Dairy farm cost efficiency in leading milk-producing regions in Poland

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ABSTRACT

This paper examines the cost efficiency of dairy farms in 2 important regions of commercial milk production in Poland (i.e., Wielkopolskie and Podlaskie). Both regions gained importance following the market-driven resource allocation mechanism adopted after Poland's transition to the market economy in 1989 and accession to the European Union (EU) in 2004. The elimination of the dairy quota system in the EU in 2015 offers new expansion opportunities. The analysis of trends in cow numbers, milk production, and yield per cow shows different patterns of expansion of the dairy sector in the 2 regions. We selected dairy farm data from the Farm Accounts Data Network database for both regions and applied the cost frontier estimation model to calculate the relative cost-efficiency index for the period 2004 to 2009. The indexes compare each farm in the sample to the most efficient dairy farm in each region separately. Additionally, the top 5% of dairy farms with the highest relative cost efficiency index from each region were compared in terms of production costs with published results from a study using the representative farm approach. The comparison of results from 2 different studies permits a conclusion that Wielkopolskie and Podlaskie dairy farms are able to compete with farms from the 4 largest milk-producing countries in the EU. Although both regions can improve yields per cow, especially Podlaskie, both regions are likely to take advantage of the expansion opportunities offered by the 2015 termination of the milk quota system.

Key words: cost frontier estimation, milk yield trend, cow herd trend, milk production trend, cost efficiency index

INTRODUCTION

This paper examines the cost efficiency of dairy farms in 2 regions (known as voivodeships) essential to com-

mercial milk production in Poland (i.e., Wielkopolskie and Podlaskie; Figure 1). Both regions compete in cost efficiency because they do not enjoy large concentrations of consumers like Mazowieckie voivodeship, with the largest urban population in Poland, the capital Warsaw. Both Wielkopolskie and Podlaskie regions gained importance in response to the adoption of the market-driven resource allocation mechanism after Poland's transition to the market economy in 1989. Later, each achieved substantial gains in dairy sector performance after the country's accession to the European Union (EU) on May 1, 2004. For example, milk production in Wielkopolskie voivodeship increased by 24% and in Podlaskie voivodeship by 40.4% between 2004 and 2012 (Roman, 2014). The shares of the country's milk production in Wielkopolskie and Podlaskie voivodeships increased from 11.4 and 14.1% in 2004 to 14.2 and 19.1% in 2013, respectively (GUS, 2015).

Dairy sector developments in both regions illustrate the tendency toward increasing regional concentration of production driven by the natural resource base that was distorted before 1989 by the centrally planned economic system based on artificial pricing. The geography in the 2 regions includes wide river valleys suitable for pasture and hay production, although the climate is milder in Wielkopolskie than Podlaskie voivodeship. In some areas of both regions, land quality is relatively low and field crop farming generates lower returns.

This paper briefly describes major changes in the dairy sector since the transition to the market economy in Poland and stresses the importance of cost-efficiency analysis at the regional level rather than the aggregate level of macro-regions formed under the Farm Accounts Data Network (FADN) accounting system. Although a similar quantitative cost efficiency analysis of dairy farms was almost impossible before Poland joined the FADN data system, the rapid restructuring and spatial concentration of milk production confounds the true trends underlying the observed changes in Poland's dairy sector at the macro region level. Despite its limitations, the cost frontier estimation applied in the current study and estimated using disaggregated FADN data provides previously unavailable insights about the

Received October 28, 2014.

Accepted June 23, 2015.

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Figure 1. Location of Wielkopolskie and Podlaskie voivodeships in Poland. Color version available online.

current regional situation of dairy farms by allowing for comparison of relative cost efficiency in 2 leading dairy-producing regions. Specifically, descriptive statistical analysis demonstrates the growth of the dairy sector in 2 regions, Wielkopolskie and Podlaskie voivodeships, whereas the estimated and graphically shown trends in the number of cows, yield per cow, and milk production in each region reveal that although each region expands dairy production, the pattern of expansion varies. The calculation of the cost efficiency index allows, in relative terms, assessment of each farm in the sample against the most efficient farm within the region. The individual cost efficiency indexes identify the top performing farms in each region and allow their characterization by selected relevant farm indicators. Additionally, the latter are compared with results of published studies using the representative farm approach. The outcome provides insights into the potential competitiveness of dairy farms in 2 selected regions of Poland in anticipation of the termination of the milk quota system in the European Union. The use of results of the 2 methods

(i.e., cost frontier function and the representative farm approach) provides a richer picture of the current situation and facilitates forecasting undertaken by users of these results.

The quota system has been limiting EU milk production. Between 2004 and 2013, EU milk production barely changed from 148.7 to 152.4 Mt. During the same period, milk production in the United States increased from 77.5 to 91.3 Mt (17.7%), and the production in New Zealand rose from 15 to 18.9 Mt (25.6%). Poland produced 11.8 Mt in 2004 and 12.7 Mt (7.6%) in 2013, using almost all its quota every year and the 1% annual quota increase permitted by the EU. Poland is the fourth largest milk producer in the EU following Germany, France, and the United Kingdom, and ahead of the Netherlands and Italy between 2004 and 2013.

The impending termination of the dairy quota system within the EU in April 2015 will remove any limits on milk production, allowing farmers in either region to expand production and compete with higher-cost producers. Poland has been leading in utilization of

the dairy production quota among the EU countries in recent years (Guba and Dąbrowski, 2012). The penalties of overproduction are particularly severe in the last year of the quota system (Agencja Rynku Rolnego, 2015). In the last 2 quota years, Polish dairy farms produced a surplus of 0.2% and 5.6%, respectively, in 2013–2014 and 2014–2015 and were assessed €46.4 and €172.4 million in penalties.

