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Are there trade-offs between animal welfare and egg-producing farm efficiency?

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Abstract: Agribusiness is currently faced with the challenge of providing sufficient quality food for a growing population with limited natural resources. Egg production, as an important source of nutrition, is a dynamically developing sector of livestock production on a global scale. Simultaneously, the increasing public and legal considerations of animal welfare affect egg-producing operations. This paper aims to provide insight into missing evidence in the trade-offs between animal welfare and efficiency in egg-producing farms in the Czech Republic and the European Union. Detailed data were gathered on the extent of the enriched cage and indoor cage-free housing systems (aviaries/barns) among the main 30 Czech table-egg-producers. Original micro data enlarged the information on table-egg producers collected using the Orbis database. For the efficiency analysis at the EU level, data on the housing systems were obtained from Eurostat and combined with aggregated data from the Orbis database. A robust data envelopment analysis was applied which benefits from including animal-welfare variables directly into the efficiency evaluation. The results showed a negative, but statistically insignificant, relationship between the animal welfare and efficiency of the egg producers for the Czech Republic table-egg producers as well as those on the EU-country level.

Keywords: agribusiness; bio-economics; data envelopment analysis; operations management; poultry industry; table-eggs

Egg production is currently considered the fastest-growing sector of the livestock industry worldwide (Abin et al. 2018) for which animal welfare has become a key concern. In 2018, a petition named 'End the Cage Age' was launched within the EU, supported by many personalities and animal protection and welfare organisations. Within one year, the petition was signed by about 1.4 million EU citizens (Rodenburg et al. 2020). Increased public interest in animal welfare, in particular, in appropriate housing conditions, has resulted in partial positive changes over time, including the housing of laying hens (Schütz et al. 2023). Within the EU, animal welfare in laying hens has been monitored and addressed for a long time (Appleby 2003). A recent European Commission report (European Commission 2022) states that 'in 2019, 47.8% of laying hens were kept in enriched cages, 29.3% in barn and aviary systems, 17.0% in free-range housing, while the

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proportion of organic housing was only 5.9%. However, the proportion of these housing systems differs in each Member State. In Malta, Lithuania, Portugal, Slovakia, Poland, and Latvia, the vast majority of laying hens (> 80%) are kept in enriched cages. In contrast, non-caged housing is dominant in the Netherlands, Denmark, Sweden, Germany, Austria, and Luxembourg.'

In many EU Member States, such as the UK (until 2019), Germany, Spain, Italy, and Poland, egg production is widely integrated, with large companies sometimes keeping more than a million laying hens in cage systems. EU-based producers of table eggs must comply with EU legislation on food safety, animal welfare, and environmental protection. The result is high-quality poultry production, including table eggs, but at an extra cost. The welfare Directive 99/74/EC, which determines minimum standards for the protection of laying hens, is especially relevant for the egg sector. Only enriched cages or cage-free systems (either in barns or free-range) have been used for laying hens since 2012. Moreover, starting in 2027, the Czech Republic will ban the housing of laying hens in cages (Act No. 501/2020 Coll.), making indoor-free housing (aviaries/barns) the only viable alternative. In any case, more space is required for the hens than before, which can be achieved by reducing the number of hens or by increasing the housing capacity for hens. According to van Horne and Bondt (2023), maintaining production levels will require investment in housing and equipment as well as an increase in operating costs, which may affect the table egg production efficiency.

Recently, attention has been given to evaluating animal welfare or environmental impacts in relation to the production efficiency in the poultry scientific literature, however, studies focusing on an empirical analysis of this phenomenon are rare. In Spain, the Life Cycle Assessment methodology was used to analyse the environmental impacts of intensive egg production (Abin et al. 2018). The production of feed for laying hens was found to be the most significant contributor to harmful environmental impacts. The production of new laying hens and, in general, the process of replacing old laying hens with new ones was found to be a less important factor of environmental damage. The feed and pullet were confirmed as inputs in the data envelopment analysis (DEA) model combined with the Life Cycle Assessment to reveal the environmental impact of industrial egg production from the efficiency viewpoint in Canada (Turner et al. 2022). They showed that egg farms in six different housing systems were operating on high levels of efficiency concerning the feed and pullet inputs per tonne of eggs. However, certain reductions in the inputs were possible, which could translate into decreases in the total environmental impacts of the egg production.

