ADJUSTMENT COSTS AND EFFICIENCY IN POLISH AGRICULTURE: A DYNAMIC EFFICIENCY APPROACH

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Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.

Abstract

This paper aims to understand the state of adjustment process and dynamic structure in Polish agriculture. A dynamic cost frontier model using the shadow cost approach is formulated to decompose cost efficiency into allocative and technical efficiencies. The dynamic cost efficiency model is developed into a more general context with a multiple quasi-fixed factor case. The model is implemented empirically using a panel data set of 1,143 Polish farms over the period 2004 to 2007. Due to the regional disparities and a wide variety of farm specialization, farms are categorized into two regions and five types of farm production specialization. The estimation results confirm our observation that adjustment is rather sluggish implying that adjustment cost are considerably high. It takes up to 30 years until Polish farmers reach their optimal level of capital and land input. Allocative and technical efficiency differ widely across regions. Moreover, efficiency is rather stable over time and among farm specialisations. However, their results indicate that the regions characterized by the larger farms perform slightly better.

Keywords: Polish agriculture, dynamic efficiency, adjustment cost, shadow cost approach

JEL codes: D21, D61, Q12

1 INTRODUCTION

During socialist time, Polish agriculture didn't experience large restructuring processes like the sector did in other centrally planned economies. As a consequence, farm structures in 1990 were merely the same as before World War II, especially because the socialistic government prohibited structural changes in private agriculture. Compared to other countries in the EU, Polish agriculture is greatly dominated by small holdings with comparatively low levels of specialisation. They were additionally characterized by a relatively low degree of market integration. In the 1990s it was expected that after 50 year of the congestion significant adjustment processes would occur which would have changed farm structure significantly. Given the poor economic development in the 1990 the stagnation of farm structures was not really astonishing since the absorption capacity of the other sectors for labour was rather limited. However, the situation has changed over the past decade as the economy is prospering and offering plenty of alternative possibilities to earn a living. This demand pull puts a competitive thread to labour input in agriculture. In addition, it was supplemented by a supply push resulting from more intense competition within the sector after Poland's accession to the EU. However, the empirical evidence reveals that the structural adjustment process and agricultural change have been rather sluggish. In the first years after accession, neither a pronounced trend in farm growth leading to a higher degree of specialisation nor changes in the specialisation in production could be observed.

This suggests that eitheQr farm structure and farm size in Poland was at its optimal level, or that adjustment cost hinder a fast adjustment to optimal input levels. Given the structure of the agricultural sector, it can be expected that adjustment costs are considerable. This hypothesis results from the low level of specialisation. In order to benefit from the fruits of larger holdings especially economies of scale, farmers were required to change their whole production program. The specialisation processes can be assumed to have been accompanied by high adjustment costs since fundamental changes of the production technologies would have been required. Thus, the role of adjustment costs and dynamic cost structure are becoming important issues for investigating the performance in Polish agriculture. Moreover, whether adjustment costs are significant and whether they can be regarded as a source of the sluggish adjustment processes are of interest to policymakers.

The main purpose of the paper is to understand the state of adjustment process and dynamic structure in Polish agriculture. To meet this goal this paper extends the adjustment costs model with technical and allocative ineffcinecy of Rungsuriyawiboon and Stefanou (2007) into a more general context with a multiple quasi-fixed factor case. The model is implemented empirically using a panel data set of 1,143 Polish farms over the period 2004 to 2007. The study period allows examining the post-accession performance of Polish farms. Due to a large difference across regions and a wide variety of farm specializations, the study focuses on two regions (i.e. North and South) and five types of farm production specialization (i.e. field crops, dairy cattle, grazing livestock, granivores and mixed farms). The production technology of Polish farm is presented by one output variable (the aggregate of crop and livestock), four variable inputs (labor, overhead, fertilizer, livestock) and two quasi-fixed factors (land and capital).

Rungsuriyawiboon and Stefanou (2007) built on the work of Epstein and Denny (1983); Vasavada and Chambers (1986); Howard and Shumway (1988); Luh and Stefanou (1991, 1993); Fernandez-Cornejo et al. (1992); Manera (1994) and Pietola and Myers (2000) and formalize the theoretical and econometric models of dynamic efficiency in the presence of intertemporal cost minimizing firm behavior. The dynamic efficiency model is developed by integrating the static production efficiency model and the dynamic duality model of intertemporal decision making. Basically, technical and allocative inefficiencies are considered following by the shadow coast approach developed by Kumbhakar and Lovel (2000). The dynamic efficiency model defines the relationship between the actual and behavioral value function of the dynamic programming equation (DPE) for a firm's intertemporal cost minimization behavior. Therefore, the dynamic efficiency model provides the system of equations which allows measuring both technical and allocative inefficiency of firms. Recently, Huettel, Narayana and Odening (2011) extend the Rungsuriyawiboon and Stefanou (2007) model by developing a theoretical framework of a dynamic efficiency measurement and optimal investment under uncertainty.

The remainder of the paper is organized as follows. The next section presents the theoretical framework and mathematical derivations of the dynamic efficiency model for the multiple quasi-fixed factor case. The following section discusses the data set and the definitions of the variables used in this study. The next section elaborates the econometric model of the dynamic efficiency model with the two-quasi-fixed factor case. The results of empirical analysis are presented and discussed in the next section and the final section concludes and summarizes.

2 Theoretical Framework and Model Specification

2.1 Dynamic Intertemporal Cost Minimizing Firm

Dynamic economic problem facing a cost minimizing firm behavior can be addressed by characterizing firm investment behavior as the firm seeking to minimize the present value of production costs over an infinite horizon. This framework allows one to analyze the transition path of quasi-fixed factors to their desired long-run levels. The underlying idea is that the adjustment process of quasi-fixed factors generates additional transition costs and the optimal intertemporal behavior of the firm can be solved by using the notion of adjustment costs as a means to solve the firm's optimization problem. With the presence of adjustment costs for the quasi-fixed factors, a firm faces additional transition costs of quasi-fixed factors beyond acquisition costs in the decision making process. This dynamic intertemporal cost minimizing firm model is dealt with two sets of control variables, variable input and dynamic factors (i.e. net investment of quasi-fixed factors), and it can be solved by the appropriate static optimization problem as expressed in the DPE or Hamilton-Jacobi-Bellman equation (Epstein and Denny 1983). The dynamic duality model of intertemporal cost minimizing firm behavior provides readily implemental systems of dynamic factor demands consisting of optimal net investment demand for quasi-fixed factors and optimal variable input demand.

Let x and q denote a nonnegative vector of variable inputs and quasi-fixed factors, $\mathbf{x} \in \Re_{+}^{N}$ and $\mathbf{q} \in \Re_{+}^{Q}$, respectively, where w and p denote a strictly nonnegative vector of variable input price and quasi-fixed factor price, $\mathbf{w} \in \Re_{+}^{N}$ and $\mathbf{p} \in \Re_{+}^{Q}$, respectively.

