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Are technological or efficiency differences more pronounced between Hungarian and Polish poultry farms? A stochastic metafrontier analysis

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Abstract: The efficiency of poultry production plays a crucial role in ensuring food security and maintaining human health sustainability. Although extensive research has been done on the largest poultry-producing countries, the European Union's contribution has not been thoroughly investigated, especially in Central and Eastern Europe. This study aims to fill this gap by analysing the technical efficiency of poultry farms in Hungary and Poland. We use the stochastic metafrontier approach to Farm Accountancy Data Network (FADN) data from 2010 to 2015. The results suggest that both countries have technical inefficiencies. The meta technical efficiency (*MTE*) was higher in Poland than in Hungary, driven by both a higher technology gap ratio (*TGR*) and higher (country-specific) technical efficiency (*TE*) in Poland. In both countries, returns to scale were increasing, which suggests that policies that increase scale of operation could increase efficiency. Furthermore, the study highlights the importance of technological gaps for several farms both in Poland and Hungary; therefore, policies should also focus on supporting investments in technology adoption and innovation. This could involve providing subsidies or grants for the adoption of advanced farming technologies, such as automated feeding systems or data analytics for optimizing production processes.

Keywords: agriculture; comparative analysis; Hungary; Poland; SFA; technical efficiency

The poultry industry plays a major role in food security by producing poultry meat and eggs. Thus, the efficiency of the poultry sector is a key issue in the sustainability of human health. However, research on the efficiency of poultry production is limited, especially in comparison to that in the crop and milk sectors. Studies focus mainly on the largest poultry-producing countries, including China (Zhu and Qin 2015; Xin et al. 2016; Zhong et al. 2021), Brazil (Piran et al. 2021), Iran (Heidari et al. 2011a, b; Amid et al. 2016; Ebrahimi et al. 2016; Mahjoor 2013), Malaysia (Gabdo et al. 2017a, b), Thailand (Areerat et al.

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2012), and Turkey (Dogan et al. 2018; Parlakay and Çimrin 2021).

Although the European Union is a key player in the world poultry market, only Greece is represented in efficiency studies of the poultry sector (Keramidou and Mimis 2011; Keramidou et al. 2011; Hatzizisis et al. 2019). Thus, knowledge of the technical efficiency of European poultry farms is limited. Moreover, all previous studies have focused on only one country; no cross-country comparisons of poultry sectors have been conducted.

Understanding the efficiency of the poultry sector is crucial for several reasons. Firstly, it provides insights into the inherent capacity of poultry farms in Hungary and Poland to maximise output while maintaining inputs. Meta-technical efficiency analysis enables policymakers to identify areas of improvement, tailor interventions, and enhance the overall productivity of the poultry sector. This is especially important given the increasing global demand for poultry products. Secondly, as efficiency is a key driver of economic sustainability, monitoring it also offers a lens into the long-term viability of poultry farming in Hungary and Poland.

In Poland and Hungary, the poultry industry represents a significant portion of the agricultural sector, making them good candidates for investigation. The relative importance of this sector is greater in these countries than in the European Union (EU) and other Central and Eastern European (CEE) countries. According to the Economic Accounts for Agriculture (EAA) released in 2023, poultry breeding contributed 11.7% and 11% to agricultural production in Poland and Hungary, respectively, which represented the two highest shares in the EU. In both countries, we observed similar processes in the poultry sector, as indicated by the data in Table 1. There were, however, some differences in intensity. Despite a slower increase in poultry prices, the sector grew faster in Poland, primarily due to a higher increase in both exports and domestic consumption. However, the growth in Hungary's production value was primarily due to an increase in prices as the number of animals generally declined. The process of concentration was also stronger in Hungary, with a faster decrease in the number of holdings and an increase in the average number of animals per holding. Therefore, the situation in both countries seems similar enough for comparison and sufficiently different for some variation in efficiency patterns to be expected.