Concerning the methodology, the DEA has been commonly applied in agribusiness. The trade-off between the cow's welfare and technical efficiency was not found at dairy farms in Germany when using an output-oriented DEA with two inputs (labour and feed costs) and two outputs (milk and farm animal welfare), see Schulte et al. (2018). For 76 sheep farms in Italy, the DEA was applied by Cecchini et al. (2021) to evaluate their efficiency in terms of transforming inputs (labour hours, feed supply, available area, livestock units) into outputs (annual meat and wool production).

The aim of the paper is a contribute to filling the evidence gap for the (non)existence of trade-offs between animal welfare and efficient egg-producing farming. Particularly, we evaluate the efficiency of table eggs producers in the Czech Republic and EU Member States when considering animal welfare and answer the question of whether there is any significant relationship.

MATERIAL AND METHODS

Data. In our study, we focus on comparisons of enriched cage systems (CSs) and barn and aviary systems (BASs). We used financial data on hen table-egg-producing companies and data on lying hen farming systems from 2016 to 2018. This period was not burdened by extraordinary events, such as the COVID-19 pandemic, the pressure to abolish cage farming was minimal and subsidies to increase the welfare of laying hens were rarely used in the Czech Republic. Such an environment is suitable for assessing the real efficiency of table-egg producers concerning the proportion of laying hens kept in BASs to the sum of laying hens kept in BASs and CSs denoted as the BAS ratio.

Detailed data on the extent of enriched cage and cage-free laying hen keeping of Czech table egg producers were provided by the International Poultry Testing (2023), with the kind permission of the Ministry of Agriculture of the Czech Republic. It includes 49 producers of various sizes (large companies as well as private individuals) whose production is commercial and covers almost 100% of the table egg production in the Czech Republic.

The firms' financial indicators were obtained from the Orbis database (Bureau van Dijk 2021). In line with

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previous experience (Staňková et al. 2022), nominal values of the total assets (*TA*s), capital (*CAP*), turnover (*TURN*), and number of employees (*NEMPs*) were used for the efficiency analysis and profit margin (*PM*) for illustrative purposes. Variables expressed in EUR are given in 2016 prices. The turnover represents the total revenue of the company for a given period achieved at a certain number of employees, the total assets including mainly the physical assets of the company (buildings, machinery, materials, inventory, cash), and the capital in the sense of the value of the capital or shareholder capital. The total assets are partly a component of the capital, and together they explain the company's financing style (equity financing, bank loans, share issues).

Due to the poor quality of reporting by some table egg producers, it was necessary to exclude entities with missing or unreliable data, which concerned mainly private individuals. In total, 30 table egg producers remained in the sample, which covers 94–96% of the total table egg production in BASs and 91–94% in CSs. The characteristics of the variables for the set of 30 producers of table eggs in the Czech Republic are shown in Table 1.

For the efficiency analysis at the EU country level (note that we are dealing with the pre-Brexit period, the UK is included), data on the keeping of laying hens in different farming systems were obtained from the European Commission (2022). The Orbis database was again used to obtain the data on egg producers (*TAs*, *CAP*, *TURN*, *NEMPs*), the variables expressed in EUR are given in 2016 prices. Companies were identified using the United States Standard Industrial Classification (US SIC) primary code 0252 – Chicken eggs. Companies involved in the production of hatching eggs were excluded using a text analysis of the company activity descriptions. For each country, data on individual companies were aggregated. The computational system MATLAB R2023a was employed for the data mining and further manipulation of the data.