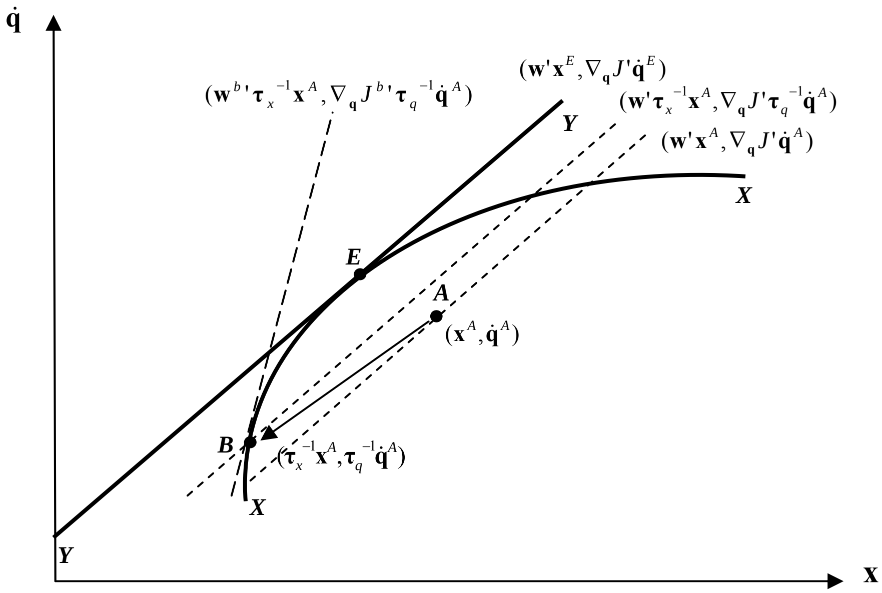
The value function of the DPE for the intertemporal cost minimizing firm behavior can be expressed as

$$(1) \qquad rJ(\mathbf{w}',\mathbf{p}',\mathbf{q}',y,t) = \min_{\mathbf{x},\dot{\mathbf{q}}>0}\{\mathbf{w}'\mathbf{x} + \mathbf{p}'\mathbf{q} + \nabla_{\mathbf{q}} J'\dot{\mathbf{q}} + \gamma(y - F(\mathbf{x}',\mathbf{q}',\dot{\mathbf{q}}',t)) + \nabla_t J\}$$

where r is the constant discount rate; y is a sequence of production targets over the planning horizon; t is time trend variable; $\nabla_{\mathbf{q}} J$ is a $(Q\times 1)$ strictly nonnegative vector of the marginal valuation of the quasi-fixed factors; $\dot{\mathbf{q}}$ is a $(Q\times 1)$ nonnegative vector of net investment in quasi-fixed factors; γ is the Lagrangian multiplier associated with the production target; $F(\mathbf{x}',\mathbf{q}',\dot{\mathbf{q}}',t)$ is the single output production function; $\nabla_t J$ is the shift of the value function due to technical change.

Equation (1) can be viewed as the dynamic intertemporal model of firm's cost minimization problem in the presence of the perfect efficiency. When a firm does not minimize its variable and dynamic factors given its output and does not use the variable and dynamic factors in optimal proportions given their respective prices and the production technology, the firm is operating both technically and allocatively inefficient. Measure of firm's inefficiency can be done by adopting a shadow price approach as described in Kumbhakar and Lovell (2000). Figure 1 shows the bundle of variable and dynamic factors $(\mathbf{x},\dot{\mathbf{q}})$. The curve XX represents the isoquant. All curves to the southeast of XX represent higher output levels. Since $\nabla_{\mathbf{x}} F > 0$ and $\nabla_{\dot{\mathbf{q}}} F < 0$, it is downward sloping, moreover, $\nabla_{\mathbf{xx}}F<0$ and $\nabla_{\dot{\mathbf{q}}\dot{\mathbf{q}}}F<0$ implies that the function is concave[1]. The line YY represents the isocost curve derived from the long-run shadow cost function in equation (1). According to the definition of costs, they are increasing in variable inputs and higher net investments. Point E represents the point that the firm will choose to minimum long-run costs occurred at the contact point of the isoquant and isocost curves such that $\nabla_{\mathbf{x}}\dot{\mathbf{q}}=-(\mathbf{w}/\nabla_{\mathbf{q}}J)=-(\nabla_{\mathbf{x}}F/\nabla_{\dot{\mathbf{q}}}F)$;; $\nabla_{\mathbf{q}}J<0$.

Figure 1. The dynamic intertemporal cost model in the presence of the inefficiency



Consider Point A in Figure 1 where a firm uses the bundle of inputs $(\mathbf{x}^A,\dot{\mathbf{q}}^A)$ available at price $(\mathbf{w},\nabla_{\mathbf{q}}J)$ to produce output y measured using the XX curve. Given the input price $(\mathbf{w},\nabla_{\mathbf{q}}J)$, a minimum cost will occur at point E with the cost of $(\mathbf{w}'\mathbf{x}^E,\nabla_{\mathbf{q}}J'\dot{\mathbf{q}}^E)$. The firm is technically inefficient, because the operation is not on the XX curve. Thus both, the variable input use as well as dynamic factor can be reduced, and thus, costs can be saved without an adjustment of production (e.g. moving from point A to point B in figure 1). Let $\boldsymbol{\tau}_x^{-1}$ and $\boldsymbol{\tau}_q^{-1}$ denote an input-oriented measure of the technical efficiency of the producer for variable and dynamic factors, respectively. The firm will be technically

[1] Total differentiating $y=F(\mathbf{x},\mathbf{q},\dot{\mathbf{q}},t)$ leads to $\nabla_{\mathbf{x}}Fd\mathbf{x}+\nabla_{\mathbf{q}}Fd\mathbf{q}+\nabla_{\dot{\mathbf{q}}}Fd\dot{\mathbf{q}}+\nabla_{t}Fdt=0$. Given $d\mathbf{q}=0$ and $dt=0$, slope of the isoquant yields $\nabla_{\mathbf{x}}\dot{\mathbf{q}}=-\frac{\nabla_{\mathbf{x}}F}{\nabla_{\dot{\mathbf{q}}}F}$. Differentiating the slope of the isoquant with respect to $\mathbf{x}$ shows that

$$\nabla_{\mathbf{xx}}\dot{\mathbf{q}}=-\left[\frac{\nabla_{\dot{\mathbf{q}}}F\nabla_{\mathbf{xx}}F-\nabla_{\mathbf{x}}F\nabla_{\dot{\mathbf{q}}\dot{\mathbf{q}}}F}{(\nabla_{\dot{\mathbf{q}}}F)^2}\right]<0 .$$

efficient at point B under the input uses of $(\boldsymbol{\tau}_x^{-1}\mathbf{x}^A, \boldsymbol{\tau}_q^{-1}\dot{\mathbf{q}}^A)$ with the cost of $(\mathbf{w}'\boldsymbol{\tau}_x^{-1}\mathbf{x}^A, \nabla_{\mathbf{q}} J'\boldsymbol{\tau}_q^{-1}\dot{\mathbf{q}}^A)$. At point B the firm is still allocatively inefficient, because the marginal rate of substitution at $(\boldsymbol{\tau}_x^{-1}\mathbf{x}^A, \boldsymbol{\tau}_q^{-1}\dot{\mathbf{q}}^A)$ diverges from the actual input price $(\mathbf{w}, \nabla_{\mathbf{q}} J)$. However, the firm is allocatively efficient relative to the shadow input price $(\mathbf{w}^b, \nabla_{\mathbf{q}} J^b)$. The shadow prices (internal to the firm) are defined as input prices forcing the technically efficient input vector to be the cost minimizing solution for producing a given output. Shadow prices will differ from market (actual) prices in the presence of inefficiency. Figure 1 illustrates the presence of the technical and allocative inefficiency in the dynamic intertemporal model of this cost minimizing firm behavior.

2.2 Derivation of Dynamic Efficiency Model

In the presence of inefficiency, the dynamic efficiency model with intertemporal cost minimizing firm behavior can be formulated using the shadow price approach. A basic idea underlying the construction of the dynamic efficiency model is to define the relationship between actual and shadow (behavioral) value functions of the DPE for the firms' intertemporal cost minimization behavior. The behavioral value function of the DPE is expressed in terms of shadow input prices, quasi-fixed factor and output whereas the actual value function can be viewed as the perfectly efficient condition. The shadow input prices are constructed to guarantee optimality relationship and they will differ from market (actual) prices in the presence of inefficiency. The inefficiency of firm can be measured and evaluated as a deviation between the behavioral and actual value function.

