the legal maximum in Germany (TierSchNutztV) in three of the aviary systems and three of the small group systems. Reasons for exceeding the maximum acceptable stocking density were that the area under the aviary was closed in order to prevent mislaid eggs, for example.

Multiblock redundancy analysis was chosen to group variables into thematic blocks. Thus allowing in a single analysis to calculate the joint impact of thematically related variables on the one hand, and on the other hand to consider individual variable influences (Bougeard et al., 2012). However, due to the relatively small sample size, especially as regards small-group housing, the analyses were restricted to identifying the most important explanatory factors. For each single explanatory factor a regression coefficient along with a confidence interval is output. While the confidence intervals inform about the reliability of the estimation, the regression coefficients indicate strength and direction of effects. However, the point estimates of the regression coefficients should be interpreted carefully regarding the exact size of the effects (see Table 2 and 3).

The overall coefficient of determination of the models analyzed here could be expected to be relatively low, because we have explanatory variables in the model, which only might affect one out of three outcome variables. Considering this, a 46.4 % or 45.6 % explanation of the variance of the total outcome by the investigated explanatory variables fits the expectations. For the outcome specific coefficients of determination higher values may have been expected. Due to their observed values it can be concluded that further factors influence costs and returns in egg production that were not investigated in this study. Nevertheless, this does not invalidate the significant effects that could be identified in the present study.

The algorithm for grouping the variables into the respective blocks would also have to be addressed. Especially as regards the productivity data, which were grouped in a specific animal associated block, it might be argued whether these variables might not have been better included in the direct management block. However, the BIP of the respective blocks mainly depended on single variables. Therefore, in the following the discussion focuses on the regression coefficients of single variables rather than on thematic blocks, which makes the grouping algorithm less important.

4.2 Determinants of economic success

One of the objectives of the project, to which this study contributed, was to define management recommendations for existing laying hen farms, while at the same time accounting for the differences as regards productivity and many of the main cost determining factors between farms keeping their hens in small-groups or aviaries (Tauson et al., 1999; Klemm, 2004; LayWel, 2006b; Damme, 2008; Singh et al., 2009). Therefore, it seemed appropriate to compute a separate model for each housing system.

On the participating farms returns and costs per egg were within the expected range (Damme, 2008). Nonetheless, it should be noted that many of the participating farms keeping hens in small-group housing showed a negative net total per egg. Especially smaller farms that had higher operating and building costs per egg (Thobe and Haxsen, 2014) could not compensate those with the reduced prices obtained with caged eggs (Beck, 2013).The productivity data as regards mortality, laying performance and feed conversion rate for the small-group housing as well as aviaries showed slightly better results than published in literature (VanHorne, 1996; LayWel, 2006b). This might partly be due to selection bias, as participation in the project, to which the study contributed, was voluntary and by trend more farms with higher level of management may have participated. On the other hand, it can be assumed as well, that as alternative housing systems become more common, improvements based on scientific knowledge such as compatible genotypes or rearing conditions (Aerni et al., 2005) as well as technical modifications become more widespread (Tauson, 2005), on average leading to improved welfare and performance.

Small-Group Housing. The results confirm prior knowledge that the feed conversion rate is one of the most important cost-incurring factors as feed costs constitute about 39 to 47 % of all costs in German egg production (Klemm, 2004; Damme, 2008). However, at the same time an increased feed requirement per egg also resulted in higher returns for this egg. This may be difficult to explain. Drivers for increasing returns per egg despite a seemingly less optimal (feed) management might have been a more favorable size distribution of the eggs, better egg quality or the marketing strategy of the farmer. When considering the net total gain per egg, the influence of the feed conversion rate became less clear, showing the importance of a differentiated view on the economic efficiency and considering different indicators.

However, on the participating farms additional factors were of similar importance. Especially the farm size showed a significant association with a higher net total gain, which can be explained by the advantages larger farms have through lower overheads. For example, their personnel expenses per hen are generally lower (Thobe and Haxsen, 2014). Through bulk buying they also might bargain better conditions for feed cost. However, as the effect of farm size on the direct costs is only marginal, this was not the main reason for an increased net total on larger farms.

As in Germany and other European countries most of the retailers do not sell eggs produced in enriched cages anymore (European Commision, 2003; Böttcher et al., 2008), farmers have to accept the lower prices of the food processing industry (Beck, 2013). A way to circumvent this might be to sell eggs directly to the consumer. Resulting higher personnel costs, etc. (Klemm, 2004; Damme, 2008) can be compensated by the higher prices achieved, as also shown by the results of this study. The net total of those farms which (partly) sell their eggs directly, is higher by trend. Although this finding seems to contradict assumptions that consumers prefer eggs from animal friendlier housing systems, the direct contact to the producer may outweigh considerations of animal welfare, or certain consumers prefer cage eggs for hygienic reasons.

Aviary. In small-group housing systems the food conversion rate is the main cost-driving component, as more than a third of all costs in egg production are accounted for by food costs (Damme, 2008). In loose housing systems hens generally have higher basic energy needs for maintenance than in cage systems (Tauson et al., 1999; Michel and Huonnic, 2003), as a larger part of their energy is used for various behavioral exercises. However, when assessing only farms with aviary systems, higher feed conversion rates might mainly be due to a less optimal (feed) management. Furthermore, the (not significant) association between feed conversion rate and more returns per egg, cannot compensate for the increased costs, leading to a significantly negative effect of the feed conversion rate on the net total per egg.

