





Article

Efficiency of Pig Production in the Czech Republic and in an International Context

Jaroslav Havlíček ¹, Ludmila Dömeová ¹, Luboš Smutka ², Helena Řezbová ³,
Lucie Severová ⁴, Tomáš Šubrt ¹, Karel Šrédí ⁴ and Roman Svoboda ^{4,*}

¹ Department of Systems Engineering, Faculty of Economics and Management, Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Prague 6, Czech Republic; havlicekj@pef.czu.cz (J.H.); domeova@pef.czu.cz (L.D.); subrt@pef.czu.cz (T.Š.)

² Department of Trade and Finance, Faculty of Economics and Management, Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Prague 6, Czech Republic; smutka@pef.czu.cz

³ Department of Economics, Faculty of Economics and Management, Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Prague 6, Czech Republic; rezbova@pef.czu.cz

⁴ Department of Economic Theories, Faculty of Economics and Management, Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Prague 6, Czech Republic; severova@pef.czu.cz (L.S.); sredl@pef.czu.cz (K.Š.)

* Correspondence: svobodar@pef.czu.cz; Tel.: +420-224-382-156

Received: 6 October 2020; Accepted: 16 November 2020; Published: 2 December 2020



Abstract: This study presents a comparison of the performance and the ranking of pork producers in 16 countries over the period 2012–2017. Data envelopment analysis (DEA) is used to make the ranking and identify the best practices among the involved countries (“peers”). For the DEA analysis, the output is aggregated into the category Carcass meat production in sow/year/kg, the inputs into Feed costs, Other variable costs, Labor costs, Depreciation and finance costs. In the first round of evaluation, only Brazil, the USA and The Netherlands were designated as peers. Significant differences between the highest-ranking values (1) and the lowest-ranking values (0.709) showed greater differences between European and non-European pork manufacturers. To get more European countries among the peers, non-European countries the USA and Brazil were excluded from the second round of evaluation. The second round of evaluation indicated that Belgium, the Czech Republic, Denmark, Finland, Italy, the Netherlands and Spain are efficient producers with regard to the given inputs. The ratings of Germany, Italy and France are close to one (with differences of less than 4%); therefore, these countries can also be classified as efficient units. The identification of peers among selected EU producers represents “best practices” in the field.

Keywords: data envelopment analysis; decision-making unit; pig production; pork meat production; ranking; peer

1. Introduction

Pork is one of the mainstays of the Czech diet. For many years, pig farmers suffered because of low pork meat price because of regional overproduction and massive competition. As regional meat processing plants reduced the prices in the past, pig farmers realized their production for unsustainable price for more than one decade. Many farmers were forced to close down their production and lost all of their pigs as a result [1]. Between the turn of the millennium and March of 2019, the number of farmed pigs dropped from nearly 3.69 million down to 1.54 million, according to the Czech Statistical Office [2]. The before mentioned development resulted in the low self-sufficiency in pork production, which decreased to 51.5% in the Czech Republic in 2018 [3].

The situation changed in 2019. Since mid-March of 2019, the prices of pigs processed at slaughterhouses have gone up by approximately a fifth, while individual, separately traded pig carcass parts have seen an increase of up to 40% in the Czech Republic. The rise in prices is especially due to the higher proportion of meat being sold to China and several others mainly Asian countries. The growth of pig price must be understood as a results of several factors influencing European and local pig market in one moment. African swine fever significantly reduced pig production in Asia (mainly in China). The pork meat price in affected countries suddenly increased and individual countries also increased their imports. The unexpected growth of imports resulted in growth of world pork meat price and territorial volume and structure of pork meat trade changed. Many countries significantly increased their exports to China and in many regions the available volume of pork meat decreased. Such situation could be seen mainly in European Union as the key pig meat producers increased their exports to China. Just between 2018 and 2019 the EU exports increased from 1.34 million tons up to 2.34 million tons (e.g., Spain increased exports by 100%, Germany by 68%, France by 56%, Denmark by 69%, The Netherlands by 72) [4]. The reduced local pork meat supply in Europe resulted in the growth of local pork meat and pig price. Between 2018 and 2019 the European Union (EU) pig meat price increased from cc 135 EURO/100 kg carcass to cc 200 EURO/100 kg carcass [5]. During the same time period, Czech pig meat market price increased also from 137 EURO/100 kg carcass to 200 EURO/100 kg carcass [6]. Based on available data and research findings it is more than evident that the price of meat is not only factors influencing the ability of pig producers to survive. Another key driver is related to ability of farmers to manage the pig production process itself. The factor productivity and efficiency of individual processes connected to pig farming are also important.

The article follows previous research concerning the identification of best practices on the European pig market through the use of benchmarking. This was used to identify the critical success factors over which an organization has some control, in areas or processes for which this is necessary in order to achieve the best outcomes in the market. The results of previous studies [7] imply that total factor productivity has slightly decreased in the EU over the analyzed period; however there are significant differences between the OMS ('old' member states, that is, the EU-15) and NMS ('new' member states) and across Member States.

A univariate time series model was used to analyze the position of the Czech Republic among selected European pig producers in the period 2010–2018 [8]. The goal of the study is to compare and rank pig producers in selected 14 European countries, Brazil and the USA in terms of efficiency of production in the period 2012–2017. Performing manufacturers' assessments to identify the best practices leads to recommendations on the cost reduction and/or the changing of the production structure. The units that achieve the highest score in the benchmarking become the "benchmarks" or "peers" for others.

2. Materials and Methods

There are several ways to estimate the efficiency rates of producers involved in the evaluation. The most frequent are multicriteria decision-making methods and data envelopment analysis (DEA). The multicriteria decision-making methods suggest that the decision maker defines the weights of criteria, that is, determines the significance of inputs and outputs in the model. Based on this, the model evaluates units and ranks them from best to worst. On the other hand, DEA models derive the weights of inputs and outputs using optimization procedures. Solving the models using linear programming methods, the units are divided into efficient and inefficient. If a unit is inefficient, the DEA model offers target values of inputs and outputs which lead to efficiency. In our paper, we are proposing the DEA method.

The DEA is a nonparametric technique used in the estimation of the efficiency of a homogeneous set of producers that are called Decision-Making Units (DMUs). DEA started out as a theoretical method in 1978 and it is widely applicable in developing and new areas today. The DEA models

are used to identify the so-called “effective DMUs”, which can then be used to construct an efficient production frontier.

In this study, we follow previous methodology concerning the cost of pig meat and the productivity of the pig production up to farm-gate level. DEA models are used for mutual benchmarking among the studied countries to answer the question of how to change inputs to improve the efficiency of pig meat production [9]. Mutual comparison enables smaller units (regions, companies) to compare their own operations and achievements with the best available one and thereby to design and implement their own strategy for improving their performance.

2.1. Model Description

Since the original DEA study [10], the implementation of the DEA models shows rapid and continuous growth in the field of applications of efficiency and productivity in both public and private sector activities. A comprehensive listing and analysis of DEA research covering the first 20 years of its history is not fully available. In 2002, Emrouznejad, Parker and Tavares [11] identified 3203 publications and 6 years later, in 2008, inventoried more than 7000 publications. This growth reflects not only the easier access to developing bibliography databases but also the need for user-friendly measurement methods. A listing of the most utilized/relevant journals, a keyword analysis and selected statistics are presented, for example, in Chaowarat, Piboonrugnroj and Shi [12], García-Alcaraz et al. [13], Zhou et al. [14].