Let $\mathbf{x}^b$ and $\dot{\mathbf{q}}^b$ denote a nonnegative vector of behavioral variable inputs and behavioral dynamic factors, $\mathbf{x}^b \in \Re_+^N$ and $\dot{\mathbf{q}}^b \in \Re_+^Q$, respectively. Following the shadow price approach, $\mathbf{x}^b$ and $\dot{\mathbf{q}}^b$ can be expressed in terms of actual variable and dynamic factors as $\mathbf{x}^b = \boldsymbol{\tau}_x{}^{-1}\mathbf{x}$ and $\dot{\mathbf{q}}^b = \boldsymbol{\tau}_q{}^{-1}\dot{\mathbf{q}}$, respectively where $\boldsymbol{\tau}_x$ and $\boldsymbol{\tau}_q$ are the inverse of producer-specific scalars providing input-oriented measures of the technical efficiency in variable input use and dynamic factor use, respectively. Let $\mathbf{w}^b$ and $\nabla_{\mathbf{q}} J^b$ denote a strictly nonnegative vector of behavioral variable input price and behavioral dynamic factors, $\mathbf{w}^b \in \Re_+^N$ and $\nabla_{\mathbf{q}} J^b \in \Re_+^Q$, respectively. Similarly, $\mathbf{w}^b$ and $\nabla_{\mathbf{q}} J^b$ can be expressed in terms of actual price of variable and dynamic factors as $\mathbf{w}^b = \boldsymbol{\Lambda}_n \mathbf{w} \quad (n = 1,...,N)$ and $\nabla_{\mathbf{q}} J^b = \boldsymbol{\Sigma}_q \nabla_{\mathbf{q}} J^a \ (q = 1,...,Q)$, respectively where $\boldsymbol{\Lambda}_n$ and $\boldsymbol{\Sigma}_q$ are allocative inefficiency parameters for the nth variable input and the qth dynamic factor, respectively.

Consider the behavioral input prices and quantity, the DPE for the firms' intertemporal cost minimization behavior can be expressed as

$$(2) \qquad rJ^b(\mathbf{w}^b{}', \mathbf{p}', \mathbf{q}', y, t) = \mathbf{w}^b{}'\mathbf{x}^b + \mathbf{p}'\mathbf{q} + \nabla_{\mathbf{q}} J^b{}'\dot{\mathbf{q}}^b + \gamma^b(y - F(\mathbf{x}^b{}', \mathbf{q}', \dot{\mathbf{q}}^b{}', t)) + \nabla_t J^b$$

where γ^b is the behavioral Lagrangian multiplier defined as the short-run, instantaneous marginal cost; $\nabla_t J^b$ is the shift of the behavioral value function.

Differentiating (2) with respect to $\mathbf{p}$ and $\mathbf{w}^b$ yields the behavioral conditional demand for the dynamic and variable factors, respectively. Using $\dot{\mathbf{q}}^b = \boldsymbol{\tau}_q{}^{-1}\dot{\mathbf{q}}$ and $\mathbf{x}^b = \boldsymbol{\tau}_x{}^{-1}\mathbf{x}$, the optimized demand for the dynamic and variable factors yield

(3) $\dot{\mathbf{q}}^\circ = \boldsymbol{\tau}_q \dot{\mathbf{q}}^b = \boldsymbol{\tau}_q (\nabla_{\mathbf{qp}} J^b)^{-1} \cdot (r\nabla_{\mathbf{p}} J^b - \mathbf{q} - \nabla_{\mathbf{p}t} J^b)$

(4) $\mathbf{x}^\circ = \boldsymbol{\tau}_{\mathbf{x}} \mathbf{x}^b = \boldsymbol{\tau}_{\mathbf{x}} \boldsymbol{\Lambda}_n^{-1} (r\nabla_{\mathbf{w}} J^b - \nabla_{\mathbf{wq}} J^b{}' \dot{\mathbf{q}}^b - \nabla_{\mathbf{w}t} J^b)$

where $\nabla_{\mathbf{w}^b} J^b = \boldsymbol{\Lambda}_w^{-1} \nabla_{\mathbf{w}} J^b$

The value function in actual prices and quantities as the optimal level can be defined as

(5) $rJ^a(\cdot) = \mathbf{w}'\mathbf{x}^\circ + \mathbf{p}'\mathbf{q} + \nabla_{\mathbf{q}} J^a{}' \dot{\mathbf{q}}^\circ + \nabla_t J^a$

Differentiating (5) with respect to $\mathbf{p}$ and $\mathbf{w}$, and applying the same step as for the behavioral value function yield

(6) $\dot{\mathbf{q}}^\circ = (\nabla_{\mathbf{qp}} J^a{}')^{-1} (r\nabla_{\mathbf{p}} J^a - \mathbf{q} - \nabla_{\mathbf{p}t} J^a)$

(7) $\mathbf{x}^\circ = (r\nabla_{\mathbf{w}} J^a - \nabla_{\mathbf{qw}} J^a{}' \dot{\mathbf{q}} - \nabla_{\mathbf{w}t} J^a)$

Using the behavioral demand function in (6) and (7), the value function in actual prices and quantities (5) can be written as

(8)
$$\begin{aligned} rJ^a(\cdot) \quad = \quad & \mathbf{w}'\boldsymbol{\tau}_x \boldsymbol{\Lambda}_n^{-1} (r\nabla_{\mathbf{w}} J^b - \nabla_{\mathbf{qw}} J^b{}' ((\nabla_{\mathbf{qp}} J^b{}')^{-1} (r\nabla_{\mathbf{p}} J^b - \mathbf{q} - \nabla_{\mathbf{p}t} J^b)) - \nabla_{tw} J^b) \\ & + \mathbf{p}'\mathbf{q} + \boldsymbol{\Sigma}_q^{-1} \nabla_{\mathbf{q}} J^b{}' \boldsymbol{\tau}_q (\nabla_{\mathbf{qp}} J^b{}')^{-1} (r\nabla_{\mathbf{p}} J^b - \mathbf{q} - \nabla_{\mathbf{p}t} J^b) + \nabla_t J^b \end{aligned}$$

where $\nabla_t J^a = \nabla_t J^b$ implying a shift in the behavioral value function is the same proportion as that in the actual value function.

Differentiating (8) with respect to $\mathbf{p}$, $\mathbf{q}$ and t (neglecting third derivative) and substituting into (6) yields

(9)
$$\begin{aligned} & \dot{\mathbf{q}}^\circ \left[\mathbf{I}/r + \boldsymbol{\tau}_q \boldsymbol{\Sigma}_q^{-1} (\nabla_{\mathbf{qp}} J^b + \nabla_{\mathbf{qq}} J^b{}' (\nabla_{\mathbf{qp}} J^b{}')^{-1} \nabla_{\mathbf{pp}} J^b - \mathbf{I}/r) - \boldsymbol{\Sigma}_q^{-1} \nabla_{\mathbf{qp}} J^b \right] = \\ & \quad \left[r\mathbf{w}' \boldsymbol{\tau}_x \boldsymbol{\Lambda}_n^{-1} (\nabla_{\mathbf{wp}} J^b - \nabla_{\mathbf{qw}} J^b{}' (\nabla_{\mathbf{qp}} J^b{}')^{-1} \nabla_{\mathbf{pp}} J^b) + \right. \\ & \quad + \boldsymbol{\tau}_q \boldsymbol{\Sigma}_q^{-1} \left[r\nabla_{\mathbf{q}} J^b{}' (\nabla_{\mathbf{qp}} J^b{}')^{-1} \nabla_{\mathbf{pp}} J^b - \nabla_{\mathbf{q}t} J^b{}' (\nabla_{\mathbf{qp}} J^b{}')^{-1} \nabla_{\mathbf{pp}} J^b \right] \\ & \quad \left. + (\mathbf{I} - \boldsymbol{\tau}_q \boldsymbol{\Sigma}_q^{-1}) \nabla_{\mathbf{p}t} J^b \right] \end{aligned}$$