Two major events shaped the dairy sector in Poland in recent decades: the adoption of the market mechanism in 1989 and the accession to the EU in 2004. First, the adoption of the market mechanism in 1989 fundamentally changed the dairy sector in Poland and after the initial contraction, the sector adapted and milk production costs decreased. Milk production amounted to 15 billion kg in 1990 and the total number of cows was 5 million (Trajer and Krzyżanowska, 2014). By 2004, the number of farms raising cows decreased by about 58% (from 1,831,000 in 1990 to 737,000 in 2004; Trajer and Krzyżanowska, 2014) and the total herd was 2.8 million head. After the accession to the EU on May 1, 2004, milk production began to increase slowly within the limits permitted by the Common Agricultural Policy (CAP). Production reached 12.36 billion kg in 2011 (Lira, 2013). In 2013, 380,000 cows were present on family farms (Trajer and Krzyżanowska, 2014). Since the early 1990s, the yield per cow has been steadily increasing.

The regional differences in milk production have become increasingly visible over time once the market signals influence farmers' decisions (Parzonko, 2013). In recent years, dairying has declined in many areas of the country. For example, in Podkarpackie voivodeship, milk production declined by 48.5% between 2004 and 2012 (Roman, 2014), while at the same time changing its character from commercial milk production to organic milk production (Szumiec et al., 2014). The regional polarization of milk production was reflected in the diverting milk procurement trends (Parzonko, 2013), with Wielkopolskie voivodeship and Podlaskie voivodeship among the top 3 regions in commercial farm milk sales in 2012 (Roman, 2014). Revoredo-Giha and Renwick (2010) showed a similar level of cost efficiency across various dairy farm sizes and across 4 aggregate FADN regions in Poland, and Barnes et al. (2011) reported on the relatively strong position of the Polish dairy sector among EU countries. However, another study of Polish dairy farms based on 4 FADN regions suggested difficulties in discerning the relative reserves in cost efficiency in leading milk-producing regions in Poland, leading to the recommendation to disaggregate analysis from the FADN regional to sub-regional level (Sobczyński et al., 2013). The current

study applies the subregional analysis focusing on the 2 leading milk-producing areas of Wielkopolskie and Podlaskie voivodeships as the dairy sector prepares for the elimination of the quota system.

Second, the effects of the EU CAP increasingly limit milk production in northern EU countries. The European Commission suggested an increase in milk market transparency and proposed some modifications in 2012 (Wysokiński and Jarzebowski, 2013). Milk procurement prices are lower in Poland than in other EU countries except for Lithuania, Latvia, and Estonia (all 3 are marginal dairy producers). In November 2014, the raw milk price was €29.61/100 kg in Poland and was 16% lower than the average of the EU15 ("old" EU countries, before May 1, 2004) and 2% lower than in EU13 (new EU members joining EU after May 1, 2004). Polish domestic prices were 27% lower than in the United States (€40.66/100 kg), but 24% higher than in New Zealand (€23.86/100 kg). The competitiveness of the Polish dairy sector is illustrated by the positive balance in international dairy trade, which increased by 24% as measured in raw milk equivalent, and the net balance increased by 11%, reaching €1.06 billion in 2014 (Seremak-Bulge and Zdziarska, 2015). In 2015, the dairy quota system will be abolished under the CAP in the EU and allow competition among dairy farms across the member countries. Under those circumstances, further expansion of the Polish dairy sector is expected.

MATERIALS AND METHODS

Trends in Milk Production, Cow Herds, and Yields Per Cow

The 2 regions characterized by the growing importance of milk production have rather different dairy sectors. To show the differences, we use annual data from published sources issued by the Main Statistical Office (Polish acronym: GUS) to estimate simple trend equations for the period 1999–2013. For that purpose, the milk production, cow herd, and yield per cow have been regressed on the time trend assuming the discrete values starting with 1 for 1999 observations and ending with 15 for observations for 2013.

As noted earlier, since the adoption of a market economy, the cow herd has been gradually shrinking in Poland. Figure 2 shows the number of cows on family dairy farms in the 2 regions and the calculated trends (see also Table A1). During much of the period 1999–2013, the trends in Wielkopolskie and Podlaskie voivodeships were divergent. In Wielkopolskie voivodeship, the number of cows was declining until Poland

Figure 2. Cow numbers and trends in cow numbers in Wielkopolskie and Podlaskie voivodeships, Poland, 1999–2013. Source: Authors' calculations based on Bank Danych Lokalnych GUS available online at http://stat.gov.pl/bdlen/app/strona.html?p_name=indeks.

joined the EU. Then, between 2004 and 2010, the number of cows stabilized, but between 2011 and 2013 the downward trend resumed. The fitted linear trend explains about 48% of the observed variation (R^2 is 0.4761). In the case of Podlaskie voivodeship, the cow herd was expanding through 2009 and only in the last 4 yr of the considered period has the number of cows shown a declining tendency. The R^2 is 0.7960, considerably higher than in Wielkopolskie. The gap in the herd size between the 2 regions was increasing through much of the period and showed only slight narrowing in 2013. Overall, the increasing number of cows in Podlaskie voivodeship seems to have been a major contributor to the increasing milk production, whereas in Wielkopolskie voivodeship the milk production showed a slight tendency to increase, and the size of the cow herd was decreasing.