DEA has been easily applicable due to the existence of study literature by Fulginiti [15], Emrouznejad, Parker and Tavares [11] and Hwang et al. [16], free software—Cooper, Seiford and Tone [17]—and the teaching of DEA in graduate programs. Nowadays, it is quite usual for practitioners and decision-makers who are not professionals in operational research to run their own efficiency analyses.

There are many areas where the DEA can be applied. For example, a recent study by Liu et al. [18] states that the DEA is mostly used in banking, health care, transportation and education. Yang [19] shows that in the last decade, approximately 66 % of studies applied the DEA on empirical data and the rest of the studies dealt with a methodological approach to the DEA. The application areas that have shown the highest growth momentum recently are energy, environment and agriculture.

The methodological problems of DEA applications are widely discussed in the papers. Avkiran and Parker [20] investigated the basic dimensions underlying the progress realized by the DEA methodologies, borrowing from the social sciences literature. Emerging evidence of a declining number of influential methodological-based publications and a flattening diffusion of applications imply the unfolding maturity of the field.

Generally, two DEA types of models are used in the modelling process: input-oriented models and output-oriented models. An inefficient DMU can be made efficient by decreasing the inputs while the outputs remain constant (input orientation) or by increasing the outputs while keeping the inputs constant (output orientation).

The efficiency of DMUs is defined as (a) technical efficiency and (b) pure technical efficiency which are explained as follows:

(1) Technical efficiency measures the performance of a DMU relative to other DMUs in a group and is expressed by the ratio of sum of the weighted outputs to the sum of the weighted inputs:

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \dots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \dots + v_m x_{mj}} = \frac{\sum_{r=1}^n u_r y_{rj}}{\sum_{s=1}^m v_s x_{sj}}, \quad (1)$$

where ‘ x ’ and ‘ y ’ denote input and output and ‘ v ’ and ‘ u ’ represent input and output weights, respectively; ‘ s ’ is the number of inputs, ‘ r ’ is the number of outputs and ‘ j ’ represents j -th DMU.

Charnes, Cooper and Rhodes [10] translated Equation (1) into linear programming model (Equations (2)–(5)), where z is the technical efficiency representing i -th DMU.

$$z = \sum_{r=1}^n u_r y_{ri} = \max \quad (2)$$

$$\sum_{s=1}^m v_s x_{sj} = 1 \quad (3)$$

$$\sum_{r=1}^n u_r y_{ri} - \sum_{s=1}^m v_s x_{sj} \leq 0 \quad (4)$$

$$u_r \geq 0, \quad v_s > 0, \quad i = 1, 2, \dots, k; \quad j = 1, 2, \dots, k. \quad (5)$$

The evaluation of the DMU's efficiency is calculated by means of the corresponding dual model. The relationships between the primary and dual models are evident in the matrix notation. The dual model corresponding to the linear programming model (Equations (2)–(5)) can be stated as follows.

Primary model:

$$z = u^T Y_q \quad (6)$$

$$v^T X_q = 1 \quad (7)$$

$$u^T Y - v^T X \leq 0 \quad (8)$$

$$u \geq 0, \quad v \geq 0. \quad (9)$$

Dual model:

$$f = \theta - \varepsilon(e^T s^+ + e^T s^-) \quad (10)$$

$$Y\lambda - s^+ = Y_q \quad (11)$$

$$X\lambda + s^- = \theta X_q \quad (12)$$

$$\lambda \geq 0, \quad s^+ \geq 0, \quad s^- \geq 0. \quad (13)$$

$\lambda = (\lambda_1, \lambda_2, \dots, \lambda_n) \geq 0$ is the vector of weights assigned to each of the DMUs, s^+ and s^- are slack variables balancing input and output of the DMUs. Variable θ measures the position among non-efficient DMUs and the production frontier originated by efficient DMUs. Vector e^T is the unit vector and ε is an infinitesimal constant.

Equations (6)–(13) are known as the CCR DEA model (e.g., Charnes, Cooper and Rhodes model), in which we assume that the increase/decrease in inputs will result in a proportional linear increase/decrease in outputs. The CCR model has linear production frontier made of peer DMUs.

(2) Banker, Charnes and Cooper (BCC) [21] developed another form of the DEA model, known as the BCC DEA model (e.g., Banker, Charnes and Cooper model), based on *pure technical efficiency* which assumes that a change in inputs would result in a disproportionate change in increase/decrease of outputs. For this purpose, it is sufficient to extend the models (Equations (6)–(13)) by the convexity condition $e^T \lambda = 1$ as follows:

$$f = \theta - \varepsilon(e^T s^+ + e^T s^-) \quad (14)$$

$$Y\lambda - s^+ = Y_q \quad (15)$$

$$X\lambda + s^- = \theta X_q \quad (16)$$

$$e^T \lambda = 1 \quad (17)$$

$$\lambda \geq 0, \quad s^+ \geq 0, \quad s^- \geq 0. \quad (18)$$

The BCC model has its production frontiers spanned by the convex hull originated by DMUs. The frontier has the linear and concave shape of a piecewise function.

The presented models and their modifications find the best set of weights for each input and output variable.

The dual solution of the Equations (3) and (4) radially contracts the input vectors (X, Y) to a projected point ($X \lambda, Y \lambda$) on the efficient frontier. Coefficients $\lambda = (\lambda_1, \lambda_2, \dots, \lambda_n) \geq 0$ express the relative distance of the DMU from the efficient frontier originated by peers.

The DEA models measure the relative efficiency; that is, the efficiency of each DMU relative to the best DMUs in the sample (called “peer units”). Applying the DEA in evaluating the performance of a set of DMUs enables the formation of two clusters: DMUs that comprise an efficient frontier and inefficient DMUs lying below the frontier [9].

The great advantage of the DEA model is the possibility of incorporating a larger number of inputs and outputs. It is clear from the conditions of this model that in BCC models a higher number of units will be marked as efficient.

If a DMU is fully efficient in both the technical and pure technical efficiency scores, it is operating at the most productive scale.

2.2. Model Implementation

The research examines the analysis of the relative costs of pig meat production up to farm gate level. The sample size includes 16 countries in total: Austria, Belgium, Brazil, the Czech Republic, Denmark, Finland, France, Germany, Great Britain, Hungary, Ireland, Italy, the Netherlands, Spain, Sweden and the USA. In this article, DMUs refer to each of 16 selected countries.

The methodology of this study is based on the work of Avkiran and Parker [20]. The formulas and computations in this study were taken over from the publication by Brožová, Houška and Šubrt [22].

The DEA modelling projects the inefficient DMUs onto the production frontiers implementing the CCR-projection and/or the BCC projection, among others. There are three directions implemented in the practice, according to Cooper & Seiford [23]:

1. The input oriented approach aims to reduce the input amounts as much as possible while keeping at least the present output levels.
2. The output oriented approach maximizes output levels under no more than the present input consumption.
3. Models that deal both with input excesses and output shortfalls simultaneously to try to maximize both jointly. If achievement of efficiency or failure to do so, is the only topic of interest, then these different models will all yield the same result insofar as technical and mix inefficiency is concerned.