Similarly, differentiating (8) with respect to $\mathbf{w}$, $\mathbf{q}$ and t (neglecting third derivatives) and substituting into (7) yields

$$
\begin{aligned}
\mathbf{x}^{\circ} = \quad & \boldsymbol{\tau}_w \boldsymbol{\Lambda}_n^{-1} \begin{bmatrix} r\mathbf{w}'(\nabla_{\mathbf{ww}} J^b - \nabla_{\mathbf{qw}} J^b{}'(\nabla_{\mathbf{qp}} J^b{}')^{-1} \nabla_{\mathbf{wp}} J^b) + r\nabla_{\mathbf{w}} J^b \\ -\nabla_{\mathbf{w}t} J^b + \nabla_{\mathbf{qw}} J^b{}'(\nabla_{\mathbf{qp}} J^b{}')^{-1} \nabla_{\mathbf{p}t} J^b \end{bmatrix} \\
(10) \qquad & + \boldsymbol{\tau}_q \boldsymbol{\Sigma}_q^{-1} \left[r\nabla_{\mathbf{q}} J^b{}'(\nabla_{\mathbf{qp}} J^b{}')^{-1} \nabla_{\mathbf{wp}} J^b - \nabla_{\mathbf{q}t} J^b{}'(\nabla_{\mathbf{qp}} J^b{}')^{-1} \nabla_{\mathbf{wp}} J^b \right] \\
& - \dot{\mathbf{q}}^{\circ} \boldsymbol{\tau}_w \boldsymbol{\Lambda}_n^{-1} (\nabla_{\mathbf{qw}} J^b - \nabla_{\mathbf{qw}} J^b{}'(\nabla_{\mathbf{qp}} J^b)^{-1} (\nabla_{\mathbf{qp}} J^b - \mathbf{I}/r) + \boldsymbol{\tau}_q \nabla_{\mathbf{qw}} J^b) \\
& - \dot{\mathbf{q}}^{\circ} \boldsymbol{\tau}_q \boldsymbol{\Sigma}_q^{-1} (\nabla_{\mathbf{qq}} J^b{}'(\nabla_{\mathbf{qp}} J^b{}')^{-1} \nabla_{\mathbf{wp}} J^b)
\end{aligned}
$$

The dynamic efficiency model in the presence of inefficiencies consists of the actual conditional demands for dynamic factors in equation (9) and variable inputs in equation (10).

3 Data Discussions

3.1 Definition of Variables

The empirical analysis focuses on agricultural production in Poland using a balanced subpanel of the Polish FADN dataset for the period 2004-2007[2]. In our analysis, the production technology of Polish farm is presented by one output variable, four variable inputs (i.e. labor, overhead, crop input, livestock input) and two quasi-fixed factors (i.e. land and capital). Labour and land were given in physical inputs, e.g. total labour input expressed in annual work units (= full-time person equivalent) and total utilized agricultural area in hectare, respectively. All other inputs and outputs were provided in nominal monetary values. Capital input comprises land improvement, permanent crops, farm buildings, machinery, equipment and the breeding livestock. Material input in crop production is the aggregate of fertilizer, seed, pesticide and other inputs expenditure for crop production. Material input in livestock production comprises feed and other input expenditure for livestock production. Overheads include expenditures for energy, maintenance, purchased services and other not assignable inputs.

The volume of capital input was captured by dividing the capital input by the price index of fixed assets. This index was only available for the national level. Rental prices for capital were derived by calculating the product of the price index of fixed assets times the sum of the nominal interest rate and the depreciation rate (Jorgenson 1963). The latter two variables were calculated from the data set[3]. Price indices for variable inputs were only available at the national level[4]. Farm specific prices indices were derived using the following procedure: First we calculated the volume of the individual inputs by dividing the data in current prices by the corresponding price index at the national level. Second, for each of the three categories the corresponding inputs were aggregated. Third, the relations of input in current and constant prices constitute the farm specific price indices.

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[2] The Farm Accountancy Data Network (FADN), Source: http://ec.europa.eu/agriculture/rica/

[3] Depreciation rate was by the relation of depreciation and fixed assets. The interest rate was the relation of interest paid and the amount of proportion of interest paid and long and medium-term loans.

[4] All price indices were taken form national statistics and the EUROSTAT website.

Table 1: Descriptive statistics of the variables, 2004-2007*

		Pomorze and Mazury				Malopolska and Pogórze			
	Variable	Mean	Std..	Min	Max	Mean	Std	Min	Max
p_c	P_CROP	1.003	0.200	0.749	1.477	1.037	0.200	0.731	1.488
p_a	P_ANIM	1.026	0.039	0.910	1.457	0.971	0.044	0.378	1.072
p_y	P_OUT	1.017	0.102	0.767	1.408	0.999	0.101	0.771	1.357
y_c	X_CROP	80,498	137,764	341	3,555,780	44,965	75,273	739	1,289,640
y_a	X_ANIM	123,552	274,984	40	5,539,070	68,915	129,130	521	2,256,540
y	X_OUT	204,050	339,487	10792	6,063,050	113,880	176,891	2,727	2,529,410
Share on crop production		42.2%	22.7%	0.2%	100.0%	43.3%	21.8%	0.4%	99.1%
w_l	P_LAB	13,966	813	12,010	17,739	14,195	937	12,010	19,140
w_2	P_CRP_I	1.002	0.056	0.927	1.173	1.002	0.061	0.929	1.186
w_3	P_ANI_I	1.003	0.074	0.925	1.083	1.003	0.074	0.925	1.083
w_4	P_OVER	0.988	0.035	0.915	1.082	0.987	0.036	0.916	1.242
p_l	P_LAN	225	41	116	340	227	51	113	374
p_k	P_CAP	0.924	0.521	0.006	4.370	1.093	0.611	0.033	3.607
x_1	X_LAB	2.075	1.148	0.510	16.900	1.916	1.048	0.250	18.420
x_2	X_CRP_I	31,279	50,165	228	1,080,980	15,130	27,013	105	442,185
x_3	X_ANI_I	69,638	183,282	88	3,450,370	33,569	66,487	264	823,026
x_4	X_OVER	21,217	29,872	849	733,522	11,395	17,707	647	316,292
l	X_LAN	48.9	58.3	2.0	699.1	21.2	25.2	0.4.2	253
k	X_CAP	764,458	745,718	28,719	1,0948,300	458,427	529,251	49,035	8,947,220

- Total of 5,480 observations; 3,012 for the North region and 2,468 for the South region

No reliable price information for land and labour are available from Polish statistics. However, the data set contains information on land rents and wages paid for some firms. Farm specific prices were calculated in the following manner. First the available information was regressed on several farm specific indicators.[5] We used this information in a stepwise procedure to find the best fit between prices and regressors. The estimation results were then used to determine the factor prices for each farm.

For output we could resort to regional price information on farm products. We used this information to constructs multilateral consistent Törnquist Theil Indices for crop, animal and total output using the approach developed by Caves et al. (1982). The output volumes were given the relation of data in current prices and the output price indices.