Figure 3 shows the plot of the milk production volume on farms in Wielkopolskie and Podlaskie voivodeships and the fitted linear trend lines. Although both regions produce very similar volumes of milk at the beginning of the period, by 2004 when Poland joined the EU, Podlaskie produced more than 50% greater milk volume than Wielkopolskie voivodeship, and with the exception of 2010, production continued to increase. In contrast, the production in Wielkopolskie stayed largely flat until 2004, fluctuating slightly above 1,030 billion kg. Volume increased in 2006 but then

stagnated until 2011. Since 2011, the volume produced in Wielkopolskie voivodeship accelerated and has been growing at a faster rate than in Podlaskie voivodeship, but the total volume produced is much larger in the latter region.

The estimated trends (Figure 3; Table A1) fit much closer the values from Podlaskie than Wielkopolskie voivodeship as measured by the R^2 (0.9757 vs. 0.7146). It appears that changes in milk production in Wielkopolskie voivodeship were less predictable and that other factors influenced the actual total production. The changing volume produced led to mergers among dairy processing cooperatives. Moreover, Wielkopolskie voivodeship reported the fastest growth in registered producer groups formed by dairy farmers to facilitate milk marketing (Trajer and Krzyżanowska, 2014). The groups are sanctioned by EU policies and qualify for financial grants during the first 3 yr of operation. Wielkopolskie voivodeship has the largest number of producer groups in the country, 102 compared with 4 in Podlaskie voivodeship.

Figure 4 shows the actual yields per cow in both regions together with the fitted linear trends (see also Table A1). The average yield per cow in Podlaskie was consistently below the average yield per cow in Wielkopolskie. Moreover, although yields in both regions were increasing, the gap between them has not closed and in the last 2 yr has been wider than at any earlier

Figure 3. Milk production and trends in milk production on family dairy farms in Wielkopolskie and Podlaskie voivodeships, Poland, 1999–2013. Calculations based on Bank Danych Lokalnych GUS available online at http://stat.gov.pl/bdlen/app/strona.html?p_name=indeks.

period. The calculated trend fits better observed yields in Podlaskie voivodeship than Wielkopolskie voivodeship (R^2 values are 0.8724 and 0.7255, respectively). The values are relatively high, and as shown earlier, the linear trend fits better with Podlaskie than Wielkopolskie data.

Overall, the expansion of the dairy sector in Podlaskie seems to be exploiting natural conditions and appears to have substantial reserves captured by the linear trend. The dairy sector in Wielkopolskie has not been expanding in terms of the size of the herd, but through increased yield per cow. The observed tendencies suggest the possibility of more opportunities to lower the cost in Podlaskie voivodeship than in Wielkopolskie voivodeship. The source of growth in the latter region seems to be the exploitation of technology and genetic improvement. In Podlaskie, the source of expansion is the increasing number of cows and, especially in recent years, increased efficiency reflected in higher yields per cow. However, given the focus on cost efficiency, the study involves an intra-region comparison and provides insights within each of the leading yet very different regions about the gap between the most cost-efficient dairy farm and the less cost efficient. The outcome offers indirect evidence of possible improvements in milk production efficiency in the near future and the possible competitive position of the Polish dairy sector within the EU when the dairy quota system is abolished in April 2015.

Data

The FADN database has been available for EU member countries for some time. The FADN is the only database that collects information according to a single template (uniform for all countries). The data for each EU member country are statistically representative samples of commercial farms (though participation is voluntary). The FADN sample is statistically representative in 3 aspects: location (according to FADN regions), economic size, and farm type. It includes annual records of a wide range of financial and non-financial data for a selection of full-time farms across the EU. In the case of Poland, the data used were available after the country's accession to the EU (i.e., since 2004–2005). The country has been divided into 4 FADN regions, and each consists of 4 administrative provinces called voivodeships. To discern the cost efficiency within a particular voivodeship, the authors, using individual subregion codes, subdivided the FADN region, and the number of dairy farms was determined for each voivodeship. The current study uses 189 dairy farms in Wielkopolskie voivodeship and 505 dairy farms in Podlaskie voivodeship. The obtained sample is an unbalanced panel set for the period 2004–2009 (the data reporting system changed after 2009). The estimates of parameters are consistent by applying a fixed effects efficiency estimator. Table 1 shows descriptive statistics for each region.

Figure 4. Milk yield per cow and trends in milk yield per cow on family dairy farms in Wielkopolskie and Podlaskie voivodeships, Poland, 1999–2013. Authors' calculations based on Bank Danych Lokalnych GUS available online at http://stat.gov.pl/bdlen/app/strona.html?p_name=indeks.

Costs and outputs by farm type were computed directly from the FADN data. Costs were allocated to 1 of 5 groups: materials (e.g., feed, fertilizer), energy,

labor (i.e., all labor used including that of the farmer, farm family, business partners, and hired workers), land (owned and rented), and capital (e.g., rent, deprecia-

Table 1. Elasticities of substitution for imports used on dairy farms in Wielkopolskie and Podlaskie voivodeships¹

Region	Elasticity				
	Materials	Energy	Labor	Land	Capital
Wielkopolskie voivodeship					
Materials	0.183	−0.570	0.001	−0.212	−0.096
	0.49	−0.75	(0.00)	(−0.78)	−0.17
Energy		−14.245	0.857	−1.243	4.810
		−1.70	(1.82)	(−2.51)	(1.77)
Labor			−1.339	0.017	0.766
			(−3.31)	(0.04)	(2.46)
Land				−5.578	1.501
				(−5.10)	(3.97)
Capital					−2.120
					(−1.69)
Podlaskie voivodeship					
Materials	−0.255	−1.478	0.495	−0.275	0.209
	−0.78	−2.65	(4.46)	(−1.10)	(0.53)
Energy		−3.051	0.372	−0.725	2.445
		−0.57	(1.92)	(−1.78)	(1.58)
Labor			−1.004	0.470	0.334
			(−7.13)	(1.91)	(2.48)
Land				−2.641	0.360
				(−3.08)	(1.17)
Capital					−1.373
					(−2.03)

¹*t*-statistics in parentheses.

tion). Three outputs were considered: crops, livestock, and other outputs, all of them in real terms.