Table 1. Changes in poultry producing farms and their environment in Poland and Hungary in the years 2010–2015

Measures	Hungary	Poland
Production value 2010 / 2015[a]	+18.8%	+44.9%
No. of specialised farms 2010 / 2016[b]	–51.3%	–28.5%
No. of animals 2010 / 2016[c]	–9.1%	+18.1%
Average No. of animals per holding 2010 / 2016[d]	+86.7%	+65.1%
Real price change 2010 / 2015[e]	+11.7%	+6.3%
Nominal value of the trade balance 2010 / 2015[f]	+36.4%	+129.0%
Food supply 2010 / 2015[g]	+5.8%	+12.6%

[a]values at constant prices (2010 = 100); [b, c, d]livestock units of poultry in specialised poultry farms; [e]price indices of agricultural products, real index, poultry; [f]live animal + meat; [g]food supply quantity (g / capita / day)

Source: Eurostat (2021), FAO (2021)

The paper contributes to the literature in three ways. First, we investigate the technical efficiency of poultry farms in Central and Eastern Europe – namely in Hungary and Poland.

Second, we present a cross-country comparison, an approach that has been seldom used in the agricultural literature, with a few exceptions (Latruffe et al. 2012; Baráth et al. 2021). Finally, we employ a recent stochastic metafrontier approach to assess technological heterogeneity between countries.

MATERIAL AND METHODS

We used the Farm Accountancy Data Network (FADN) data for individual farms specialised in poultry production over the period 2010–2015 with balanced panel data. The sample sizes were N = 174 for Poland and N = 390 for Hungary. The value of total outputs, depreciation, and total specific costs were deflated to constant 2010 prices using nominal price indices and Eurostat and FADN annual currency exchange rates. The selection of variables was based on earlier studies of the poultry sector (Begum et al. 2012; Xin et al. 2016) and data availability.

The average farm size in terms of output was similar in the examined countries (Table 2). Concerning the inputs, the deprecation costs were slightly larger in Poland, while labour input and the number of poultry were slightly larger in Hungary. However, what differentiated the countries most was sample diversity. The coefficient of variation was much higher for Hungary for all variables.

We applied a stochastic metafrontier approach (SMF). Metafrontier models were used in situations

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Table 2. Descriptive statistics for the research sample

Variable	Mean	SD	Min	Max	*CV*
Poland (N = 174)					
Output (SE131)	364 803.1	274 388.1	32 774.5	1 423 098.0	0.8
Labour (SE010)	3.7	2.4	1.0	11.7	0.7
Depreciation (SE360)	15 832.4	11 708.9	320.9	57 422.2	0.7
Specific costs (SE281)	237 941.3	189 552	18 282.9	1 066 151.0	0.8
Number of poultry (SE105)	182.9	152.7	8.4	669.6	0.8
Hungary (N = 390)					
Output (SE131)	289 988.1	1 016 157	558.6	9 151 011.0	3.5
Labour (SE010)	4.6	15.5	0.4	148.1	3.4
Depreciation (SE360)	7 674.1	16 765.0	63.8	135 423.6	2.2
Specific costs (SE281)	206 595.6	702 363.1	287.4	728 410.4	3.4
Number of poultry (SE105)	277.9	930.3	4.9	9 901.8	3.3

SE131 – total output in EUR in 2010 prices; SE010 – total labour input in annual work unit (full-time person equivalent); SE360 – depreciation in EUR in 2010 prices (as a robustness test, we tried different capital variables, but we received meaningful results only with depreciation.); SE281 – total specific cost in EUR in 2010 prices (feed and other specific costs); SE105 – number of poultry in livestock units; *CV* – coefficient of variation

Source: FADN (https://agridata.ec.europa.eu/extensions/FarmEconomyFocus/FADNDatabase.html)

where firms could be classified into two or more groups, and where firms in different groups chose input-output combinations from potentially different sets of production possibilities (O'Donnell 2018). Within a group, all firms chose output-input combinations from the same set of production possibilities (group-specific frontier), and the metafrontier was the envelope of the group-specific frontiers.