Robust data envelopment analysis. For the efficiency evaluation, we employ a robust DEA using the algorithm proposed by Simar and Wilson (2007). This approach utilises bootstrapping in order to correct the bias of the estimated technical efficiency scores in DEA models. Bootstrapping involves sampling observations with replacements from the original dataset to create new 'random' datasets (or 'pseudo samples') of the same size (Simar and Wilson 1998). In this manner, an empirical distribution suitable for estimating the true distribution of the efficiency scores is obtained. By employing the second procedure of Simar and Wilson (2007), we obtain not just more robust DEA results, but we can also benefit from the possibility of including specific contextual variables directly into the efficiency evaluation. We can perform a statistical inference on them and evaluate their effect on DEA scores, so it is not necessary to perform second-stage regression to identify the factors of efficiency. Due to the focus of our application, we have chosen a model with an output orientation. As there is no clear opinion on the type of returns to scale in the application area, we decided to employ both the Charnes, Cooper and Rhodes (CCR) and Banker, Charnes, Cooper (BCC) models. The robust data envelopment analysis was performed using the rDEA package for the statistical computing software R.

Table 1. Characteristics of the final dataset of table-eggs producers in the Czech Republic

Variable	2016			2017			2018		
	mean	min.	max.	mean	min.	max.	mean	min.	max.
BAS (thousands hens)	13	0	93	19	0	142	25	0	226
CS (thousands hens)	120	0	451	133	0	532	138	0	529
BAS (%)	16	0	100	18	0	100	19	0	100
TAs (thousands EUR)	7 670	25	28 157	8 575	27	30 537	8 775	27	30 681
CAP (thousands EUR)	1 942	4	9 055	2 009	4	9 359	1 974	4	9 108
NEMPs (persons]	79	3	375	78	5	370	75	4	369
TURN (thousands EUR)	6 517	53	29 383	7 652	58	32 487	7 138	17	30 070
PM (%)	2.3	–27.8	12.0	9.3	–6.7	24.4	5.0	–5.1	24.4

BAS – barn and aviary system; *CS* – enriched cage system; *TAs* – total assets; *CAP* – capital; *NEMPs* – number of employees; *TURN* – turnover; *PM* – profit margin

Source: Authors' own calculation

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Cluster analysis and one-way analysis of variance. A hierarchical cluster analysis was employed for the assessment and characterisation of clusters of similar companies. The number of lying hens in CS and BAS was used for this purpose. To achieve stable results of clustering, the numbers and variables were averaged across the years. The Euclidean distance between objects and the Ward distance between clusters was evaluated as the best possibility. Because we want to account for the size of the farms, data standardisation was not used. A one-way analysis of variance was employed for testing of the means equality for different clusters. Assumptions of the global test were verified by the Levene test of variance equality and the Shapiro-Wilk test of normality. After the rejection of the null hypothesis, the Scheffe test was employed for testing the pairwise differences between the means. The computational system MATLAB R2023a was employed for this task.

RESULTS

Results of the efficiency analysis for the Czech Republic. First, the output-orientated bootstrapped DEA scores were calculated to find the technical efficiency scores under the CCR and BCC models for individual Czech farms. The input variables included the total assets (*TAs*), capital (*CAP*), and number of employees (*NEMPs*), and on the output side, we used the turnover (*TURN*). The proportion of hens kept in BASs was used as the factor expressing the animal housing conditions. Bootstrapping with 100 replications in the first loop and 1 000 replications in the second loop was applied for the calculation of the bias correction of the scores and the construction of the confidence intervals for the effect of the BAS ratio. To account for a possible lag in the effect of investment in the new technologies, we worked with two-year time windows: 2016–2017 and 2017–2018. No farm in our sample was identified as fully efficient in any of the model specifications, which is a consequence of using the bootstrapping procedure. There are just minor differences between the efficiency scores obtained by the CCR and BCC models, and the correlation between them was 0.90 in 2016–2017 (or 0.74 in 2017–2018). This may suggest that farms were operating close to their optimal size. The efficiency scores are quite stable over time. In the years 2016–2017, the BCC efficiency ranged from 0.219 to 0.865; in the second period, it was 0.122 to 0.893. The mean value was 0.592 in the first two years and 0.550 in 2017–2018, which indicates that, on average, farms were lacking 45% of their optimal output to become technically efficient. The regression coefficient of the contextual variable (which represents animal welfare) was negative for both models in both periods, but its 95% confidence interval ranged from negative to positive values, so the effect of the BAS ratio on efficiency was not statistically significant (Table 2).