The estimation of cost functions requires input prices. But FADN data include only input expenditures and not the input prices paid (or quantities used). Therefore, Eurostat's input price indices data (base year 2004) were used for agricultural materials, energy, and capital as an estimate of prices paid by farmers. The labor and land input prices were estimated from the FADN data.

Cost Frontier Estimation Approach

An inefficient farm can improve its efficiency through better input use (Langemeier, 2010). The current study focuses on cost efficiency to provide empirical evidence of the extent it may be lacking among farms in 2 leading dairy regions in Poland. The stochastic cost frontier model implies that the most efficient farms are located on the frontier function. The measure of cost efficiency, an index, assumes values from 0 to 1, where 1 is the highest efficiency level. The fixed effects stochastic cost frontier model can be written as follows (Kumbhakar and Knox Lovell, 2003):

$$\ln E_{it} = \ln C(Q_{it}, W_{it}, \tau_t; \Omega) + v_{it} + u_i, \quad [1]$$

where i denotes farms and t denotes the periods. In Equation [1], $\ln E_{it}$ is the logarithm of the observed expenditure and $\ln C(Q_{it}, W_{it}, \tau_t; \Omega)$ is the logarithm of the deterministic cost function that depends on the outputs, Q_{it} ; the input prices, W_{it} ; a deterministic trend, τ_t , to capture technological change; and a vector of parameters, Ω . The statistical error is represented by v_{it} , which is assumed to be independent and identically distributed with mean zero and variance σ_v^2 . The time invariant inefficiency term, u_i , is positive.

The estimation of the stochastic cost frontier [i.e., $\ln C(Q_{it}, W_{it}, \tau_t; \Omega) + v_{it}$] and the inefficiency terms (i.e., u_i) requires the choice of a functional form for the deterministic part of the stochastic cost frontier [i.e., $\ln C(Q_{it}, W_{it}, \tau_t; \Omega)$]. The selection of a generalized multiproduct translog cost function (Caves et al., 1980) imposes fewer *a priori* restrictions than other functional forms commonly used for the task. As explained by Caves et al. (1980) in the context of multiproduct estimation, some outputs might not be present on a farm, and therefore the logarithm used in the translog function will produce an error. Instead, they propose the use of a Box-Cox transformation to substitute for the logarithm of the output terms. Note that the Box-Cox transformation is only one of the possibilities. Therefore, this paper applies $f(Q) = Q$, which provides a hybrid between the translog function and the quadratic

function. Thus, for the case of n inputs and m outputs, the cost function is given by

$$\begin{aligned} \ln C(Q_{it}, W_{it}, \tau_t; \Omega) = & \alpha_0 + \phi_0 \tau_t + \phi_0 \tau_t^2 + \sum_{j=1}^n \alpha_j \ln W_{jt} \\ & + \frac{1}{2} \sum_{j=1}^n \sum_{k=1}^n \beta_{jk} \ln W_{jt} \ln W_{kt} + \frac{1}{2} \sum_{j=1}^m \sum_{k=1}^m \delta_{jk} f(Q_{jit}) \ln W_{kt} \\ & + \sum_{j=1}^m \gamma_j f(Q_{jit}) + \frac{1}{2} \sum_{j=1}^m \sum_{k=1}^m \rho_{jk} f(Q_{jit}) \cdot f(Q_{kit}). \end{aligned} \quad [2]$$

Letters α , β , γ , ρ , δ and φ represent parameters that are estimated using the described data, and j and k are indicators distinguishing between m outputs for each output Q and the interaction term of outputs in [2]. As the stochastic cost frontier is a cost function, it has to satisfy the properties of any cost function (Chambers, 1988). Price homogeneity and symmetry were directly imposed in [2] through the following restrictions to the parameters [3]:

$$\begin{aligned} \sum_{j=1}^n \alpha_j = 1; \sum_{j=1}^n \delta_{jk} = 0; \sum_{j=1}^n \beta_{jk} = 0; \\ \sum_{k=1}^n \beta_{jk} = 0; \sum_{j=1}^n \sum_{k=1}^n \beta_{jk} = 0; \beta_{jk} = \beta_{kj}. \end{aligned} \quad [3]$$

The restriction [3] imposed on [2] retains the same notation including j and k . A stochastic cost frontier using a panel data fixed effects model considers inefficiency as a time invariant (Schmidt and Sickles, 1984; Kumbhakar and Knox Lovell, 2003; Greene, 2005). A common problem in the estimation is that the use of a fixed effect model precludes the use of time invariant variables. However, in the context of cost function estimation, this can be overcome due to the fact that the parameters associated with input prices can be estimated from the cost share equations, where the inefficiency term (i.e., the fixed effect terms) do not appear.

The equation to be estimated is presented in [4], where the intercept in [4] is $\alpha_{0i} = \alpha_0 + u_i$.

$$\begin{aligned} \ln E_{it} = & \alpha_{0i} + \phi_0 \tau_t + \phi_0 \tau_t^2 + \sum_{j=1}^n \alpha_j \ln W_j \\ & + \frac{1}{2} \sum_{j=1}^n \sum_{k=1}^n \beta_{jk} \ln W_j \ln W_k + \frac{1}{2} \sum_{j=1}^m \sum_{k=1}^m \delta_{jk} f(Q_{jit}) \ln W_k \\ & + \sum_{j=1}^m \gamma_j f(Q_{jit}) + \frac{1}{2} \sum_{j=1}^m \sum_{k=1}^m \rho_{jk} f(Q_{jit}) \cdot f(Q_{kit}) + v_{it}. \end{aligned} \quad [4]$$

The data set does not contain input prices for each farm. However, in the context of cross-section estimation, the approach is to assume that all farmers face the same prices (e.g., Alvarez and Arias, 2003). However, for estimating a cost function using panel data it is possible to introduce prices, assuming that all the farmers face the same input prices within a year (i.e., across farms), but that prices change over time. In a different context, similar assumptions can be found in the estimation of demand systems, where price elasticities are sometimes estimated from time series because of the lack of variability of prices in cross section datasets (Hsiao, 1993, p. 206).