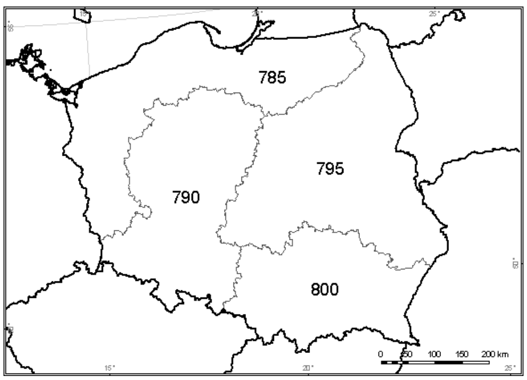
3.2 Selection of Regions

The data set covers all Polish FADN regions, however, due to the disparity across regions, this paper focuses on farms located in 2 regions, Pomorze and Mazury (785) in the northwest and Malopolska and Pogórze (800) in the southeast of Poland. A total number of 1,470 farms were extracted from the data, 763 in Pomorze and Mazury and

[5] These includes dummy variables on specialisation, farm size in European Size Units, location by Wojwodship (e.g. region), altitude of the farm, the existence of environmental limitations, the availability of structural funds and the education level of the farmer.

617 in Malopolska and Pogórze. Figure 2 illustrates the location of farms in each region. These regions were selected because of the pronounced differences in production structures (Table 1). Compared to the Malopolska and Pogórze, the Pomorze and Mazury exhibit higher levels of labor productivity (by 40%) and capital productivity (by 7%). They, however, have lower levels of land productivity (by 23%), crop productivity (by 13%), animal productivity (by 14%) and overhead productivity (by 4%). Moreover, the northwestern region is characterized by comparatively large enterprises, while the Southeast is dominated by rather small farms.

Figure 2: Polish FADN regions



785 Pomorze and Mazury
790 Wielkopolska and Slask
795 Mazowsze and Podlasie
800 Malopolska and Pogórze

Source: http://ec.europa.eu/agriculture/rica/regioncodes_en.cfm?CodeCountry=POL

This structure finds its expression in the amount of production as well as in the intensity of input use. Farms in Pomorze and Mazury operate twice as much land as farms in the Southeast. The other inputs per farm are also considerable higher in the Northwest. However, since labor input is about the same in both regions, agriculture in Malopolska and Pogórze is more labor intensive than in Pomorze and Mazury. The regional diversity in input use results in corresponding differences in the amount of production. However, there is no pronounced regional specialization of production. In both regions, about 40% of total production results from crop production (table 1). Given the diversity of input use among the regions we expect pronounced regional differences in the exploitation of production possibilities (technical efficiency). In addition, we assume that considerable differences regarding allocative efficiencies exist.

Table 2 shows types of farm production specialization varying in each region over the study period. Farms in both regions tend to specialize in raising dairy cattle, other grazing livestock, granivores, a variety of field crops, or mixed farms. Over the study period, mixed farms are a common specialization in these regions accounting for nearly 50% in the Pomorze and Mazury and more than 50% in the Malopolska and Pogórze. The dairy cattle farms are another specialization in the Pomorze and Mazury accounting for 20% followed by the field crop farms, granivroes and grazing livestock farms. In the Malopolska and Pogórze, the field crop farms are another specialization accounting for 20% followed by the dairy cattle farms, granivores and grazing livestock farms. In both regions, the mixed farms tend to decrease over the year while the dairy cattle farms and granivores tend to increase. It has been observed that 243 farms in the Pomorze and Mazury and 210 farms in the Malopolska and Pogórze had switched the specializations over the study period.

Table 2: Farm specialization in each region, 2004-2007 (Percentage share)

	Year							
	2004		2005		2006		2007	
Specialization	Pomorze/ Mazury	Malo-polska/ Pogórze	Po-morze/ Mazury	Malo-polska/ Pogórze	Po-morze/ Mazury	Malo-polska/ Pogórze	Po-morze/ Mazury	Malo-polska/ Pogórze
Field crops	18.5	21.8	17.7	19.4	17.2	17.8	17.0	21.5
Dairy cattle	20.3	8.9	21.1	9.7	21.9	11.0	21.7	12.0
Grazing livestock	2.8	4.9	2.5	5.8	3.2	6.3	5.3	6.8
Granivores	8.8	7.6	10.2	8.3	10.6	8.9	10.9	9.1
Mixed farms	49.6	56.8	48.4	56.8	47.1	56.0	45.1	50.6

4 ECONOMETRIC MODEL

Equations (9) and (10) constitute a system of quasi-fixed and variable factor demands that can be estimated using appropriate econometric approaches. However, before presenting our estimation strategy, a few more ideas regarding the empirical implementation will be presented. Our empirical model distinguished between the two quasi-fixed factors, net investment and land. In order to ease the derivation and the empirical setup we assume that both net investment and land are independent. Under this simplifying assumption, $\nabla_{\mathbf{qp}} J^b$, $\nabla_{\mathbf{qq}} J^b$ and $\nabla_{\mathbf{pp}} J^b$ are diagonal matrices, e. g. the off-diagonal elements $J^b_{kp_l}$, $J^b_{lp_k}$, J^b_{kl} and $J^b_{p_k p_l}$ are each equal to zero. Therefore, the demand equation (9) becomes:

$$\begin{aligned}(11)\qquad & \dot{k}^o(1/r + \boldsymbol{\tau}_q \boldsymbol{\Sigma}_k^{-1}(J^b_{kk}(J^b_{kp_k})^{-1} J^b_{p_k p_k} + J^b_{kp_k} - 1/r) - \boldsymbol{\Sigma}_k^{-1} J^b_{kp_k}) \\ & = r\boldsymbol{\tau}_x \boldsymbol{\Lambda}_n^{-1} \mathbf{w}'(J^b_{\mathbf{w}p_k} - J^b_{k\mathbf{w}}(J^b_{kp_k})^{-1} J^b_{p_k p_k}) \\ & + \boldsymbol{\tau}_q \boldsymbol{\Sigma}_k^{-1}(rJ^b_k(J^b_{kp_k})^{-1} J^b_{p_k p_k} - J^b_{tk}(J^b_{kp_k})^{-1} J^b_{p_k p_k})\end{aligned}$$

$$\begin{aligned}(12)\qquad & \dot{l}^o(1/r + \boldsymbol{\tau}_q \boldsymbol{\Sigma}_l^{-1}(J^b_{ll}(J^b_{lp_l})^{-1} J^b_{p_l p_l} + J^b_{lp_l} - 1/r) - \boldsymbol{\Sigma}_l^{-1} J^b_{lp_l}) \\ & = r\boldsymbol{\tau}_x \boldsymbol{\Lambda}_n^{-1} \mathbf{w}'(J^b_{\mathbf{w}p_l} - J^b_{l\mathbf{w}}(J^b_{lp_l})^{-1} J^b_{p_l p_l}) \\ & + \boldsymbol{\tau}_q \boldsymbol{\Sigma}_l^{-1}(rJ^b_l(J^b_{lp_l})^{-1} J^b_{p_l p_l} - J^b_{tl}(J^b_{lp_l})^{-1} J^b_{p_l p_l})\end{aligned}$$