This third approach is applied in this study.

The ranking evaluation will be carried out with average data from the period 2012–2017. DMUs which have the same or fairly close ranking are clustered into the same group. This operation can reduce the total amount of DMUs.

The authors of the study used only trustworthy European sources of data which ensures that a farm structure in one country is only compared to another country with the same structure. A large number of inputs and outputs is characteristic for the pig production sector. For simplicity, the output was aggregated into only one category: *Carcass meat production in sow/year/kg* while the inputs were aggregated into four categories: *Feed costs, Other variable costs, Labor costs, Depreciation and finance costs*.

The choice between input and output orientation depends on the properties of the set of DMUs under study. Because there is only one output, while several inputs are used in this study, the input-oriented approach implementing BCC(I) and CCR(I) is assumed to be more appropriate for the task. Models BCC(O) and CCR(O) will finalize the overall evaluation.

2.3. Data Search and Elaboration

The data relating to the period 2012–2017 were collected mostly from the annual InterPIG reports [24]. Missing data were extracted directly from national databases; see Table 1.

Table 1. Searching for relevant data in national databases. [24–27].

Country	Data Source	Country	Data Source	Country	Data Source
Brazil	Embrapa	Czech Republic	UZEI	Denmark	SEGES
France	IFIP	Great Britain	AHDB	Netherlands	LEI Wageningen
Ireland	Teagasc RER	Sweden	Svenska Pig	Hungary	Government

2.4. Input and Output Data for DEA Models

The authors used 6-year data averages (the period 2012–2017). This allows pig producers to be compared on the same scale. Table S1—“Input and output data for selected DMUs for the period 2012–2017” (Supplementary Materials) shows basic descriptive statistics for input and output variables.

The InterPIG methodology was used in the research. Within this methodology, however, there are some national differences in definition of data. These differences were appropriately addressed. There is a wide variation in physical performance measures reported by countries, which can lead to a worsening in the marginal daily live weight gain and the marginal feed conversion ratio: (a) differences between countries in the weight of animals produced, (b) increase in slaughter weights, (c) length of time an animal is in the system.

The data were standardized on the basis of three weights: (a) transfer from breeding unit to rearing unit: 8kg (in GB = 7.1 kg), (b) transfer from rearing unit to finishing unit: 30kg (in GB = 37.1kg), (c) live weight at slaughter: 120kg (in GB = 105.4 kg).

To ensure data consistency, all the financial data were converted into the EURO currency, using the fixed EUROSTAT exchange rates published for 2012–2017.

2.5. Data for DEA Ranking Procedure

Table 2 shows data for the data envelopment analysis ranking process. Average values from the period 2012–2017 present the financial performance through these inputs: *Feed costs, Other variable costs, Labor costs, Depreciation and finance costs for inputs*. These data represent the relative average costs of production within each country and make it possible to provide an accurate comparison within 0.80–1.5 €/kg of deadweight. The output represents *Carcass meat production sow/year/kg*.

Table 2. Data for data envelopment analysis (DEA) ranking. [24–27].

	(I) Feed	(I) Other Variable Costs	(I) Labor	(I) Depreciation and Finance	(O) Carcass Meat
Countries	EURO/kg/deadweights				Sow/year/kg
AUS	0.982	0.260	0.167	0.272	2191
BEL	1.192	0.208	0.125	0.197	2403
BRA	1.025	0.133	0.079	0.100	2217
DEN	0.941	0.244	0.141	0.211	2428
CR	1.141	0.449	0.150	0.127	2068
FIN	0.916	0.314	0.160	0.250	2297
FRA	0.945	0.243	0.145	0.213	2345
GER	0.969	0.291	0.145	0.235	2494
GB	1.077	0.265	0.162	0.210	1844
HUN	1.006	0.289	0.148	0.229	2072
IRE	1.146	0.250	0.133	0.202	2095
ITA	1.284	0.235	0.166	0.229	2586
NL	0.951	0.329	0.150	0.203	2586
SPA	1.037	0.217	0.096	0.137	1978
SWE	1.013	0.240	0.188	0.394	2167
USA	0.808	0.153	0.106	0.117	2167
EU	1.031	0.266	0.147	0.225	2447

2.6. Processing of Data

The authors used “DEA-Solver-LV 8.0” [28] to calculate DEA models. This program includes 28 clusters of DEA and enables the solution of models of up to 50 DMU.

Models CCR and BCC were used to check the consistency of traditional unit ratings with DEA results. Using these models, the efficiency scores for each country were calculated. Countries which have the same or fairly close ranking were subsequently clustered into the same group.

3. Results

3.1. First Round of Ranking

Efficiency scores, calculated for each individual country using CCR and BCC models, are presented in Table 3. The efficiency scores for input and output oriented CCR models are reciprocal values (Equation (1)). Thus, the CCR models in Table 3 give the same values.

Table 3. The efficiency scores for countries using CCR and BCC models.

DMUs ¹	CCR(I)		CCR(O)		DMUs ¹	BCC(I)		BCC(O)	
	Rank	Score	Rank	Score		Rank	Score	Rank	Score
BRA	1	1	1	1	BRA	1	1	1	1
NL	1	1	1	1	DEN	1	1	1	1
USA	1	1	1	1	ITA	1	1	1	1
DEN	4	0.956	4	0.956	NL	1	1	1	1
GER	5	0.950	5	0.950	USA	1	1	1	1
FIN	6	0.922	6	0.922	GER	6	0.973	6	0.991
FRA	7	0.920	7	0.920	BEL	7	0.963	7	0.988
BEL	8	0.831	8	0.831	FIN	8	0.930	8	0.965
AUS	9	0.827	9	0.827	FRA	9	0.926	9	0.925
SPA	10	0.826	10	0.826	SPA	10	0.919	10	0.894
SWE	11	0.794	11	0.794	CZECH	11	0.833	11	0.885
CZECH	12	0.783	12	0.783	AUS	12	0.831	12	0.882
ITA	13	0.768	13	0.768	HUN	13	0.803	13	0.859
HUN	14	0.762	14	0.762	SWE	14	0.797	14	0.845
IRE	15	0.721	15	0.721	GB	15	0.750	15	0.816
GB	16	0.635	16	0.635	IRE	16	0.750	16	0.728

¹ Decision-Making Units.

Prerequisites of pure technical efficiency assume that a change in inputs would result in a disproportionate change in outputs. It means that in BCC trials, efficiency is equal to or higher than in CCR trials. Practical experience shows that BCC models give a higher number of peer units and are more selective. The same is true in our case.

Following the ideas presented before, we start the evaluation of pig meat producers implementing both CCR and BCC models. The first round of the DEA procedure assigns peer positions to Brazil, the Netherlands and the USA; see Table 3.

Combining scores, the ranking procedure enables the categorization of countries into four domains: DEA-EXCELLENT, DEA-GOOD, DEA-AVERAGE, DEA-SUFFICIENT; see Table 4.