Recently, two different SMF approaches have been introduced that respect the stochastic nature of the group-specific frontier and the metafrontier, one by Huang et al. (2014) and the other by Amsler et al. (2017).

We applied the Amsler et al. (2017) approach. The description of the method was based on Amsler et al. (2017) and O'Donnell (2018).

Let us assume that we observed data on n farms grouped into S groups. For a given farm i, we observed y_i, x_i, and d_i, where y_i is log output, $x_i = 1, x_{i2}, \ldots, x_{ik}$ is a vector of inputs, and $d_i \in 1, \ldots, S$ is the group to which farm i belongs.

The relationship between the observed output and the inputs of farm i can be written in the form of a stochastic frontier model as follows:

$$y_i = x'_i\beta_{d_i} + v_{i,\,d_i} - u_{i,d_i} \tag{1}$$

where: d_i – group to which farm i belongs; v_{i,d_i} – usual error (noise) term; $u_{i,d_i} \geq 0$ – measure of technical inefficiency.

The central question of the metafrontier literature is: how much could the farm have produced if it had used the technology of a different group. Therefore, the given farm i is conceptually represented by a set of stochastic frontier models:

$$y_{is} = x'_i\beta_s + v_{is} - u_{is},\ s = 1, \ldots, S \tag{2}$$

According to Equation (2) we can distinguish between stochastic frontiers (f_{is}) and the metafrontier (f_i) as follows:

$$y_{is} = x'_i\beta_s + v_{is} - u_{is},\ s = 1, \ldots, S, \text{ with } y_{is} \leq f_{is} \tag{3}$$

$$f_i = \max[f_{i1}, \ldots, f_{iS}] \tag{4}$$

Farm i's inefficiency, denoted by (U_i) relative to the stochastic metafrontier (f_i) can be decomposed as follows:

$$U_i = U_{i,\,d_i} + M_{i,\,d_i} \tag{5}$$

where: $U_{i,\,d_i} = f_{i,d_i} - y_i = u_{i,\,d_i}$ – the one-sided technical inefficiency term for farm i in the stochastic frontier model for group d_i; $M_{i,\,d_i} = f_i - f_{i,\,d_i}$ – metafrontier distance.

In order to get coherent predictions of the above-defined quantities, the first step was to obtain maximum

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likelihood (*ML*) estimates of the parameters of the production frontier. The second step was to use these parameter estimates to draw random samples of observations of $v_{i,\, di}$ and u_{i,d_i} for all $d_i \in S$. The final step was to use these random samples to predict U_i, $U_{i,\, di}$, and $M_{i,\, di}$. Detailed description of the algorithm for drawing B random samples ($b = 1, \ldots, B$) of observations on the noise and inefficiency effects can be found in Amsler et al. (2017) and O'Donnell (2018). We refer the reader to these papers and do not describe the algorithm in detail here to save space.

In the empirical literature, the usual quantities of interests are: *i*) the technical efficiency (*TE*) that shows the ratio between farms observed and potential output [i.e. it shows how well farmers make use of their own technology (group-specific technical efficiency)]; *ii*) the technology gap ratio (*TGR*) that measures the ratio between each group's frontier and the metafrontier; and *iii*) the meta technical efficiency (*MTE*) that measures the ratio between farms observed output and the metafrontier. *MTE* is the product of *TGR* and *TE*.

We used the Cobb–Douglas (CD) functional form. In order to examine the effect of technological change, we added the time trend to our model. We also attempted to estimate the translog functional form, but it violated both monotonicity and quasi-concavity criteria, so we decided to use the CD function instead. The empirical model is as follows:

$$\ln y_{it} = \alpha_d + \sum_{k=1}^{K} \beta_{k,d_i} \ln x_{kit} + \beta_{td_i} t + v_{i,d_i} - u_{i,\, d_i} \tag{9}$$

where: $t = 1, \ldots, T$ – time trend representing technological change; $d_i \in$ {Hungary, Poland}.