In addition, the demand for variable inputs (10) is given by:

$$
\begin{aligned}
x^{o} = {} & \boldsymbol{\tau}_{x}\boldsymbol{\Lambda}_{n}^{-1}\begin{bmatrix} \mathbf{w}'(r\nabla_{\mathbf{ww}}J^{b} - r\nabla_{k\mathbf{w}}J^{b}(\nabla_{kp_k}J^{b})^{-1}\nabla_{\mathbf{w}p_k}J^{b} - r\nabla_{l\mathbf{w}}J^{b}(\nabla_{lp_l}J^{b})^{-1}\nabla_{\mathbf{w}p_l}J^{b}) \\ + r\nabla_{\mathbf{w}}J^{b} - \nabla_{t\mathbf{w}}J^{b} + \nabla_{k\mathbf{w}}J^{b}(\nabla_{kp_k}J^{b})^{-1}\nabla_{tp_k}J^{b} + \nabla_{l\mathbf{w}}J^{b}(\nabla_{lp_l}J^{b})^{-1}\nabla_{tp_l}J^{b} \end{bmatrix} \\
& + \boldsymbol{\tau}_{q}\boldsymbol{\Sigma}_{k}^{-1}(rJ_{k}^{b}(J_{kp_k}^{b})^{-1}J_{\mathbf{w}p_k}^{b} - rJ_{kt}^{b}(J_{kp_k}^{b})^{-1}J_{\mathbf{w}p_k}^{b}) \\
(13) \qquad & + \boldsymbol{\tau}_{q}\boldsymbol{\Sigma}_{l}^{-1}(rJ_{l}^{b}(J_{lp_l}^{b})^{-1}J_{\mathbf{w}p_l}^{b} - J_{lt}^{b}(J_{lp_l}^{b})^{-1}J_{\mathbf{w}p_l}^{b}) + J_{t\mathbf{w}}^{b} \\
& - \dot{k}^{o}\begin{bmatrix} \boldsymbol{\tau}_{x}\boldsymbol{\Lambda}_{n}^{-1}(J_{k\mathbf{w}}^{b} - J_{k\mathbf{w}}^{b}(J_{kp_k}^{b})^{-1}(J_{kp_k}^{b} - 1/r) + \boldsymbol{\tau}_{q}^{-1}J_{k\mathbf{w}}^{b}) \\ + \boldsymbol{\tau}_{q}\boldsymbol{\Sigma}_{k}^{-1}(J_{kk}^{b}(J_{kp_k}^{b})^{-1}J_{\mathbf{w}p_k}^{b}) \end{bmatrix} \\
& - \dot{l}^{o}\begin{bmatrix} \boldsymbol{\tau}_{x}\boldsymbol{\Lambda}_{n}^{-1}(J_{l\mathbf{w}}^{b} - J_{l\mathbf{w}}^{b}(J_{lp_l}^{b})^{-1}(J_{lp_l}^{b} - 1/r) + \boldsymbol{\tau}_{q}^{-1}J_{l\mathbf{w}}^{b}) \\ + \boldsymbol{\tau}_{q}\boldsymbol{\Sigma}_{l}^{-1}(J_{ll}^{b}(J_{lp_l}^{b})^{-1}J_{\mathbf{w}p_l}^{b}) \end{bmatrix}
\end{aligned}
$$

Equations (11) to (13) form the system equation of the dynamic efficiency model in the presence of inefficiencies. To estimate the dynamic efficiency model, one must specify a functional form to the behavioral value function. In addition, all inefficiencies must be specified to implement the estimation of all coefficient parameters of the behavioral value function. A quadratic behavioral value function assuming symmetry of the parameters can be expressed as[6]

(14) $$J^{b}(\cdot) = \beta_0 + \mathbf{w}'\boldsymbol{\beta} + \frac{1}{2}\mathbf{w}'\mathbf{B}\mathbf{w},$$

where $\mathbf{w}' = (\mathbf{w}^{b}\ p_k\ p_l\ k\ l\ y\ t)$; $\boldsymbol{\beta}$ and $\mathbf{B}$ are a vector and a symmetric matrix of parameters, respectively.

The system (11) to (13) is recursive with the endogenous variables of net investment and land, serving as an explanatory variable in the variable input demand equations. Because of this structure, estimation can be accomplished in two stages. In the first stage, the optimized actual investment demands in capital and land are estimated by using the maximum likelihood estimation (MLE). In the second stage, since the optimized actual variable input demand equations are overidentified, the system of variable input demand equations is estimated by using a generalized method of moments (GMM) estimation giving all parameter values that were obtained in the first stage. The consistency of the system GMM estimator relies upon the assumption of no serial correlation in the idiosyncratic error terms. Following the Newey and West (1994) procedure, a lag of two periods (one period) of autocorrelation terms is used to compute the covariance matrix of the orthogonality conditions for the GMM estimation in the northwest (southwest) model. Another essential assumption for the consistency of the system GMM estimator crucially depends on the assumption of exogeneity of the instruments. The validity of the instrument variables is tested by performing the Hansen's (1982) J-test of overidentifying restrictions. Under the null hypothesis of orthgonality of the instruments, the test statistic is asympototically distributed as chi-square with as many degrees of freedom as

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[6] The behavioral value function in equation (25) must satisfy the following regularity conditions. $J^{b}(\cdot)$ is nonincreasing in (k, l); nondecreasing in $(\mathbf{w}^{b}, p_k, p_l, y)$; convex in (k, l) ; concave in $(\mathbf{w}^{b}, p_k, p_l)$ and linearly homogenous in $(\mathbf{w}^{b}, p_k, p_l)$.

overidentifying restrictions. The null hypothesis fails to reject implying that the additional instrumental variables are valid, given a subset of the instrument variables in valid and exactly identifies the coefficient.

5 EMPIRICAL RESULTS

The dynamic efficiency model defined in section 4 can be viewed as the perfectly inefficient model. When all inefficiency parameters in dynamic and variable factors are equal to one, the model is reduced to the dynamic intertemporal cost minimizing firm as presented in Epstein and Denny (1983). In this section, the analysis begins by estimating two models; (a) a full model is based on the assumption that firms are perfectly inefficient in dynamic and variable factor demands. This model allows capturing all inefficient parameters in the dynamic efficiency model. Following Cornwell, Schmidt and Sickles (1990), all allocative and technical efficiencies of dynamic and variable factors are specified to vary across production specialization[7] and through time, and (b) a restricted model is based on the assumption that firms are perfectly efficient in dynamic and variable factor demands. The restricted model is estimated by setting all inefficient parameters of the full model equal to one.

A hypothesis test regarding the presence of the perfect efficiency in production is conducted using the likelihood ratio (LR) test. The LR test is approximately chi-square distributed with the degrees of freedom equal to the number of restrictions. Table 3 presents the estimated coefficients and standard errors for the structural parameters of the dynamic efficiency model in both models.[8] The estimation results from both models are similar and provide the same sign for all parameter estimates except for the estimated parameters, β_{w3w3}, β_{w2w4}, β_{w2l}, β_{w4t} and β_{lt}. Most coefficient estimates particularly the first-order coefficient are significant at the 95% confidence interval using a two-tailed test except for the estimated parameters β_{w2} and β_{w3} in the restricted model. The LR test of the null hypothesis that firms are perfectly efficient in dynamic and variable factor demands is rejected at the 95% confidence level, implying the firms in this study operated inefficiently in the production.

[7] Types of production specialization are classified into 5 categories: field crops, dairy cattle, grazing livestock, granivores and mixed farms as described in section 3.

[8] The full set of estimated coefficients including the dummy variables used to calculate all inefficiency parameters of dynamic and variable inputs are not reported.