Table 4. Ranking of countries by CCR and BCC models on a <0–1> scale.

RANK GROUPS	PEERS-EXCELLENT			GOOD				
	1			<0.90–0.99>				
DMUs	BRA	NL	USA	DEN	GER	FIN	FRA	BEL
Average	1	1	1	0.978	0.966	0.935	0.922	0.903
Rank	1	1	1	4	5	6	7	8
RANK GROUPS	AVERAGE				SUFFICIENT			
	<0.80–0.90>				<0.70–0.79>			
DMUs	AUS	SPA	SWE	CZECH	ITA	HUN	IRE	GB
Average	0.842	0.866	0.808	0.821	0.884	0.796	0.730	0.709
Rank	9	10	11	12	13	14	15	16

The ranking separates countries well and the ranking values are selective. Among the EU countries, Brazil and the USA, there are considerable differences between the highest and the lowest ranking scores.

Only one European country, the Netherlands, is assigned among the peer units (DEA excellent). Significant differences between the highest-ranking values (1) and the lowest-ranking values (0.709) show greater differences between the European and non-European pork manufacturers.

For mutual benchmarking, there is a need for more European countries among peer units. Therefore, we reduce the set of DMUs, excluding non-European countries the USA and Brazil from the evaluation.

3.2. Second Round of Ranking for Reduced Set of DMUs

The number of DMUs was reduced: Brazil and USA were excluded from the evaluation. CCR and BCC models were applied to evaluate the reduced set of DMUs involving 14 European pig meat producers. Efficiency scores calculated for each European country are included in Table 5.

Table 5. The efficiency scores: CCR and BCC models—reduced set of Decision-Making Units (DMUs).

CCR(I), CCR(O)			BCC(I)			BCC(O)		
DMUs	Rank	Score	DMUs	Rank	Score	DMUs	Rank	Score
BEL	1	1	BEL	1	1	BEL	1	1
CZECH	1	1	CZECH	1	1	CZECH	1	1
DEN	1	1	DEN	1	1	DEN	1	1
NL	1	1	FIN	1	1	FIN	1	1
SPA	1	1	ITA	1	1	ITA	1	1
GER	6	0.989	NL	1	1	NL	1	1
ITA	7	0.972	SPA	1	1	SPA	1	1
FRA	8	0.966	FRA	8	0.999	GER	8	0.990
FIN	9	0.924	GER	9	0.989	FRA	9	0.966
SWE	10	0.881	SWE	10	0.970	AUS	10	0.885
AUS	11	0.862	AUS	11	0.957	SWE	11	0.885
IRE	12	0.841	HUN	12	0.941	IRE	12	0.851
HUN	13	0.804	GB	13	0.901	HUN	13	0.817
GB	14	0.723	IRE	14	0.892	GB	14	0.733

When CCR and BCC trials are compared, the efficiency scores for the BCC trial are higher than those given by the CCR trial. The BCC model is less selective.

The results given in Table 5 indicate that the CCR trial offers 5 peers: BELGIUM, THE CZECH REPUBLIC, DENMARK, FINLAND and ITALY. The BCC trial expands peers to include THE NETHERLANDS and SPAIN.

Table 7. Cont.

BCC(I)	GOOD		AVERAGE		SUFFICIENT		
DMUs	GER (λ)	FRA (λ)	SWE (λ)	AUS (λ)	IRE (λ)	HUN (λ)	GB (λ)
Peers	BEL (0.031)				BEL (0.039)		DEN (0.667)
	DEN (0.392)	DEN (0.974)	DEN (0.572)	DEN (0.934)	DEN (0.952)		NL
	NL (0.537)	SPA (0.026)	SPA (0.428)	FIN (0.066)	SPA (0.224)	SPA (0.048)	(0.033)
	SPA (0.040)				SPA (0.738)		SPA (0.299)

3.4. Projection of Non-Efficient DMUs onto DEA Efficient Frontier

The CCR(I) model operates with the frontier consisting of 5 DEA-excellent DMUs: Belgium, the Czech Republic, Denmark, the Netherlands and Spain; see Table 8.

Table 8. Participation on projection of selected countries-CCR(I)-peers.

CCR(I)-Peers	BEL	CZECH	DEN	NL	SPA
Participation on projection	4x	0x	9x	5x	4x

The BCC(I) model operates with the frontier consisting of 7 DEA-excellent DMUs: BELGIUM, THE CZECH REPUBLIC, DENMARK, FINLAND, ITALY, THE NETHERLANDS and SPAIN; see Table 9.

Table 9. Participation on projection of selected countries-BCCR(I)-peers.

BCC(I)-Peers	BEL	CZECH	DEN	FIN	ITA	NL	SPA
Participation on projection	2x	0x	7x	1x	0x	2x	6x

In both the CCR(I) and BCC(I) models, the most frequent roles of peers are played by DENMARK (16x), SPAIN (10x) and THE NETHERLANDS (5x). These countries will probably be able to offer best practice experience for the future benchmarking procedures. On the other hand, THE CZECH REPUBLIC (0x) and ITALY (0x), although they were ranked among peers, do not participate in the projection.

Other countries should lower their production costs if they want to reach the efficiency frontier. Coefficients “λ” indicate the required degree of approach to the assigned peer country (see Table 7).

For the calculation, we use the data in Tables 2 and 7.

Table 10 presents the projected input values of non-efficient DMUs on the efficient frontier originated by peers. The projection was computed separately for CCR(I) and BCC(I) models; see Tables 5 and 7.

The following examples illustrate how a non-sufficient country can reduce input costs to become an excellent country in terms of DEA.

Example 1:

Let's implement the CCR model for Hungary.

HUNGARY is ranked as a DEA non-sufficient producer. Three peers—DENMARK (0.437), THE NETHERLANDS (0.329) and SPAIN (0.359)—originate HUNGARY's DEA frontier. To reach the frontier and become DEA-excellent, HUNGARY should *reduce Feed costs* from 1.006 € to the value $0.437 \cdot 0.941 + 0.329 \cdot 0.951 + 0.081 \cdot 1.037 = 0.808$ €, that is, reduce Feed costs by 19.6%.

Similarly, *Other variable costs*—0.289 €—that it has now, should be reduced to the value $0.437 \cdot 0.243 + 0.329 \cdot 1.329 + 0.081 \cdot 0.217 = 0.232$ €, that is, Other variable costs should be reduced by

19.6%. For *Labor costs*, a similar calculation gives the value 0.119 €, for example, reduced by 19.6%; for *Depreciation costs*, the value 0.170 €, that is, reduced by 25.6%; see Table 10.

Table 10. Assignment of peers along CCR and BCC input models.