To reveal the potential structure in egg-producers stemming from the animal welfare handling, a cluster analysis was applied (see the characteristics for clusters in Table 3). Cluster 1 is made up of large companies, where egg production is based on farms of hundreds of thousands of laying hens kept in the CS housing type. Firms in this cluster have, on average, the highest total assets and especially turnover, and the capital endowment is lower than in the other clusters. Companies in Cluster 2 have fewer hens than those in Cluster 1, and the share of BAS farms is even lower. Mostly, they do not keep laying hens in the BAS at all. These are still relatively large companies, which can be considered to have a much wider portfolio of agricultural production than the companies in Cluster 1. Cluster 3 contains smaller companies with holdings in the lower tens of thousands of laying hens. There is a high proportion of BAS. Surprisingly, the average number of employees is the same as for the larger companies in the other clusters. Part of this may be due to the way staff numbers are reported (the value of 75 is one of the options that companies can tick when reporting to the Statistics Authority instead of the actual figure), but it may also be a reason for the higher staffing burden imposed by the BAS. This is also suggested by the lowest average profitability rate of these companies compared to other clusters. It is noteworthy that the large companies from Cluster 1 have larger BAS holdings in absolute terms than the companies from Cluster 3, and, at the same time, achieve a noticeably larger profit margin.

Table 2. The regression coefficient of the *BAS* ratio and its confidence interval for the Czech farms

Model	2016–2017		2017–2018	
	BCC	CCR	BCC	CCR
BAS ratio regression coefficient	–0.44	–0.39	–0.15	–0.34
95% lower bound	–1.65	–1.41	–1.26	–1.64
95% upper bound	0.77	0.63	0.95	0.96

BAS – barn and aviary system; BCC – Banker, Charnes and Cooper model; CCR – Charnes, Cooper and Rhodes model

Source: Authors' own calculation

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Table 3. Average characteristics of determined clusters

Cluster	*BAS* (hens)	CS (hens)	*BAS* (%)	*PM* (%)	*TAs* (EUR)	*CAP* (EUR)	*NEMPs* (persons)	*TURN* (EUR)
1	44 137	386 571	8.8	9.1	13 819 771	1 337 364	74	13 214 081
2	2 965	106 228	2.4	4.6	10 062 143	2 927 986	79	8 844 737
3	17 590	11 305	32.9	2.6	4 064 898	1 585 300	78	2 471 127

BAS – barn and aviary system; *CS* – enriched cage system; *PM* – profit margin; *TAs* – total assets; *CAP* – capital; *NEMPs* – number of employees; *TURN* – turnover
Source: Authors' own calculation

It can be concluded that the large producers are testing the possibilities of BAS keeping while generating profits that can be used to finance the transition from CS to BAS. The profit margin is not as large for the Cluster 2 firms, and BAS keeping is sparse there. It is possible that these companies will not make the transition to BAS at all or will only do so with significant subsidy support. In addition to the aforementioned variability in the profit margin, we also observe visible differences in the efficiency of the DMUs across the Clusters (in 2017–2018, the average BCC scores were 0.669, 0.602, and 0.445 for Cluster 1, 2, and 3, respectively). The statistical significance of these differences was determined by a one-way analysis of variance, where the means equality is not rejected with P = 0.052 (the Levene test does not reject the variance equality (P = 0.913), the Shapiro-Wilk test does not reject the normality of any sample with the lowest