Table 3. Estimated parameters of the dynamic efficiency for the full and restricted models

Parameter[a]	Full Model		Restricted Model		Parameter[a]	Full Model		Restricted Model	
	Estimates	Std Err	Estimate	Std Err		Estimates	Std Err	Estimate	Std Err
β_o	-0.152***	0.022	-0.614***	0.082	β_{w2t}	0.748	1.116	1.663***	0.475
β_{w2}	0.320**	0.212	0.248	0.209	β_{w3w4}	1.013*	0.599	4.772	6.817
β_{w3}	0.289***	0.025	0.197*	0.142	β_{w3pk}	-1.936	1.826	-0.989	1.337
β_{w4}	0.086***	0.021	0.187***	0.023	β_{w3pl}	7.213	4.624	0.683	2.846
β_{pk}	0.209***	0.002	0.381***	0.002	β_{w3k}	-8.368***	1.769	-4.940***	1.214
β_{pl}	0.011***	0.004	0.081***	0.014	β_{w3l}	4.776***	1.502	1.503	1.009
β_k	-0.800***	0.002	-0.180***	0.002	β_{w3y}	1.072	1.702	1.755	1.125
β_l	-0.027***	0.001	-0.267***	0.015	β_{w3t}	-1.151	3.835	-2.399	3.528
β_y	0.128***	0.002	0.430***	0.017	β_{w4pk}	-0.961***	0.185	-1.188***	0.171
β_t	0.015***	0.005	0.009**	0.003	β_{w4pl}	-0.888*	0.528	-1.094**	0.534
β_{w2w2}	23.002***	3.296	13.905***	3.236	β_{w4k}	-1.347***	0.218	-1.312***	0.220
β_{w3w3}	1.280	14.762	-7.647	10.102	β_{w4l}	0.139	0.201	0.091	0.202
β_{w4w4}	0.764***	0.185	0.728***	0.186	β_{w4y}	0.709***	0.223	0.642***	0.224
β_{pkpk}	0.153***	0.004	0.152***	0.003	β_{w4t}	-0.346	0.262	0.086	0.219
β_{plpl}	0.047	0.032	0.040	0.032	β_{pkk}	83.897***	2.011	43.628***	0.313
β_{kk}	-0.131***	0.005	-0.129***	0.005	β_{pky}	-9.681***	0.319	-9.714***	0.292
β_{ll}	-0.021***	0.003	-0.022***	0.003	β_{pkt}	0.335	0.493	0.514	0.443
β_{yy}	0.120***	0.004	0.120***	0.004	β_{pll}	36.798***	7.115	20.036***	0.780
β_{tt}	0.018	0.040	0.055	0.033	β_{ply}	-1.499*	0.866	-2.050**	0.858
β_{w2w3}	5.757**	2.864	2.883	1.780	β_{plt}	1.895*	1.149	0.997	0.932
β_{w2w4}	-3.059	2.615	3.361**	1.449	β_{ky}	-9.524***	0.379	-9.475***	0.379
β_{w2pk}	0.056	0.403	0.464**	0.236	β_{kt}	0.642	0.490	1.322***	0.402
β_{w2pl}	1.993*	1.107	0.480	0.539	β_{ly}	-1.791***	0.249	-1.908***	0.247
β_{w2k}	0.131	0.436	0.789***	0.234	β_{lt}	0.605	0.406	-0.020	0.331
β_{w2l}	0.187	0.375	-0.704***	0.200	β_{yt}	-0.852*	0.453	-0.733**	0.368
β_{w2y}	-0.294	0.427	-0.169	0.222					

Note: Full model refers to the dynamic model in the presence of the perfect inefficiency while the restricted model refers to the dynamic model with assuming all inefficiency parameters equal to one.

[a] Price of labor (w_1) was normalized. Subscripts on β_{wn} coefficients refer to price of nth inputs: 2 = crop; 3 = livestock; 4 = overhead; 5 = capital; 6 = land. Under the assumption that the quasi-fixed factor, k and l, are independent, the estimated parameters, β_{kl}, β_{kpl}, β_{lpk} and β_{pkpl} are assumed to be zero.

* significant at 10%; ** significant at 5%; *** significant at 1%. The regressions that also include dummy variables used to calculate all efficiency parameters of dynamic and variable inputs are not reported.

Table 4. Estimated parameters of the dynamic efficiency for the North and South models

Parameter[a]	Northwest Model (Pomorze and Mazury)		Southwest Model (Malopolska and Pogórze)		Parameter[a]	Northwest Model (Pomorze and Mazury)		Southwest Model (Malopolska and Pogórze)	
	Estimates	Std Err	Estimate	Std Err		Estimates	Std Err	Estimate	Std Err
β_{o}	-0.202***	0.034	-0.103***	0.032	β_{w2t}	0.099	0.168	0.026	0.174
β_{w2}	0.154	0.329	0.243	0.319	β_{w3w4}	2.891*	1.580	0.600	1.714
β_{w3}	0.521***	0.213	0.410***	0.224	β_{w3pk}	-0.027	0.228	-0.789***	0.274
β_{w4}	0.069***	0.017	0.085***	0.017	β_{w3pl}	0.331	0.703	1.063	0.738
β_{pk}	0.179***	0.003	0.201***	0.003	β_{w3k}	-0.597***	0.261	1.137***	0.268
β_{pl}	0.103	0.224	0.016**	0.007	β_{w3l}	0.710***	0.251	-0.066	0.213
β_{k}	-0.579***	0.002	-0.789***	0.003	β_{w3y}	0.120**	0.024	0.673***	0.241
β_{l}	-0.125***	0.011	-0.326***	0.028	β_{w3t}	-0.069	0.572	-0.099	0.584
β_{y}	0.136***	0.003	0.137***	0.002	β_{w4pk}	-0.087***	0.026	-0.149***	0.031
β_{t}	0.065	0.726	0.011	0.008	β_{w4pl}	-0.153**	0.076	-0.110	0.093
β_{w2w2}	31.428***	5.152	10.493**	5.143	β_{w4k}	-0.146***	0.032	-0.112***	0.036
β_{w3w3}	4.591	4.136	5.259	7.622	β_{w4l}	-0.013	0.030	-0.008	0.031
β_{w4w4}	0.808***	0.275	1.284***	0.301	β_{w4y}	0.093***	0.033	0.046	0.036
β_{pkpk}	0.163***	0.004	0.170***	0.005	β_{w4t}	-0.056	0.039	-0.011	0.043
β_{plpl}	0.080*	0.047	0.033	0.053	β_{pkk}	97.651***	2.256	75.465***	2.137
β_{kk}	-0.137***	0.007	-0.159***	0.006	β_{pky}	-0.114***	0.004	-0.128***	0.004
β_{ll}	-0.039***	0.005	-0.020***	0.004	β_{pkt}	0.001	0.007	-0.002	0.008
β_{yy}	0.138***	0.006	0.157***	0.006	β_{pll}	71.542**	17.382	61.018**	13.256
β_{tt}	0.052	0.062	-0.030	0.060	β_{ply}	-0.031**	0.013	-0.038***	0.014
β_{w2w3}	0.444*	0.143	9.059**	4.398	β_{plt}	0.034**	0.017	-0.013	0.019
β_{w2w4}	-0.682*	0.385	0.477	0.422	β_{ky}	-0.098***	0.005	-0.123***	0.005
β_{w2pk}	0.074	0.058	-0.113*	0.063	β_{kt}	0.009	0.007	-0.010	0.008
β_{w2pl}	0.269	0.165	0.098	0.177	β_{ly}	-0.030***	0.004	-0.025***	0.003
β_{w2k}	0.068	0.066	-0.134*	0.069	β_{lt}	0.021***	0.006	-0.009	0.006
β_{w2l}	0.195***	0.062	0.189***	0.053	β_{yt}	-0.021***	0.006	0.021***	0.007
β_{w2y}	-0.172***	0.064	0.234***	0.061					

Note: The northwest model refers to the full dynamic efficiency model using the data in the Pomorze and Mazury while the southwest model refers to the full dynamic efficiency model using the data in the Malopolska and Pogórze.

[a] Price of labor (w_1) was normalized. Subscripts on β_{wn} coefficients refer to price of nth inputs: 2 = crop; 3 = livestock; 4 = overhead; 5 = capital; 6 = land. Under the assumption that the quasi-fixed factor, k and l, are independent, the estimated parameters, β_{kl}, β_{kpl}, β_{lpk} and β_{pkpl} are assumed to be zero

* significant at 10%; ** significant at 5%; *** significant at 1%. The regressions that also include dummy variables used to calculate all efficiency parameters of dynamic and variable inputs are not reported.