CCR(I)		Feed		Other Variable Costs			Labor			Depreciation		
DMU	Input	Change	%	Input	Change	%	Input	Change	%	Input	Change	%
GER	0.969	0.958	−1.1	0.291	0.287	−1.1	0.145	0.143	−1.1	0.235	0.203	−13.6
ITA	1.284	1.249	−2.8	0.235	0.228	−2.8	0.166	0.136	−17.7	0.229	0.213	−6.7
FRA	0.945	0.912	−3.4	0.243	0.235	−3.4	0.145	0.136	−6.2	0.213	0.204	−4.3
FIN	0.916	0.847	−7.6	0.314	0.290	−7.6	0.160	0.133	−16.7	0.250	0.181	−27.5
SWE	1.013	0.892	−11.9	0.240	0.211	−11.9	0.188	0.123	−34.4	0.394	0.186	−52.8
AUS	0.982	0.847	−13.8	0.260	0.224	−13.8	0.167	0.127	−24.0	0.272	0.190	−30.2
IRE	1.146	0.964	−15.9	0.250	0.210	−15.9	0.133	0.112	−15.9	0.202	0.167	−17.3
HUN	1.006	0.808	−19.6	0.289	0.232	−19.6	0.148	0.119	−19.6	0.229	0.170	−25.6
GB	1.077	0.778	−27.7	0.265	0.191	−27.7	0.162	0.103	−36.7	0.210	0.152	−27.7

BCC(I)		Feed		Other Variable Costs			Labor			Depreciation		
DMU	Input	Change	%	Input	Change	%	Input	Change	%	Input	Change	%
AUS	0.982	0.939	−4.3	0.260	0.248	−4.3	0.167	0.142	−15.0	0.272	0.214	−21.3
FRA	0.945	0.944	−0.1	0.243	0.243	−0.1	0.145	0.140	−3.6	0.213	0.209	−1.7
GER	0.969	0.958	−1.1	0.291	0.288	−1.1	0.145	0.144	−1.1	0.235	0.203	−13.6
GB	1.077	0.970	−9.9	0.265	0.239	−9.9	0.162	0.128	−21.1	0.210	0.189	−9.9
HUN	1.006	0.946	−5.9	0.289	0.243	−16.1	0.148	0.139	−5.9	0.229	0.208	−9.1
IRE	1.146	1.022	−10.8	0.250	0.223	−10.8	0.133	0.107	−19.4	0.202	0.156	−22.8
SWE	1.013	0.982	−3.0	0.240	0.232	−3.0	0.188	0.122	−35.0	0.394	0.180	−54.4

Example 2:

Let us implement the BCC model for FRANCE.

FRANCE is ranked as a DEA non-sufficient producer. Two peers—DENMARK (0.974) and SPAIN (0.026)—originate FRANCE's DEA frontier. To reach the frontier and become DEA-excellent, FRANCE should *reduce Feed costs* from 0.945 € to the value $0.974 \times 0.941 + 0.026 \times 1.037 = 0.944$ €, that is, reduce Feed costs by 0.13%.

Similarly, *Other variable costs*—0.2434 €—that it has now, should be reduced to the value $0.974 \times 0.2438 + 0.026 \times 0.2171 = 0.2431$ €, that is, reduce Other variable costs by 0.12%. For *Labor costs*, a similar calculation gives the value 0.1399 €, that is, Other variable costs should be reduced by 3.6%; for *Depreciation costs*, the value 0.2094 €, that is, reduced by 1.7%; see Table 10. The changes that the French producers should make in general are minor and in the preliminary stage of the benchmarking procedure, FRANCE also can be classified as an excellent producer.

Similar calculations for other non-sufficient countries are presented in Table 10.

4. Discussion

According to Davis [29], there is a problem in agriculture with a high number of outputs in the field of crop and animal production. In one region, there are small farms and SMEs that produce many different products, while large farms specialize in only a few different products in the same area. This situation causes market imbalances, as large companies with a high degree of specialization influence the final prices of agricultural products. Large pig companies use processes analogous to industrial production. Their production is efficient, highly specialized, they have a competitive advantage over small standard pig farmers. Small farmers produce in a less favorable competitive environment. They often must subsidize production losses and subsidize the realization prices of carcasses from other sources. Antle et al. [30] used the DEA model to evaluate a group of farms in one region where multiple crops can be grown and where each farm produces only one crop. The authors analyze the situation between specialized single and multi-crop producers in different regions of

Turkey. Kuo et al. [31] focus on the environmental aspects of agricultural production. They emphasize that it is necessary to include these conditions among other factors of economic activities. The authors emphasize that DEA models should include requirements for the protection of animals, wildlife and the environment, although these requirements will increase the number of factors in DEA models. The emphasis on respect for environmental requirements in DEA models is also emphasized by, for example, Picazo-Tadeo et al. [32] and Coyne et al. [33].

The efficiency of pork production is also determined by the type of competition under which most companies within the industry operate. An oligopoly as the predominant type of imperfect competition in pork production may be described as a market structure characterized by a small number of firms within the industry and a relatively high degree of interdependence with respect to their decision-making. “These firms produce all or at least most, of the output” [34].

“An oligopoly can exist when only a few firms (within an industry) are selling a given product or when only a few companies are responsible for most (although not all) of the production” [35].

It usually involves large firms with a controlling share of the supply. The market concentration of pig slaughterhouses offers a good example of the pork production industry turning into an oligopoly. In 2008, the ten largest slaughterhouses in the Czech Republic slaughtered 44.65% of pigs, whereas in 2018, this figure rose up to 64%. In terms of numbers, this amounted to 1.63 million pigs in 2008 compared to the 1.49 million pigs slaughtered in 2018. Five of these slaughterhouses are operated by two corporate groups (AGROFERT, a.s., RABBIT Trhový Štěpánov, a.s.) and three family businesses based in Moravia. A comparison drawn between the efficiency of pig production and market share of Czech and German slaughterhouses shows that the slaughter market in Germany is even more concentrated. In 2018, ten of the largest slaughterhouses carried out nearly 80% of all pig slaughters (i.e., 78.9%); these ten companies slaughtered 44.74 million pigs in total. In 2018, 57.9% of pigs were slaughtered in the first three largest slaughterhouses, namely Tönnies (Rheda-Wiedenbrück), Vion (Düsseldorf) and Westfleisch (Münster) [36].

To understand the current state of pig farms, it is necessary to consider their activities in relation to their demand and supply activities. They are not able to influence both prices of inputs as well as prices of outputs. Unfortunately, pig farms and slaughterhouses are competing to each other. They are not able to cooperate—especially in the Czech Republic. There is only limited vertical integration of pig meat businesses. Farmers are not supporting meat processors and meat processors are not supporting farmers. The level of loyalty between farmers and processors is very limited. Even more there is significant tension between both of them as the final price of pigs is not set up by independent authorities but it is set up by processors. The slaughterhouses are increasing a pressure in relation to farmers and farmers (if they are not integrated) have only two options: (1) to accept price or (2) to offer their pigs abroad. The policy applied by local slaughterhouses is extremely important for pig producers and as slaughterhouses are low price oriented the attractiveness of pig production is decreasing and the result is rather low national pig meat self-sufficiency. Czech pig farmers are suffering because of much lower prices offered by especially Polish and German pig producers. However, Polish and German lower price is mainly the results of local subsidies provided by national and regional authorities. On the other hand, Czech pig farmers are not supported because of different approach applied by Czech authorities in relation to national and European subsidies distribution.