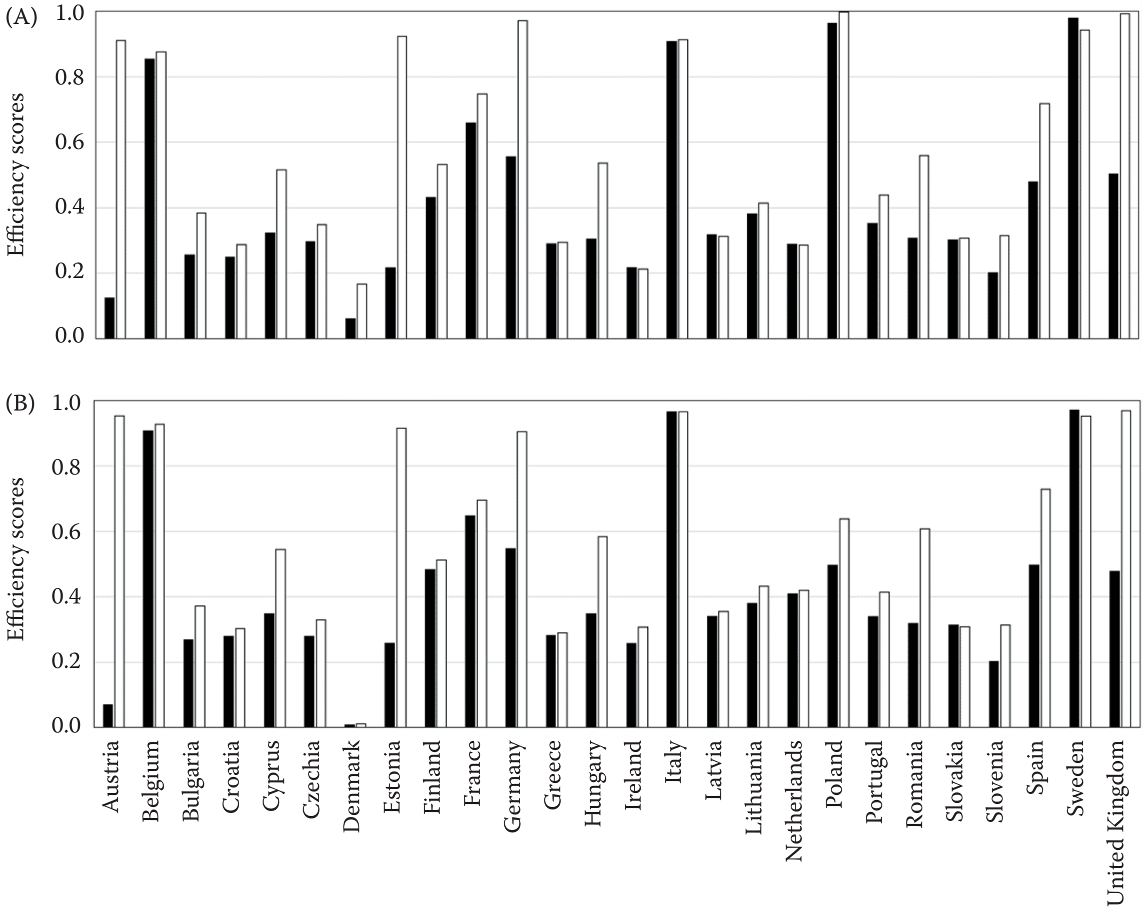

Figure 1. Efficiency scores of the European countries in (A) 2016–2017 and (B) 2017–2018 given by CCR model (black bars) and BCC model (white bars)

BCC – Banker, Charnes and Cooper model; CCR – Charnes, Cooper and Rhodes model
Source: Authors' own calculation

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P-value (0.264). As in the previous regression, there was no statistically significant association between the BAS share and firm's efficiency, although the *P*-value obtained here is practically borderline.

Results of the efficiency analysis at the EU countries level. Aggregated data on egg producers from individual European countries were analysed to check whether the effect of animal welfare on the efficiency is evident on the international level. We used the same variables as in the micro-level analysis to enter the efficiency evaluation (*TAs*, *CAP*, *NEMPs*, and *TURN* as the input and output variables for the DEA model and BAS ratio as the contextual variable). Both the CCR and BCC output-oriented models were used and the evaluated periods covered the years 2016–2017 and 2017–2018. The efficiency scores for 26 European countries are shown in Figure 1. In Table 4, we can see the regression coefficient of the BAS ratio and its 95% confidence limits. We can observe the negative effect of the contextual variable for all the specifications, which is not statistically significant. However, the sensitivity of the efficiency to changes in animal welfare is not very pronounced. The absolute value of the regression coefficient in the individual models ranged from 0.60 to 3.16, which would mean that increasing the proportion of non-caged farming by one percentage point would lead to an expected decrease in the efficiency score by 0.006 to 0.0316.