Equation [4] was estimated for 5 inputs (i.e., n) and 3 outputs (i.e., m). Given the high number of parameters to be estimated, the following econometric procedure was employed. First, the system of $(n - 1)$ cost shares was computed, using iterative seemingly unrelated regression equations and imposing the constraints in [3]. This step provided the values for all the terms in [4] that were associated with input prices. Second, all the remaining parameters of the cost function, except the fixed effect terms (i.e., output terms not associated with prices) were estimated using the within estimator (ordinary least square applied to the variables expressed as deviations of the means by farm as in Hsiao, 1993). Finally, the fixed effect terms used in the construction of the relative cost efficiency indices were estimated from equation [4] by evaluating the function at the mean value of the variables by farm (Atkinson and Cornwell, 1993; Kumbhakar and Knox Lovell, 2003; Pierani and Rizzi, 2003). The farm level estimated fixed effects used to compute the relative cost efficiency indices were assumed to be constant over time due to the short period covered by the sample (in the best case, information was available for some farms for 8 yr; Kumbhakar and Lovell, 2003, p. 170).

As shown in Kumbhakar and Knox Lovell (2003), the relative cost efficiency index, CEI_i , for a sample size N was computed as equation [5] based on the estimated fixed effect intercepts (i.e., $\hat{\alpha}_{0i}$), where for the most cost-efficient producers it has a value equal to 1:

$$CEI_i = \exp \left\{ - \left[\hat{\alpha}_{0i} - \min_i (\hat{\alpha}_{0i}) \right] \right\}, \quad [5]$$

where $i = 1, \dots, N$, the number of producers. The results of the cost function estimations for 2 voivodeships (Wielkopolskie and Podlaskie) provided insights into cost efficiency differences and were used to calculate elasticities of substitution among the input categories. The majority of the calculated elasticities are statistically significant and have expected signs (Table 2).

Table 2. Descriptive statistics for sample of dairy farms in Wielkopolskie and Podlaskie Voivodeships

Variable	Units	No of			Wielkopolskie voivodeship				Podlaskie voivodeship			
		observations	Mean	SD	Minimum	Maximum	No of observations	Mean	SD	Minimum	Maximum	
Variable cost	€	391	23,136	21,990	1,132	160,230	1,063	10,887	11,402	527	143,460	
Total cost	€	391	49,913	37,652	10,212	241,200	1,063	28,422	20,062	5,344	237,480	
Materials cost	€	391	23,136	21,900	1,132	160,230	1,063	10,877	11,402	527	143,460	
Energy cost	€	391	4,047	3,679	339	29,317	1,063	2,065	1,739	50	18,401	
Labor cost	€	391	7,975	4,226	2,639	47,397	1,063	7,004	2,594	2,118	34,045	
Land cost	€	391	1,964	3,003	14	20,803	1,063	1,065	2,143	23	29,350	
Capital cost	€	391	12,791	9,446	1,439	62,515	1,063	7,401	5,331	620	49,130	
Materials price index	Base year 2000	391	107	7	96	118	1,063	106	7	86	122	
Energy price index	Base year 2000	391	100	4	92	103	1,063	100	3	92	103	
Labor price index	Base year 2000	391	109	24	50	222	1,063	110	27	28	510	
Land price index	Base year 2000	391	177	255	1	2,709	1,063	132	158	3	2,367	
Capital price index	Base year 2000	391	103	1	100	104	1,063	102	1	100	104	
Materials cost share	Ratio	391	0.4239	0.1090	0.0876	0.6773	1,063	0.3406	0.1038	0.0764	0.6697	
Energy cost share	Ratio	391	0.0795	0.0294	0.0183	0.2161	1,063	0.0710	0.0251	0.0064	0.2236	
Labor cost share	Ratio	391	0.2003	0.0949	0.0367	0.5630	1,063	0.2961	0.1175	0.0560	0.6990	
Land cost share	Ratio	391	0.0366	0.0400	0.0003	0.4510	1,063	0.0331	0.0328	0.0009	0.4509	
Capital cost share	Ratio	391	0.2596	0.0723	0.1139	0.6381	1,063	0.2592	0.0738	0.0848	0.5670	
Total crop output	In 2000 prices	391	75	76	0	601	1,063	44	41	0	448	
Total livestock output	In 2000 prices	391	505	462	22	3,256	1,063	259	263	6	2,963	
Total other livestock	In 2000 prices	391	3	12	0	197	1,063	2	7	0	85	

RESULTS AND DISCUSSION

The cost efficiency index was calculated for every farm in Wielkopolskie and Podlaskie voivodeships against the most efficient farm in a particular area. The results are comparable among farms within an area but not across areas because the most efficient farm, which serves as the benchmark, is different in each area. The efficiency indicators are relative with respect to the frontiers represented by the most efficient producer or producers. For example, if a cost efficiency coefficient equals 0.5, it implies that the cost at the frontier is 50% of the observed cost at that particular farm in the studied area and the maximum potential cost reduction at that farm resulting from cost efficiency improvement is 50%. Ultimately, it is the farmer's decision when and how to reduce costs.