Companies in oligopolistic sectors of meat and meat product production are engaged in producing either homogeneous or heterogeneous products. With respect to homogeneous products (pigs for fattening), the competition reinforces the tendency towards a uniform balanced market price of pork due to the particularly strong interdependence of individual firms, whereby even the smallest price change initiated by one of them will considerably affect the behavior of the remaining firms. If meat processing plants produce differentiated products (dry salami, meat sausages, tripe sausages, etc.), the differences between the products of individual oligopolistic firms will not be as substantial in general; they are close substitutes.

The restrictions on (barriers against) new companies entering the sector of pork production include the relatively high capital costs of establishing a new firm, consumer preferences in relation to the existing firms, as well as the contracts and conventions between the existing firms. If economies of scale present a barrier to entering this sector, then each firm seeking to do so should be achieving average costs of its products equally as low as those of the existing firms within the industry [37]. A company that produces in several successive stages of the production process has so-called vertical economies of scale when the cost of vertically produced neighboring products is lower than it would be if it produced the products separately [38]. Then the oligopoly is affected by the size of the market and the optimal size of the company under consideration, where economies of scale can be claimed.

“Sellers in an oligopoly will usually first consider the behavior of the other party before making a decision about their prices and/or outputs” [34]. The firms mutually respond not only to price changes but also to any changes in the output, in the product quality or the product advertising. The ability of each firm within the pork producing and/or pork processing industry to make reliable estimates of the competitors’ reactions and actions hinges on the fact that only a few large firms operate in the sector, which gives the businesses a certain monopolistic advantage in that they can affect the volume of production by adjusting the price of pork or meat products. In addition, each firm is also able to control the entire market demand within the sector via its relatively higher share of the overall market supply of the goods. If a competitor is to respond to a change in the market price (market quantity), that change should essentially affect the change in its market price and market quantity.

DEA models have been applied to compare the performance of individual farms in the regions, Kuo et al. [31], Picazo-Tadeo et al. [32] and Coyne et al. [33]. In this article, the regions are considered to be individual EU countries, in which the average performance of all farms in the considered country over 4 years is compared. The model included 14 regions - EU states. Input and output oriented CCR and BCC DEA models were applied to compare the performance. The result is an overview of the best manufacturers, best practices, and instructions on how to increase production efficiency and profitability for less successful producers.

A cross-comparison of the efficiency of pig production in each country provides useful information for local and national authorities. The global liberalization of trade in agricultural products will have a significant impact on the competitiveness of agricultural producers. The pig and pork market will have to cope with an increase in imports from outside European countries. Also expect changes in subsidies and interventions in agricultural production are expected. Significant changes can also be expected in the areas of legislation where emphasis will be placed on the environmental aspects of animal production and welfare. These are all reasons why pork producers must strive to increase the efficiency and competitiveness of their production capacity. The results presented in the article demonstrate how pig producers can use DEA models to evaluate and possibly improve their performance.

Although the number of expert works dealing with the applications of DEA models is growing [39,40], most of them are focused on evaluating the efficiency of cattle and dairy farming.

The work dealing with the analysis of pig breeding in the European area is the research of the efficiency of pig breeding in Greece. Galanopoulos et al. [41], who examined the degree of efficiency of pig farming in Greece, used the “DEA data envelope analysis” technique to examine the degree of technical efficiency of commercial pig farming. The average net technical efficiency, calculated on the number of sows, was 0.83. This means that there is potential for more efficient use of inputs in pig farming. Oude Lansink and Reinhard [42] used the DEA model to compare the technical and environmental efficiency of Dutch pig farmers with current new technologies. They found that the efficiency of farms is relatively high compared to the new technologies.

As no similar study analyzing the performance of pig producers in more than one EU country is available, there is only a limited possibility to compare the results of our research with the results of other studies. In the second round of our evaluation, Belgium, the Czech Republic, Denmark, Finland, Italy, the Netherlands and Spain appear to be effective in terms of inputs and outputs. This is

confirmed, for example, by Oude Lansink and Reinhard [42], who report high efficiency in pig farming in the Netherlands.

In a previous study, a statistical model of time series was used to analyze the position of the Czech Republic among European pig producers in the period 2010–2018, Smutka, J.; Havlíček, J.; Dömeová, L. [8]. The research proved significantly that there are considerable differences among the European pig producers. Unlike time series analysis, DEA models provide more information and lead to recommendations as to which procedures lead to reduced costs, how to change the production structure. DEA models have helped identify critical success factors and offer the solutions needed to achieve the best results on the market. The results of the analysis also show that there are still differences between the “old” Member States, ie the EU-15, and the “new” Member States.

Only one European country, the Netherlands, was assigned among the peer units in the first round of evaluation. Significant differences between the highest-ranking values (1) and the lowest-ranking values (0.709) showed greater differences between the European and non-European pork manufacturers.

Brazil, the USA and the Netherlands placed first with a rating of 1 (see Table 3). Denmark, Germany, Finland, France and Belgium are placed in the “good” category with a rating of 0.90–0.99. Austria, Spain, Sweden, the Czech Republic and Italy ranked “average” with ratings of 0.80–0.90. Hungary, Ireland and the United Kingdom placed in the “sufficient” category with a rating below 0.8. The European Union (as an average) ranked the category “good” with a rating of 0.909, ranked 9th out of 16.

In terms of the efficiency of pork production examined by the DEA method, the Czech Republic, together with Spain, the Netherlands, Germany and France, is one of the best producers in Europe. This good result is a consequence of the transformation of the Czech economy into a market environment in the 1990s, which helped the Czech Republic to draw on EU resources and the experience of developed Western European economies in the field of pig farming. Respect for ecological efficiency is increasingly applied in all areas of agricultural production. In the professional literature, we encounter the measurement of ecological efficiency of production also with DEA models [43]. In our evaluation, for example, the United Kingdom is included in the group of countries rated as “sufficient”, with a score of 0.78. Given that the United Kingdom has a significant proportion of sows kept outdoors, the lower number of pigs weaned per sow per year may be the cause of relatively high production costs compared to other EU countries. If we add another “welfare” criterion to our set of criteria, including that criterion can change the rating. Taking into account the soft criteria—animal welfare and the environment - the UK could be at the forefront of the evaluation.

As the preceding analysis demonstrates, pork production in developed economies is strongly concentrated. The reason lies in profits being generated from the scale of production, facilitating both the efficiency and profitability of production. The current degree of market concentration (both at the level of Czechia as well as Germany (as local market leader) may encourage the future possible process of even more significant concentration of pig production capacities in many central and eastern European countries (including the Czech Republic), as can already be observed in several Western European countries. As the pig market is rather competitive, the economies of scale seem to be the key driver of success. Especially strong pig production entities/businesses are able to survive and compete. For their survival, the ability to subsidize (from their own resources/other business activities) their pig production in the low prices period is extremely important. Based on experience of many pig farmers, it is necessary to run pig production in much broader scope of other activities. To be specialized only in pig farming, it is considered to be extremely dangerous as in the period of low prices farmers are not able to cover their production costs. Many central European pig farmers have been also suffering because of low ability to influence market price as they are in position of price takers. Such a situation is also typical for the Czech Republic. The local farmers are squeezed between Germany and Poland (both the key European pig producers) and they are not able to set up their own price even at the level of domestic market. During the last few years, the Czech pig price has been influenced by two key factors: (1) African swine fever in Asia (reducing the global number of pigs by more than 250 million animals); (2) The growth of global pig meat price especially because of increasing imports to Asia

(mainly China) as the result of African swine fever impact (As Germany (and also other European countries) was attracted by increasing Asian/Global pig meat price (in the period under the analysis), its supply pressure in relation to European market was reduced and European pig price increased including pig meat price in the Czech republic.).