Some of the efficiency values in Figure 1 deserve further comment. The systematically very low-efficiency values for Denmark are due to data deficiencies (a small number of firms found with sufficient data) rather than relatively large inefficiency. The differences in the efficiencies given by the BCC and CCR models for Austria, Estonia, and also the United Kingdom can be explained by the suboptimal level of output of these countries. Despite these values increasing the variance of the observed efficiencies, the statistically significant effect of the BAS ratio is always maintained.

Table 4. The regression coefficient of the BAS ratio and its confidence interval for the European countries

Model	2016–2017		2017–2018	
	BCC	CCR	BCC	CCR
BAS ratio regression coefficient	–0.60	–1.83	–3.16	–3.00
95% lower bound	–4.71	–4.85	–7.31	–7.34
95% upper bound	3.51	2.69	0.99	1.34

BAS – barn and aviary system; BCC – Banker, Charnes and Cooper mode; CCR – Charnes, Cooper and Rhodes model
Source: Authors' own calculation

Countries with relatively higher efficiency of table egg production include countries with high absolute numbers of laying hens, such as France, Germany, Italy, Poland, Spain, and the United Kingdom. These countries also generally show high percentages of CS keeping (in 2018, Poland 84.5%, Spain 82.3%), but also Germany, with only 6.5% of laying hens kept in CS. The economic success of switching to BAS in Germany is discussed in e.g. Campe (2015), where the higher quality of eggs produced and consumer friendliness is mentioned among other factors. Thus, the experience from the German environment will be transferable to other countries only to a limited extent due to the high purchasing power in Germany.

Rather medium-sized producing countries such as Belgium and Sweden are also highly efficient, with a significant difference between the CS share: 36.7% in Belgium and 9.2% in Sweden (data for 2018). Among the countries with relatively lower levels of efficiency, the large producer the Netherlands stands out with a relatively low CS share of 16.1%. An interesting comparison can be made for Latvia and Lithuania, countries with very similar production levels and economic and social backgrounds. Between 2016 and 2018, there was a decrease in the CS share of 1% in Latvia and 6% in Lithuania, with Lithuania maintaining a similar level of efficiency.

DISCUSSION

Animal welfare and efficiency are linked through management and technology, and there are several potential bottlenecks of the current CS and BAS operations that affect the efficiency of production and should be considered as a background for our conclusions:

i) Laying hens are the most important input of the egg-producing process. Our results were obtained without considering the genetics of the animals. Hens have long been bred to be more productive under cage conditions, and placing such hens in a free-range system can have negative consequences. This may appear to stress the animals, and the welfare measures can turn out lower compared to the original cage system (Sherwin et al. 2010). In compliance, higher mortality was observed among hens moved to BAS (Weeks et al. 2016). This may puzzle and surprise the public and can cause further costly initiatives for egg producers or decrease demand for BAS-produced table eggs. However, we can expect that if the massive conversion to a free-range system oc-

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curs then new breeding goals will probably appear aiming at welfare and efficiency both of which could be improved at the same time (Dawkins and Layton 2012).

ii) Although there is a high commercial value in increasing animal welfare, particularly reducing the stocking density which seems to be perceived by consumers as a paramount way of improving animal welfare, is one of the costliest. Indeed, the production cost for laying hens in Northwest Europe was 16% higher in BAS compared to CS in 2021 (van Horne and Bondt 2023). To reveal the sensitivity of the efficiency on the increased costs, further research based on detailed data on the farm level will be needed.

iii) BAS will always produce lower absolute numbers of eggs than CS while requiring the same space. This need not be a problem until BAS or other, even more, space-demanding systems become major producing technology in the EU. Possibly, this could cause a pan-European lower supply of table eggs and a subsequent rise in the price of table eggs. While our results may be valid on the company level, in a global context, our assumptions about the feasibility of a massive transformation of CS to BAS and its profitability may fail.

From the production process viewpoint, in BAS and CS, the procedures are the same up to the following differences:

i) Fewer laying hens will be housed in the same house in BAS than in CS and consequently, there is a higher production cost per one hen for housing in BAS (Demircan et al. 2010).

ii) One hen in BAS consumes significantly more feed per egg than one hen in CS, there is a higher feed conversion ratio in BAS (Englmaierova et al. 2014). As feed costs represent the largest share of the cost of egg production (Turner et al. 2022), this is an important factor.

iii) There is a higher mortality of laying hens in BAS (Weeks et al. 2016).

iv) In BAS, a higher incidence of all disease categories, including bacterial, viral, parasitic, and cannibalism, was found compared to CS (Fossum et al. 2009).

v) The BAS is more demanding on labour and the significant increase in working hours (Anderson 2014) reflects in a higher labour cost.