The distribution of dairy farms in each area according to various levels of cost efficiency is illustrated in Figure 5. A wide distribution of farms is present in terms of their relative cost efficiency, but in different areas, the potential for improvement varies. The comparison between the 2 areas is indirect and based on the concentration of cost efficiency indicators within the range.

Figure 5 depicts the relative frequency of farms according to their relative cost efficiency in Wielkopolska and Podlaskie Voivodeships. It appears that a handful

of farms have been very cost efficient and outperformed the majority of farms in either region. For a portion of farms, the calculated relative cost efficiency index ranged from 0.2 to 0.5, but the relative frequency figures indicate that the majority of farms in both regions have been assigned a cost-efficiency indicator of more than 0.25. Clearly, in Wielkopolska voivodeship the best farms outdistance the majority of dairy farms. The result supports casual observation of large, well-organized, and well-managed farms with hundreds of dairy cows, while the typical dairy farm in the region may have a much smaller herd because it depends primarily on farm-produced feed. The average farm size has been limited for decades and only the collapse of state control in farming after 1989 permitted the leasing of the number of hectares that can support a large dairy farm.

The increasing role of producer groups in Wielkopolskie voivodeship (Trajer and Krzyżanowska, 2014) supports the observed polarization of dairy farms in terms of relative cost-efficiency with an uptick in the most efficient category (Figure 5). Some farms focus on cost-efficiency to remain profitable and competitive, whereas other dairy farms may include a cow operation in the mix of enterprises that defines the traditional, risk-averse approach to farming. Not surprisingly, some dairy farms from the region have been shipping raw milk to plants outside the region including plants in

Figure 5. Relative cost efficiency index values of dairy farms in Wielkopolskie ($n = 391$) and Podlaskie ($n = 1,063$) voivodeships included in the Farm Accounts Data Network (FADN) database for Poland calculated for the period 2004–2009. Authors' calculations based on estimation results using the FADN data.

Table 3. Average values of selected indicators of the most and least cost efficient 5% of dairy farms in Wielkopolskie and Podlaskie voivodeships, Poland, 2004–2009¹

Indicator	Wielkopolskie		Podlaskie	
	Top 5%	Bottom 5%	Top 5%	Bottom 5%
Total cost	173,875	14,002	85,574	9,441
Total cost to total output without subsidies	1.42	0.83	1.91	0.81
Milk yield per cows (L)	7,429	3,138	6,263	3,392
Average cow herd (no. of animals)	81.9	8.2	52.9	4.6

¹The average milk yield for all dairy farms in Wielkopolskie and Podlaskie is 5,157 L (5,311 kg) and 4,873 L (5,019 kg) per year, respectively.

Germany some 200 miles away. The earlier description of trends showed that the cow herd in Wielkopolskie voivodeship has been declining, but yield per cow has been increasing. Also, the average herd per farm has been increasing, leading to growing specialization in dairy production and gains in cost efficiency. The average yield per cow is still below the levels reported in the Netherlands, for example, and offers opportunities for improvement and lowering production costs.

The area perceived as having the largest potential for dairy production is Podlaskie voivodeship. The calculated indexes of relative cost efficiency for all sample farms are shown in Figure 5. The majority of farms have been assigned a cost-efficiency indicator ranging from 0.2 to 0.4, although the relative frequency of farms classified with the relative cost efficiency index between 0.401 and 0.7 is noticeably smaller than in Wielkopolskie voivodeship (Figure 5). As compared with the most efficient dairy farms in the region, the remaining farms have a wider gap to close than in Wielkopolskie (Figure 5). The observed distribution of relative cost-efficiency indexes in Podlaskie has to be considered in the context of earlier presented trends. The continuous expansion of milk production in Podlaskie voivodeship has resulted from expansion of the cow herd as well as gains in milk yield per cow. Despite these gains, the average milk yield in the region is considerably less than in Wielkopolskie voivodeship. The region still has considerable opportunities for improvement. Genetic improvement alone can be a source of substantial advantage for the competitiveness of dairying in the region.

Another advantage is the location of several large processing facilities in the area and within a reasonable distance in neighboring voivodeships (e.g., Mazowieckie or Warmińsko-Mazurskie). Any increased milk volume can be processed within a relatively short transportation distance from the farm. Raw milk transportation distance within Podlaskie is much shorter than the distance from Wielkopolskie voivodeship's farms to plants in Germany. The advantages for Podlaskie voivodeship farmers are especially important because the per capita milk consumption has been decreasing in Poland,

whereas the consumption of processed dairy products (except butter) has been increasing. Value-added dairy products readily absorb shipping costs.

The calculation of the relative cost efficiency index identified the most and least cost efficient dairy farms in both regions, and their selected characteristics are shown in Table 3. The contrast between the most and least efficient farms within each region is dramatic. The milk yield and cow herd are quite disparate. The comparison between the 2 regions indicates substantially higher milk yields (almost 19%) in Wielkopolskie as compared with Podlaskie, which has a 54.8% larger average herd.

The dairy industry's indisputable low production cost leader is Ireland, which maximizes its advantage resulting from natural conditions favoring dairies. But Ireland is unlikely to satisfy the EU demand for milk or dairy products. Therefore, to grasp the potential competitiveness of both Polish regions within the EU, a comparison was attempted with the 4 largest milk-producing countries, namely France, Germany, the United Kingdom, and the Netherlands. Figures for the average milk yields and herd sizes were obtained from Dairy Report 2011 (2011). The study also provided the average values of milk yield and cow herd for Poland, which are listed in Table 4 along with the current study figures for Wielkopolskie and Podlaskie. The IFCN study (Dairy Report 2011, 2011) generated the figures using the representative farm approach applied by experts from each country. The total cost of producing 100 kg of milk (assuming 1 L equals 1.03 kg) is quite competitive (Table 4) on dairy farms with the highest relative cost efficiency index and compare favorably to the other leading milk-producing countries in the EU.