5. Conclusions

Examples of best practice and their corresponding benchmarking processes seem at first sight to be simple procedures, but in the case of the real practice we encounter difficulties. This is because both the terms “best practices” and “benchmarking” can be used and explained in different ways in an organization. We can only look for examples of good practices or good performance and then apply them to the operation inside the organization.

Thus, in our research we also offer only examples of good practice that can be imitated and followed.

For the evaluation of manufacturers in the EU countries, Brazil and the USA, we used the multi-modeling method, ie we implemented both CCR and BCC models simultaneously. Because we used more inputs and only 1 output, we preferred the CCR (I) and BCC (I) models in the evaluation.

Half of the monitored EU countries ranked as efficient producers with a rating of 1.

With regard to the given inputs, the evaluation classified approximately half of the examined EU countries as effective peers.

Some other countries also have a rating very close to one, such as GERMANY and FRANCE, and can also be classified as “peers”.

The identification of “peers” among the monitored countries represents “best practices” in the field of pig production in the 14 European monitored countries.

In this work, “best practices” are used as examples for other countries, how excellent results can be achieved.

The evaluation of scores for less efficient countries makes it possible to expand the set of excellent European producers. However, it should be borne in mind that the concept of “best practice” is very subjective and that it cannot be directly and immediately implemented by experience from one country to another. Because what’s “best” in one country may not necessarily be good for another. Therefore, we have implemented in the form of multi-modeling combinations of CCR (I), CCR (O) and BCC (I) and BCC (O) models, which give more variability for the implementation of results and allow managers to make decisions that suit local conditions.

The analysis of the submitted ranking can be considered a “learning process” for individuals and organizations. Each user can choose their own procedures for evaluating the resulting data. Although the use of information from model results will not be perfect, if managers conduct it professionally, with critical oversight, it can yield adequate results.

It should also be noted that DEA models are not able to solve all problems and are not flawless. They can be used as an estimate of the “relative” efficiency of one producer in competition with a huge number of different producers in 14 European countries. Of course, the models do not answer the question of what is the “absolute” monitored efficiency of the manufacturer. The models tell us what is the position of one country within a group of other countries under precisely specified criteria. If we change the criteria, the evaluation will of course change.

Another problem we encounter when evaluating production units using DEA models is their high sensitivity to extremely large data values.

In this study, we took the first, preliminary step for benchmarking between European pork producers. We applied a “top-down” approach, using highly aggregated data at the national level for the period 2014-2017 in the models.

The next step will be to evaluate the best producers and their best practices at a lower regional and company levels. The methodology used for the lower regional level will be similar, but adapted for the new, lower level of management.

The biggest advantage of benchmarking is not measuring DEA-excellence but finding out how the best performance is achieved. A more detailed investigation in this area will be our future research.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2077-0472/10/12/597/s1>, Table S1: Input and output data for selected DMUs for the period 2012–2017.

Author Contributions: Conceptualization, J.H. and L.D.; methodology, J.H. and L.D.; software, R.S.; validation, L.S. (Luboš Smutka), T.Š. and L.S. (Lucie Severová); formal analysis, J.H., L.D. and T.Š.; investigation, L.S. (Luboš Smutka); resources, H.Ř. and R.S.; data curation, J.H., L.D. and T.Š.; writing—original draft preparation, J.H., L.D., L.S. (Luboš Smutka), H.Ř., L.S. (Lucie Severová) and K.Š.; writing—review and editing, T.Š. and R.S.; visualization, L.S. (Lucie Severová); supervision, T.Š.; project administration, L.S. (Luboš Smutka); funding acquisition, L.S. (Luboš Smutka). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Technology Agency of the Czech Republic, grant number TL01000180. “This research was also funded by the Faculty of Economics and Management, Czech University of Life Sciences in Prague, grant number 20171011”.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript or in the decision to publish the results.

References

1. Czech News Agency (CNA). Za Vepřové si Připlatíme, Cenu Táhne Zvýšená Poptávka v Číně i Málo Prasat v Tuzemsku. Available online: <https://zpravy.aktualne.cz/ekonomika/za-veprove-si-priplatime-cenu-tahne-zvysena-poptavka-v-cine-i-malo-prasat-v-tuzemsku~{}683414ec5b5311e9819e0cc47ab5f122/> (accessed on 25 August 2020).
2. Czech Statistical Office (CZSO). Soupis Hospodářských Zvířat-k 1. 4. 2019. Available online: <https://www.czso.cz/csu/czso/soupis-hospodarskych-zvirat-k-1-4-2019> (accessed on 17 June 2020).
3. Ministry of Agriculture CR. Situační a Výhledová Zpráva Vepřové Maso. 2018. Available online: http://eagri.cz/public/web/file/624777/Veprove_maso___2018.pdf (accessed on 19 June 2020).
4. Agridata. Pigmeat Trade Data. 2020. Available online: <https://agridata.ec.europa.eu/extensions/DashboardPigmeat/PigmeatTrade.html> (accessed on 27 October 2020).
5. European Commission. Pigmeat CMO Committee 22 October 2020. Available online: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/pig-market-situation_en.pdf (accessed on 27 October 2020).
6. European Commission. Pigmeat Statistics. 2020. Available online: https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/overviews/market-observatories/meat/pigmeat-statistics_cs (accessed on 27 October 2020).
7. Baráth, L.; Fertő, I. Productivity and Convergence in European Agriculture. *J. Agric. Econ.* **2016**, *68*, 228–248. [CrossRef]
8. Smutka, J.; Havlíček, J.; Dömeová, L.; Severová, L.; Šrédli, K.; Řezbová, H.; Svoboda, R. Komparace Časových Řad Výrobní Vertikály Vepřové Maso v Prostředí Vybraných Zemí EU. Available online: <https://cevema.pef.czu.cz/> (accessed on 13 September 2020).
9. Havlíček, J.; Dömeová, L.; Smutka, L.; Řezbová, H.; Severová, L.; Šubrt, T.; Šrédli, K.; Svoboda, R. Optimization Model of Farm Stages of the Pork Meat Supply Chain. In Proceedings of the 28th International Scientific Conference Agrarian Perspectives XXVIII. Business Scale in Relation to Economics, Prague, Czech Republic, 18 September 2019; Tomšík, K., Ed.; Czech University of Life Sciences Prague: Prague, Czech Republic, 2019; pp. 67–74.
10. Charnes, A.; Cooper, W.W.; Rhodes, E. Measuring the efficiency of decision making units. *Eur. J. Oper. Res.* **1978**, *2*, 429–444. [CrossRef]
11. Emrouznejad, A.; Parker, B.R.; Tavares, G. Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA. *Socio-Econ. Plan. Sci.* **2008**, *42*, 151–157. [CrossRef]
12. Chaowarat, W.; Piboonrugroj, P.; Shi, J. A review of Data Development Analysis (DEA) applications in supply chain management research. In Proceedings of the 2013 IEEE International Conference on Industrial Engineering and Engineering Management, Bangkok, Thailand, 10–13 December 2013; pp. 975–980.