The different costs per unit of output for the different housing systems are mainly determined by variations in the labour and housing costs; BAS can be said to have systematically higher costs than CS (van Horne and Bondt 2023). Consequently, these differences can affect the egg production efficiency.

However, too much focus on the efficiency in production operations can have negative consequences for people, livestock, and the environment (Wiengarten et al. 2017). The attitudes of the stakeholders have been steadily changing during the past years and we can see that consumers are more involved in animal welfare issues and even are willing to pay for it (Cecchini et al. 2018). These facts lead to voluntary (typically marketable) or forced changes in the poultry production process aimed at improving animal welfare (Castro et al. 2023).

When assessing the willingness to pay a higher price for eggs from higher welfare hens, it is necessary to take the specifics of each country into account, in particular the purchasing power of its inhabitants. Research in this area is ongoing, but the countries of Central and Eastern Europe are not well represented (Rondoni et al. 2020). It should also be mentioned that the demand of a particular person for changes leading to a higher welfare level of laying hens may not be based on knowledge of the changes in question and their effects, especially the price effects. In addition to final consumers, industrial producers using eggs and the impact of price changes on the whole sector should be considered.

Due to the higher labour intensity of BAS operations [more than 1 EUR per housed hen between CS and BAS, see van Horne and Bondt (2023)], a higher decrease in the efficiency of these processes compared to CS could be expected. Since this expectation did not materialise in our results, we suggest that the comparable efficiency of the operations is mainly due to the higher end-price of eggs of BAS operations and thus the maintenance of sales despite lower egg production in BAS. Furthermore, part of the increased costs of BAS operations (initial investment especially) may be covered by national subsidies.

Our results rather support the claim that there need not be trade-offs between animal welfare and efficient farming. This conclusion is in line with the qualitative statement of Dawkins (2017), who claimed that 'high standards of animal welfare can pay dividends in hard cash, we can make animal welfare the welcome partner rather than the opponent of efficient farming. There can be conflicts between welfare and production but, given the commercial value of high welfare standards, these conflicts may not be nearly as great as is sometimes supposed.'

The analysis is complicated by the fact that improving one aspect of welfare may lead to a deterioration of other characteristics of the production system, including other welfare parameters, and this conflict is very difficult to resolve (Dawkins 2017). In terms of operations management modelling: selecting the appropriate as-

https://doi.org/10.17221/93/2024-AGRICECON

sumptions and the relevant fidelity of the model is crucial for the validity of the results (Janová 2014; Janová et al. 2024). In our study, we considered standard inputs and outputs plus animal welfare. On the other hand, we did not take into account possible differences in waste management, energy consumption, or the impact on the well-being of workers in BAS who have to work in a highly dusty environment.

Another limitation lies in the choice and availability of financial indicators. In our case, due to their accounting definition, the *TAs* and *CAP* variables are related, which is usually inappropriate for DEA. Given that the correlation between *TAs* and *CAP* in individual years is around 0.5 for Czech companies and around 0.6 for EU countries, this does not seem to be problematic in our case. It would be useful to include, e.g. material costs in the model, ideally in a more detailed breakdown, but such data are not available for most companies.

For the future, it is necessary to consider not only the purely economic impacts of the transition to BAS, but also to focus on possible differences in waste production and management, the carbon footprint due to differences in energy intensity, and, in particular, assess the impact on workers' health.

CONCLUSION

We provided an initial insight into missing evidence in the trade-offs between animal welfare and efficiency in the egg producing industry. Based on detailed microdata from the Czech Republic and aggregated data from the European Union, our analysis rather supports the opinion that there need not be strong trade-offs between animal welfare and efficient farming. However further research is needed to analyse the situation for modified assumptions, in the global context and consider also, e.g. the well-being of the workers.

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