However, the present study shows that farms can significantly increase their returns per egg by selling a higher percentage of "Grade A" eggs. As the main part of the total returns is accounted for by the returns for eggs (Beck, 2013), the higher egg prices achieved for graded eggs, as opposed to bulk-ware, lead to a distinct increase in total returns. Higher costs for grading equipment, packaging material and labor time (Klemm, 2004) are more than compensated and the influence on the net total is a significantly positive. On the other hand, this discussion must not be concluded without consideration of the association between the percentage of "Grade A" and the percentage of eggs sold unsorted. Due to this association it cannot be clearly deduced, which one of these influences was more important for the extent of returns per egg. Nevertheless, it can be concluded, that the returns per egg depend on the amount as well as on the grading of eggs sold.

Another significant cost-driving factors in this study was the daily inspection time , because it causes higher personnel costs. However, personnel costs are not included in the direct costs (Figure 1d), which makes an association between these variables (see Table 2) at first sight seem inconsistent. However, the number of herd inspections per day, showed a positive (not significant) association with the net total per egg. In general, the interpretation of associations between increased care for the hens and returns is complicated by the possibility that care was already increased at the time the study was conducted. This might have been an attempt to tackle underlying problems, such as increased feather pecking, cannibalism or an increased number of mislaid eggs, and not a measure to prevent them. Dealing with these primary problems may be the real cause for an increase in direct costs as they are known to result in higher feed conversion rates (Tauson and Svensson, 1980) or mortality (Huber-Eicher and Sebo, 2001) as well as in a decreased laying performance (El-Lethey et al., 2000). The decreased laying performance, higher mortality etc. in turn are associated with the direct costs. Nonetheless, the profitability of these labor intensive measures is also reflected in their positive association with the returns per egg.

Mortality itself could be expected to have an influence on economic success. However, neither mortality, nor cannibalism or incidences of disease passed the selection process of the one-factorial, univariate analysis (p-value <0.15). Probably, variation in the investigated sample was not large enough to let mortality become a main driver of economic success.

The age of the layer house equipment also shows a positive influence on the net total per egg. The obvious explanation of a complete tax depreciation of older equipment probably does not apply as no layer house equipment in this study was older than 11 years. Additionally, the significantly positive impact on returns per egg seems unaccountable at first. When assessing the age of the equipment, the quality of material as well as the adequacy of equipment and facilities deteriorate with age, while the microbial and parasitical load increases. These inadequate conditions on farms with older equipment may conflict with the needs of the hens. Nonetheless, the farmer's experience in managing the building and its facilities seems to prevail over the wear and tear on the equipment. An association between the farmer's experience and the age of the facility has already been found in other livestock husbandry such as pig and broiler farming (Laanen et al., 2010; Campe et al., 2013).

The positive (not significant) association of self-mixed feed with returns and net total per egg is not simply explained by the direct influence of feed on productivity (e.g. Gunawardana et al., 2008; Safaa et al., 2008; Yuan et al., 2009; Perez-Bonilla et al., 2011). As an influence on direct costs could not be identified in this study, the positive effect on the net total per egg cannot be explained by lower feed costs due to the use of locally grown cereals, only (Henuk and Dingle, 2002). It rather can be assumed that farmers who successfully utilize self-mixed feed, have not only increased knowledge on poultry nutrition, but also on general management practice concerning egg production. Therefore, it can be assumed that the general management on farms feeding self-mixed feed was more efficient in regard to productivity of the hens as well as other economic influences.

Therefore, positive associations between management practices and total returns may be accounted for by its reflection of the farmer's management abilities as well. As shown in other fields of animal husbandry, to successfully implement management practices, farmers must not only have comprehensive knowledge of the needs of their animals but also the willingness to adopt relevant management procedures (Bigras-Poulin et al., 1985). The farmer's attitude and abilities are particularly important for high productivity and economic efficiency in loose house systems (Tauson, 2005; Sherwin et al., 2010) in the way that labour intensive measures, such as better observation of the birds, self-mixing of feed, etc. indeed pay off.

As the actual management measures applied in the field show a wide variation, they could not be identified directly. However, this study found indirect indicators of the farm management and possibly the farmer's attitude and abilities, such as the age of the layer house equipment and the percentage of eggs sold as "Grade A", which had an important effect on economic efficiency. Whereas these findings confirm prior knowledge that loose housing systems like aviaries require close attention in regard to productivity (Tauson, 2005; Sherwin et al., 2010), the study also shows that these cost and labor intensive measures may generally pay off.

5 Conclusion

It can be concluded that the economic efficiency of farms depends on more than the bare productivity of the animals. Although the feed conversion rate proved to be an important factor in the achievement of economic success, this field study showed that other factors should not be neglected.

Although there were indications that management decisions accounted for a considerable part of the economic effectiveness, they vary widely in the field. Therefore, they could not be identified in themselves. However, this study implies that management decision and the attitude of the farmer regarding animal husbandry and productivity should be taken into greater account in agricultural, economic and veterinary consultancy in the future.

Another major impact identified in this study are market outlets, which can either be conscious decisions, such as selling graded eggs or bulk-ware, but may also be beyond the influence of the farmer. Perhaps the fact that the former mass product "cage egg" now only appears profitable in niche markets, e.g. through direct marketing, shows that political decisions, decisions of the retail sector and consumer choices are important influences on the economic efficiency of egg production.

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