Table 4 lists figures for each country indicating the total cost and returns of a dairy enterprise reflecting the methodology of a representative farm approach. The first figure for each country (not the region) is the total cost and returns at farms with a small herd, whereas the second figure applies to farms with a large herd. In the case of Germany, Dairy Report 2011 lists 4 farm sizes, but the figures are listed for the small-

Table 4. Selected indicators for top 5% of farms with the highest values of the relative cost efficiency index values in Wielkopolskie and Podlaskie voivodeships, Poland, and 4 other EU member countries leading in milk production^{1,2}

Indicator	Top 5%				
	Wielkopolskie	Podlaskie	Poland	United Kingdom	France Germany the Netherlands
Total cost to total output without subsidies	0.83	0.81	—	—	—
Total cost and returns of the dairy enterprise	40 ³	39 ³	54/50 ⁴	44/47 ⁴	57/53 ⁴
Milk yield per cow	7,652 ⁵	6,451 ⁵	4,700	7,500	6,600
Average cow herd (heads)	81.9	52.9	5.4	118	47 8,600 75

¹Note: Ireland 42/36. Source: Authors' calculations for Wielkopolskie and Podlaskie; Dairy Report 2011 (2011) for 5 countries.
²Figures for France, Germany, the Netherlands, and United Kingdom are for 2010.
³Figures calculated using cost per liter in Wielkopolskie based on Farm Accounts Data Network data as €0.30; in Podlaskie cost per liter €0.29. Converted to \$ per 100 kg using the exchange rate €1 = \$1.30.
⁴In \$ per 100 kg of milk (ECM); approximation based on graph listed on page 25 in Dairy Report 2011.
⁵Converted from liters listed in Table 3 assuming 1 L = 1.03 kg.

est and largest herd sizes. The United Kingdom dairy farms have the lowest total costs and returns among the small farms, but German farms lead among the large farms. The other 3 countries, France, the Netherlands, and Poland, have higher total costs and returns. However, among large farms, Poland outperforms farms in the other 2 countries, and among small farms the figure is slightly larger than in France and markedly lower than in the Netherlands. At the same time, the average herd size and milk yield in Poland is much smaller than in the other 4 countries. This pattern suggests that the average Polish dairy farm is likely to be competitive as its milk yield and farm size continues to increase and substantial room for improvement is present because of the low current level of herd and yield. Among the considered countries, Poland, Germany, and recently, the Netherlands exceeded the allocated milk quota, whereas the United Kingdom and Ireland underutilized their quota. It appears that the latter are not keen on expanding milk production, and given the biological lag, will not be able to do so in the near future.

In this context, the top 5% of dairy farms in either region considered in the current study are likely to remain highly competitive within Poland and the EU. Leading dairy farms from the FADN sample in terms of the relative cost efficiency index seem to produce at slightly higher costs than large farms in the representative model approach, but at considerably lower costs than farms of any size in the 4 EU countries (Table 4). In Wielkopolskie, the average herd size compares well to the Netherlands, whereas milk yields are similar to those in the United Kingdom. The top farms in Podlaskie compare well with the average dairy farm in France. Ultimately, milk prices are likely to slowly converge after the milk quota system is abolished, suggesting higher prices in Poland and increasing farm revenues. Without a full analysis that accounts for prices, it is impossible to determine the full economic effect, but it appears that Polish dairy farms are likely to be competitive given the results obtained using 2 different approaches and databases.

CONCLUSIONS

This study investigates the possibilities of cost reduction by dairy farms evaluated at the lowest aggregation level within the FADN regions in Poland to provide insights into the relative competitiveness of 2 leading dairy-producing regions, Wielkopolskie and Podlaskie voivodeships. Both areas have natural resources suitable for dairy production and well-developed processing capacities but differ in climatic conditions, with Wielkopolskie having a milder climate.

After the adoption of a market economy in 1989 and the 2004 accession to the EU, milk production in Poland began to increase. However, since the early 1990s, Wielkopolskie and Podlaskie showed expansion in their regional dairy sectors and contrasted with the general decline of the dairy industry in the majority of Poland's countryside. However, whereas the Wielkopolskie voivodeship recorded a decrease in cow numbers, Podlaskie reported a fairly steady growth in the number of cows during the last 15 yr. The most important difference between the 2 regions is the faster growth of yield per cow in Wielkopolskie than in Podlaskie, allowing the former to remain competitive in milk production. The estimated linear trends of cow numbers, milk production, and milk yields used annual observation and fit significantly better the data for Podlaskie than Wielkopolskie according to the goodness-of-fit measure, the adjusted R^2 . Only since 2011 has the expansion of the cow herd in Podlaskie shown a declining tendency, but the milk yield gap between the 2 regions widened with the advantage to Wielkopolskie. The observed tendencies suggest more advanced technology is used on Wielkopolskie dairy farms, but Podlaskie farms have deeper reserves that may allow cost-cutting in the future to enhance the region's competitiveness, especially after the dairy quota system is abolished at the end of the first quarter of 2015.