A potential limitation of the applied method is that it focuses only on cross-country heterogeneity (i.e. within-country heterogeneity is not considered); therefore, technical efficiency might be confounded with intra-country heterogeneity to some extent. However, estimations of country-specific true random effect (*TRE*), true fixed effect (*TFE*), and random parameter models (*RPM*) suggested that within-country heterogeneity did not play a significant role in the present case.

To check the significance of the differences between countries, we conducted Mann-Whitney tests for all the components of efficiency and the technology gap.

RESULTS AND DISCUSSION

The results of the estimated models are presented in Table 3. The first fundamental question was whether there was inefficiency in poultry production in Poland and Hungary. Information about this can be drawn from the estimate of σ^2_u. The null hypothesis that $\sigma^2_u = 0$ was rejected in all cases, which suggests that technical inefficiency played an important role in both Hungarian and Polish poultry production. Therefore, omitting the inefficiency term from the production model would create biased results.

Additionally, all the coefficients of the production function were positive, in line with economic theory, and they were highly significant except for the time effect. For Poland, the most important factor was specific costs (feed, etc.), followed by the number of animals. In Hungary, the primary determinant was specific costs, while labour played a comparatively significant role. In both countries, the least important factor was depreciation.

Furthermore, we summed the elasticities to calculate return to scale (*RTS*); both in Poland (1.06) and in Hungary (1.05) it was above one, i.e. it suggests (slightly) increasing *RTS* in both countries, although both values were rather close to one. We also formally tested whether the production exhibited constant return to scale, i.e. whether the sum of the estimated parameters was equal to one [Table S2 in the Electronic Supplementary Material (ESM)]. The test clearly confirmed the existence of increasing returns to scale. This suggests that both countries could benefit from the increasing scale of operation in the poultry sector. In the literature, most of the studies found increasing returns to scale among poultry farms, e.g. in Greece (Keramidou et al. 2011) and Turkey (Parlakay and Çimrin 2021). Other studies also identified increasing returns to scale in the pig sector in Poland and Hungary (Baráth et al. 2021).

In all the models, the coefficients for *t* were insignificant, indicating that the production frontier remained stable in Poland and Hungary.

The results regarding the meta-technical efficiency (*MTE*) and its components (*MTE* = *TE* × *TGR*) can be seen in Figure 1 and Table S1 in the ESM.

On average, Poland's meta-technical efficiency was higher than Hungary's, at 0.94 for Poland and 0.90 for Hungary. As a robustness test, we also estimated *MTE*, applying the deterministic metafrontier method (Battese et al. 2004). This estimation confirmed our findings. The *MTE* scores, as expected (Amsler et al. 2017), were lower for both countries (0.83 for Hungary and 0.87 for Poland), but the results showed similar differences between the countries. These values can be interpreted as inefficiencies of production arising from technological limitations compared to the best

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Table 3. Estimates for the parameters of the country specific stochastic frontier models

Variables	Poland			Hungary		
	coefficients	SE	*t*-value	coefficients	SE	*t*-value
Constant	2.479	0.397	6.25	3.740	0.292	12.81
Labour (Se010)	0.082	0.036	2.25	0.239	0.026	9.12
Depreciation (Se360)	0.113	0.036	3.14	0.112	0.015	7.31
Specific costs (Se281)	0.616	0.039	15.82	0.528	0.027	19.22
Poultry (Se105)	0.244	0.034	7.26	0.168	0.032	5.18
Time	0.007	0.010	0.74	0.000	0.009	0.02
$\ln\sigma_u^2$	–3.452	0.222	–15.53	–2.790	0.151	–18.43
$\ln\sigma_v^2$	–3.004	0.409	–7.35	–2.491	0.318	–7.83
λ	1.251	0.061	–	1.161	0.061	–
RTS	1.060	–	–	1.050	–	–