13. García-Alcaraz, J.L.; Díaz-Reza, R.; Maldonado, A.; Rico-Pérez, L. Recent DEA Applications to Industry: A Literature Review from 2010 to 2014. *Int. J. Eng. Sci. Invent.* **2015**, *4*, 9–20.
14. Zhou, H.; Yang, Y.; Chen, Y.; Zhu, J. Invited Review Data envelopment analysis application in sustainability: The origins, development and future directions. *Eur. J. Oper. Res.* **2017**, *264*, 1–16. [\[CrossRef\]](#)
15. Fulginiti, L.E. Intertemporal Production Frontiers: With Dynamic DEA. *Am. J. Agric. Econ.* **1998**, *80*, 232–233. [\[CrossRef\]](#)
16. Hwang, S.N.; Lee, H.S.; Zhu, J. *Handbook of Operations Analytics Using Data Envelopment Analysis*; Springer: New York, NY, USA, 2016.
17. Cooper, W.W.; Seiford, L.M.; Tone, K. *Introduction to Data Envelopment Analysis and Its Uses: With DEA-Solver Software and References*; Springer Science+Business Media, Inc.: Berlin, Germany, 2006.
18. Liu, J.S.; Lu, L.Y.; Lu, W.; Lin, B.J. A survey of DEA applications. *Omega* **2013**, *41*, 893–902. [\[CrossRef\]](#)
19. Emrouznejad, A.; Yang, G.-L. A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. *Socio-Econ. Plan. Sci.* **2018**, *61*, 4–8. [\[CrossRef\]](#)
20. Avkiran, N.K.; Parker, B.R. Pushing the DEA research envelope. *Socio-Econ. Plan. Sci.* **2010**, *44*, 1–7. [\[CrossRef\]](#)
21. Banker, R.D.; Charnes, A.; Cooper, W.W. Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Manag. Sci.* **1984**, *30*, 1078–1092. [\[CrossRef\]](#)
22. Brožová, H.; Houška, M.; Šubrt, T. *Modely Pro Vícekriteriální Rozhodování*; Česká Zemědělská Univerzita v Praze: Prague, Czech Republic, 2014.
23. Cooper, W.W.; Seiford, L.M. *Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software Second Edition*. Available online: <https://link.springer.com/content/pdf/bfm%3A978-0-387-45283-8%2F1.pdf> (accessed on 16 June 2020).
24. InterPIG. 2017 Report: Production Costs-Swine News-Pig333, pig to Pork Community. Available online: https://www.pig333.com/latest_swine_news/interpig-2017-report-production-costs_14417/ (accessed on 24 August 2020).
25. AHDB PORK. Prices and Stats. Available online: <https://pork.ahdb.org.uk/prices-stats/> (accessed on 24 August 2020).
26. Institute of Agricultural Economics and Information (IAEI). Vývoj Měsíčních Cen Zemědělských Výrobků (CZV) v ČR. Available online: <https://www.uzei.cz/czv-komodit-v-cr/> (accessed on 23 August 2020).
27. Eurostat. Pigmeat Statistics. Available online: https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/overviews/market-observatories/meat/pigmeat-statistics_en (accessed on 24 August 2020).
28. Saitech. Decision Support Systems and Optimization Tools. Available online: <http://www.saitech-inc.com/index.asp> (accessed on 24 August 2020).
29. Davis, C. Pig Cost of Production in Selected Countries. Available online: <https://ahdb.org.uk/knowledge-library/2017-pig-cost-of-production-in-selected-countries?> (accessed on 24 August 2020).
30. Antle, J.M.; Basso, B.; Conant, R.T.; Godfray, H.C.J.; Jones, J.W.; Herrero, M.; Howitt, R.E.; Keating, B.A.; Munoz-Carpena, R.; Rosenzweig, C.; et al. Towards a new generation of agricultural system data, models and knowledge products: Design and improvement. *Agric. Syst.* **2017**, *155*, 255–268. [\[CrossRef\]](#)
31. Kuo, H.-F.; Chen, H.-L.; Tsou, K.-W. Analysis of Farming Environmental Efficiency Using a DEA Model with Undesirable Outputs. *APCBEE Procedia* **2014**, *10*, 154–158. [\[CrossRef\]](#)
32. Picazo-Tadeo, A.J.; Gómez-Limón, J.A.; Reig-Martínez, E. Assessing farming eco-efficiency: A Data Envelopment Analysis approach. *J. Environ. Manag.* **2011**, *92*, 1154–1164. [\[CrossRef\]](#)
33. Coyne, J.; Berry, D.P.; Mäntysaari, E.; Juga, J.; McHugh, N. Comparison of fixed effects and mixed model growth functions in modelling and predicting live weight in pigs. *Livest. Sci.* **2015**, *177*, 8–14. [\[CrossRef\]](#)
34. Frank, R.H.; Cartwright, E. *Microeconomics and Behavior*; McGraw-Hill: New York, NY, USA, 2016.
35. Schiller, B.R. *The Micro Economy Today*; McGraw-Hill: New York, NY, USA, 2010.
36. Maso.cz. Top 10 Německých Vepřových Porážek v Roce 2018: Koncentrace Odvětví (Mírně) Pokračuje. Available online: <https://www.maso.cz/top-10-nemeckych-veprovych-porazek-v-roce-2018-koncentrace-odvetvi-mirne-pokracuje/> (accessed on 25 August 2020).
37. Hořejší, B.; Soukupová, J.; Macáková, L.; Soukup, J. *Mikroekonomie*; Management Press: Prague, Czech Republic, 2018.
38. Azzam, A.M. Testing for Vertical Economies of Scope: An Example from US Pig Production. *J. Agric. Econ.* **1998**, *49*, 427–433. [\[CrossRef\]](#)

39. Reinhard, S.; Lovell, C.K.; Thijssen, G.J. Environmental efficiency with multiple environmentally detrimental variables; estimated with SFA and DEA. *Eur. J. Oper. Res.* **2000**, *121*, 287–303. [[CrossRef](#)]
40. Fousekis, P.; Spathis, P.; Tsimboukas, K. Assessing the efficiency of sheep farming in mountainous areas of Greece. A non-parametric approach. *Agric. Econ. Rev.* **2001**, *2*, 5–15.
41. Galanopoulos, K.; Aggelopoulos, S.; Kamenidou, I.; Mattas, K. Assessing the effects of managerial and production practices on the efficiency of commercial pig farming. *Agric. Syst.* **2006**, *88*, 125–141. [[CrossRef](#)]
42. Lansink, A.O.; Reinhard, S. Investigating technical efficiency and potential technological change in Dutch pig farming. *Agric. Syst.* **2004**, *79*, 353–367. [[CrossRef](#)]
43. Orea, L.; Wall, A.J. A Parametric Approach to Estimating Eco-Efficiency. *J. Agric. Econ.* **2017**, *68*, 901–907. [[CrossRef](#)]

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).