The cost-efficiency analysis at the level of a voivodeship avoids pitfalls of the artificial formation of FADN regions in Poland. The 4 aggregate FADN regions consist of areas that differ in natural resource endowment, type of farming and farm sizes, and agricultural and cultural traditions. Therefore, the current study is based on data that were selected for dairy farms in 2 regions and provides additional insights about the opportunities of improving cost efficiency in the near future. The approach used in this study contrasts with the method using the representative farm approach (Dairy Report 2011, 2011), which may be suitable for some countries, but unable to capture the dynamic changes in the dairy sector in other. The estimation of separate models for each voivodeship permitted the calculation of relative cost efficiency indexes and allowed the comparison of the most cost-efficient dairy farm in the region to other dairy farms in the sample. The relative cost-efficiency comparisons are valid only within the region because the most efficient farm or farms determine the cost frontier. The number of very efficient farms is limited in each region.

The cost efficiency analysis was expanded by comparing the costs of production on dairy farms in the 2 regions with results of the analysis based on the representative farm approach (Dairy Report 2011, 2011). Although not directly comparable due to dif-

ferent methodologies, results indicate that farms with the highest relative cost efficiency index values in the 2 regions have production costs as low as the lowest cost producing farms identified using the representative farm approach. It is highly plausible that milk production will expand in Poland after the elimination of the EU milk quota system in 2015. The remaining farms in each of 2 Poland's region appear to have substantial reserve and capacity for cost reduction as compared with the most efficient farm, especially in Wielkopolska, where the milk yields are already higher than in Podlaskie or the national average. Whether such opportunities will be realized depends on each farm operator and external pressures such as access to milk processing plants and prices they offer for raw milk. Operators of farms with the relative low cost-efficiency index may cease to produce milk in coming years and focus on crop production, or be absorbed by larger farms. Some large farms in Wielkopolskie voivodeship may not continue dairy production if returns become uncompetitive. Consequently, the role of Podlaskie voivodeship in dairy production could increase in the future, but gains will result from improved genetics rather than herd expansion.

Production costs are also associated with regional wage rates, but family dairy operations use mostly their own labor in Poland. However, if hired labor is used, wages in Wielkopolskie are higher than in Podlaskie voivodeship, where the average income is below the national average and on-farm jobs are limited (Klepacka 2012). Also, regional differences in the level of economic development have favored Wielkopolskie, but Podlaskie has registered significant gains, including technical infrastructure development in recent decades.

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APPENDIX

Calculations used to estimate the trend in cow numbers are shown on Figure 2. Trend for Podlaskie voivodeship:

$$y_{\text{POD}} = 8,527.99x \quad (P < 0.00001) \\ + 341,950 \quad (P < 0.00001); R^2 = 0.7960 \\ (P\text{-value for F test, } P = 7.80 \cdot 10^{-6}).$$

Trend for Wielkopolskie voivodeship:

$$y_{\text{WP}} = -2,468.58x \quad (P = 0.00441) \\ + 268,710 \quad (P < 0.00001); R^2 = 0.4761 \\ (P\text{-value for F test, } P = 0.004415).$$

Calculations used to estimate the trend in milk production are shown in Figure 3. Trend for Podlaskie:

$$y_{\text{POD}} = 86,711x \quad (P < 0.00001) \\ + 1.04664 \cdot 10^6 \quad (P < 0.00001); R^2 = 0.9757 \\ (P\text{-value for F test, } P = 7.12 \cdot 10^{-12}).$$

Trend for Wielkopolskie:

$$y_{\text{WP}} = 21,668x \quad (P = 0.00007) \\ + 953,178 \quad (P < 0.00001); R^2 = 0.7146 \\ (P\text{-value for F test, } P = 0.000072).$$

Calculations used to estimate the trend in milk yield per cow are shown on Figure 4. Trend for Podlaskie voivodeship:

$$y_{\text{POD}} = 126.51x \quad (P < 0.00001) \\ + 3,189.02 \quad (P < 0.00001); R^2 = 0.8724 \\ (P\text{-value for F test, } P = 3.55 \cdot 10^{-7}).$$

Trend for Wielkopolskie voivodeship:

$$y_{\text{WP}} = 136.79x \quad (P = 0.00006) \\ + 3,466.85 \quad (P < 0.00001); R^2 = 0.7255 \\ (P\text{-value for F test, } P = 0.000056).$$

Table A1. Cow numbers, milk yield per cow, and milk production in family dairy farms in Wielkopolskie and Podlaskie voivodeships, Poland, 1999–2013¹

Year	Cows (no. of animals)		Liters per cow per year		Milk production (1,000 L)	
	Podlaskie	Wielkopolskie	Podlaskie	Wielkopolskie	Podlaskie	Wielkopolskie
1999	348,085	272,541	3,497	3,717	1,217,261	1,013,046
2000	353,074	253,699	3,480	4,064	1,228,642	1,031,152
2001	354,297	263,893	3,610	3,973	1,278,862	1,048,576
2002	379,094	256,614	3,522	3,979	1,335,205	1,021,129
2003	381,350	257,678	3,686	4,245	1,405,741	1,093,914
2004	379,396	259,296	4,253	4,013	1,613,420	1,040,679
2005	392,186	234,749	4,132	4,326	1,620,439	1,015,460
2006	419,974	238,389	4,192	4,758	1,760,617	1,134,139
2007	437,845	250,757	4,115	4,677	1,801,901	1,172,700
2008	447,722	271,396	4,326	4,248	1,936,752	1,152,811
2009	475,614	243,992	4,467	4,753	2,124,617	1,159,651
2010	464,203	250,336	4,233	4,500	1,964,916	1,126,575
2011	440,667	234,591	4,977	4,949	2,193,153	1,160,979
2012	448,177	214,165	5,059	6,100	2,267,111	1,306,312
2013	430,918	232,323	5,468	6,115	2,356,301	1,420,691

¹Authors' calculations are based on Bank Danych Lokalnych GUS available online at http://stat.gov.pl/bdlen/app/strona.html?p_name=indeks.