RTS – return to scale

Source: Authors' estimations based on FADN data (https://agridata.ec.europa.eu/extensions/FarmEconomyFocus/FADN-Database.html)

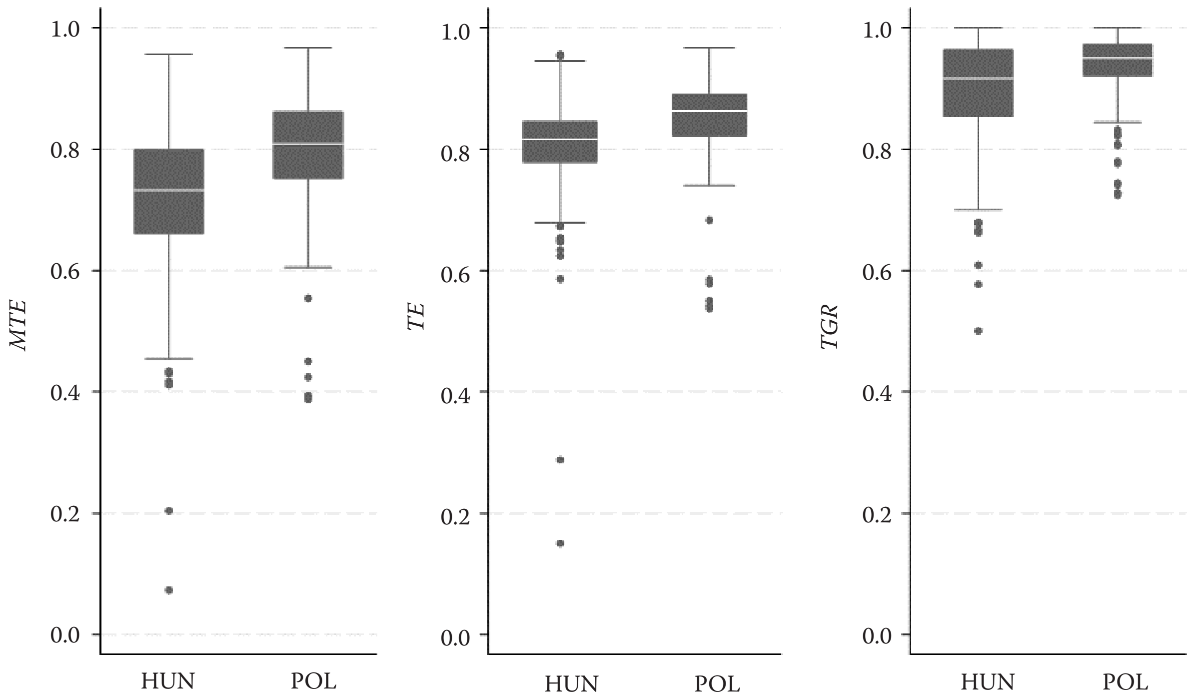

Figure 1. Distribution of meta-technical efficiency, technology gap ratio, and technical efficiency

MTE – meta-technical efficiency; *TE* – technical efficiency; *TGR* – technology gap ratio

Source: Authors' construction based on FADN data (https://agridata.ec.europa.eu/extensions/FarmEconomyFocus/FADN-Database.html

available technology. Based on these results, it can be concluded that the scale of this issue in Poland and Hungary was similar or smaller than in other countries and with other types of animal production. For beef production in Ireland, *TGR* was estimated to be 0.965, in France 0.948, in Germany 0.914, and in the UK 0.908 (Martinez Cillero et al. 2021). For dairy farms in Norwegian regions, *TGR* ranged from 0.93–0.35 (Alem 2021). For dairy farms in Belgium, the range was 0.77–0.993 (Ahikiriza et al. 2021). Fi-

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nally, for pork farms in Poland and Hungary, *TGR* was 0.51 and 0.59, respectively (Baráth et al. 2021). Furthermore, as the results highlight the importance of technological gaps for several farms both in Poland and Hungary, policies should focus on supporting investments in technology adoption and innovation. This could involve providing subsidies or grants for the adoption of advanced farming technologies, such as automated feeding systems or data analytics for optimising production processes.

Technical efficiency (*TE*) in relation to the country frontier was higher among farms in Poland (0.85) than in Hungary (0.81). In sum, the results show that on average (country-specific) technical efficiency was 5 % higher in Poland compared to Hungary, the meta-technical efficiency was 10% higher in Poland, and the technology gap ratio was 5% better in Poland (i.e. the applied technology in Poland was much closer the best available technology). Mann-Whitney and median tests (Table S1 in the ESM) confirmed that these differences were statistically significant.

Finally, we discuss how *TGR* changed over time. This data is shown in Figure 2. Throughout the entire analysis period, Poland's gap declined. The difference between the two countries was relatively constant, with only small variations observed annually, mostly as a result of shifts in the Hungarian *TGR*. It is particularly noteworthy that after 2012, the gap between the two countries narrowed slightly, as the gap narrowed in Hungary but remained unchanged in Poland. The potential reason for this narrowing gap is the significant increase in national subsidies, mainly animal welfare aid in Hungary after 2010. In 2010, the Hungarian Ministry of Agriculture provided a EUR 14 523 801 animal welfare aid to the poultry sector. In 2014, this subsidy increased to EUR 30 778 203 and in 2015 to EUR 35 495 321 (calculated using the yearly average of HUF / EUR exchange rate of the Hungarian Central Bank).

The objective of this animal welfare aid is to compensate farmers for additional animal welfare commitments. It includes several measures that might contribute to more efficient production, e.g. ensuring the humane handling and transport of animals, ensuring an appropriate building microclimate, or ensuring that feed is free of undesirable substances. In addition, other potentially efficiency-enhancing

Figure 2. Evolution of the technology gap ratio (*TGR*) in Poland and Hungary in the years 2010–2015

Source: Authors' composition based on FADN data (https://agridata.ec.europa.eu/extensions/FarmEconomyFocus/FADNDatabase.html

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types of subsidies, e.g. subsidies for the prevention of certain animal diseases or animal corpse disposal, were introduced after 2010. The amount of these subsidies subsequently increased after 2010 and almost doubled from 2010 to 2012.

CONCLUSION

The stochastic metafrontier approach (SMF) analysis of the poultry sectors in Poland and Hungary yielded valuable insights into the technical efficiency, technology gaps, and overall efficiency of these industries. Our key findings were the following.

Results revealed the presence of technical inefficiency in both the Polish and Hungarian poultry sectors, indicating the possibility of increasing poultry production by optimising resource utilisation and implementing more effective management practices. All coefficients in the production functions were positive, aligning with economic theory. Specific costs, including feed, played a crucial role in both countries, but the significance of other factors differed. In Poland, the most important factor was specific costs, followed by the number of animals, while in Hungary, specific costs and labour were key determinants. The least important factor in both countries was depreciation.

Poland demonstrated superior technical and metatechnical efficiency in comparison to Hungary. This indicates that Polish farms are closer to reaching their maximum production capacity than Hungarian farms. Both countries demonstrated increasing returns to scale, suggesting that larger farms may achieve greater efficiency. The technology gap in Hungary was decreasing. The disparity in the technological gap between Hungary and Poland had marginally diminished over time, possibly as a result of increased governmental financial support in Hungary.

The research offers some policy implications. Policies that encourage an increase in the scale of operations could further improve efficiency and economies of scale in both countries. Given the distinct importance of production factors in each country, targeted interventions are essential. Policymakers should design strategies that address specific cost challenges in Poland and a combination of specific costs and labour-related issues in Hungary. Policies aimed at narrowing the technology gap should be prioritized. Future research could explore the role of extension services, training programs, and financial incentives in promoting the adoption of advanced technologies in poultry farming.

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