Furthermore, we conduct another hypothesis test to investigate whether farms operated in different regions have identical production technologies. Therefore, the estimation of the full model using the data of all farms (table 3) is compared with the estimates using the data in each region separately. The estimated coefficients for each model using the data in the northwest (Pomorze and Mazury) and southwest (Malopolska and Pogórze) regions are presented in table 4. The estimation results from each model and all first-order coefficients have the similar sign except for the estimated parameters, β_{w2w4}, β_{w2pk}, β_{w2k}, β_{w2y}, β_{w3k}, β_{w3l}, β_{pkt}, β_{plt}, β_{kt}, β_{lt} and β_{yt}. Most coefficient estimates particularly the first-order coefficient are significant at the 99% confidence interval except for the estimated parameters β_{w2} and β_{pl}. The LR test of the null hypothesis that the group-specific technologies are identical is rejected at the 95% confidence level, implying the group-specific technologies are not the same. Therefore, the following empirical results will be discussed using the estimates obtained from the northwest and southwest models. Consequently, the parameter estimates in table 4 are used to calculate the inefficiency components reported in Table 5.

Table 5 presents average farm technical and allocative efficiencies of dynamic and variable factors by regions and all farms during 2004-2007. An estimate of the technical efficiency of dynamic and variable factors is bounded between zero and unity. The value of technical efficiency scores equal to one implies that farm can minimize both dynamic and variable factors to produce a given level of output. The estimated technical efficiencies of net investment in quasi-fixed factors range from 0.480 to 0.631 with an average of 0.536 whereas those of variable inputs range from 0.505 to 0.660 with an average of 0.576. These findings imply that the Polish farms in this study, on average, could have been reduced the dynamic and variable factors by 46% and 42%, respectively and still produce the same level of output. The average value of the northwest farm technical efficiency is 56.7% (for dynamic factors) and 58.5% (for variable inputs). Northwest farms achieved higher technical efficiencies than southeast farms (approximately 12% higher by dynamic factors and 3.5% higher by variable inputs).

In general, allocative efficiency scores are bounded between zero and unity. The value of one implies that farm can use the dynamic factors in optimal proportions given their respective prices and the production technology. Average farm allocative efficiencies of net investments in capital and land are 0.529 and 0.753, respectively. These results suggest that Polish farms could potentially reduce the net investment in capital and land demands by 47% and 25% to their cost-minimizing level of factors. The average value of the northwest farm allocative efficiencies of net investments in capital and land is 0.625 and 0.802, respectively. The findings indicate that the northwest farms have average farm allocative efficiency of dynamic factors both capital land higher than the southeast farms.

Following the shadow price approach, the price of labor input is arbitrarily specified as the numeraire. The value of allocative efficiency of variable input demands represents price distortions of the nth variable input relative to the labor input. An estimate of allocative efficiency of variable input demands less (greater) than one means that the ratio of the shadow price of the nth variable input relative to the labor input is considerably less (greater) that the corresponding ratio of actual prices. This implies that the firms are overusing (underusing) the nth variable input relative to the labor input. Table 5 also reports that average farm allocative efficiencies of crop, livestock and overhead input demands are 0.810, 0.629 and 1.848, respectively. These results imply that Polish farms are over-utilizing crops and livestock relative to the labor input while they are under-utilizing overhead relative to the labor input. The average value of the northwest farm allocative efficiencies of crop, livestock and overhead input demands is 0.739, 0.587 and 1.328, respectively. Compared to the southeast farms, the northwest farms show a higher degree of over-utilization in crops and livestock relative to labor while they indicate a lower degree of under-utilization in overhead relative to labor.

Table 5. Average farm technical and allocative efficiency scores of dynamic and variable factor demands, 2004-2007

Efficiency scores*	Northwest region (Pomorze and Mazury)	Southwest region (Malopolska and Pogórze)	All regions
TE(q)	0.567	0.497	0.536
TE(x)	0.585	0.565	0.576
AE(k)	0.625	0.414	0.529
AE(l)	0.802	0.695	0.753
AE(w_2)	0.739	0.896	0.810
AE(w_3)	0.587	0.679	0.629
AE(w_4)	1.328	2.474	1.848

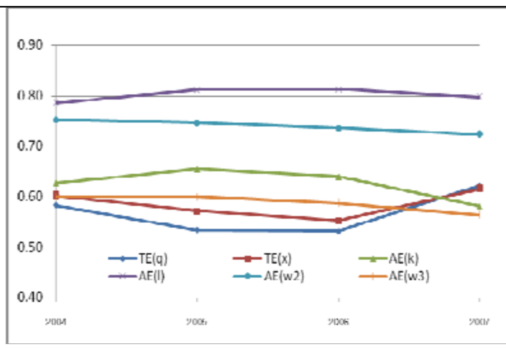
* TE(q) = technical efficiency of dynamic factors; TE(x) = technical efficiency of variable inputs; AE(k) = allocative efficiency of net investment in capital; AE(l) = allocative efficiency of net investment in land; AE(w_2) = allocative efficiency of crop input; AE(w_3) = allocative efficiency of livestock input; AE(w_4) = allocative efficiency of overhead input.

Table 6 presents average annual technical and allocative efficiency scores of dynamic and variable factor demands for each region over the period 2004-2007. The findings in table 6 allow examining the performance of Polish farm by region after the accession to the EU. The northwest farms have average annual technical efficiency of dynamic and variable factors higher than the southwest farms except the technical efficiency of variable inputs in 2005. After the EU accession, technical efficiency scores in both regions are decreasing over time and they began to rise three year after accession. Average annual allocative efficiency of dynamic factors for both capital and land in the northwest farms is higher than the southeast farms in every year over the study period. This result suggests that the northwest farms could adjust their dynamic factors to the cost-minimizing level of factors easier than the southeast farms. After the EU accession, allocative efficiency scores of the dynamic factors of the South farms are increasing over time. Allocative efficiency score of the net investment in land of the northwest farm is also increasing over time where allocative efficiency score of the net investment in capital varies considerably over the period. The estimates of allocative efficiency of variable inputs over the period indicate that after the accession farms in both regions tend to increase over-utilization in crops and livestock relative to labor. On the other hand, the findings indicate that farms in both regions tend to decrease under-utilization in overhead relative to labor after the accession. Figure 3 illustrates plots of technical and allocative efficiency scores of dynamic and variable factor demands by region over the period 2004 to 2007. The plots show that after the accession change in efficiency scores of the southeast farms is relatively more stable than the northwest farms except technical efficiency of variable inputs (Section A and B) and allocative efficiency of overhead input (Section C).

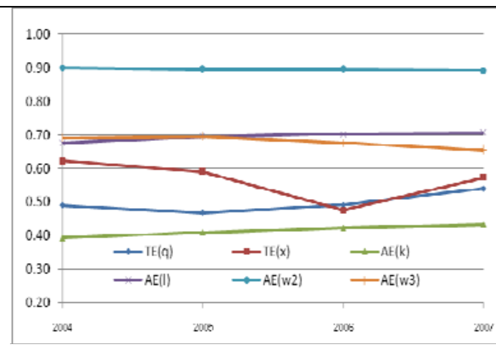
Table 6. Average annual technical and allocative efficiency scores of dynamic and variable factor demands for each region, 2004-2007

Efficiency scores	Northwest region (Pomorze and Mazury)				Southwest region (Malopolska and Pogórze)			
	2004	2005	2006	2007	2004	2005	2006	2007
TE(q)	0.582	0.534	0.532	0.622	0.491	0.468	0.491	0.540
TE(x)	0.601	0.571	0.552	0.615	0.623	0.590	0.475	0.573
AE(k)	0.627	0.654	0.640	0.581	0.393	0.409	0.422	0.433
AE(l)	0.785	0.811	0.813	0.797	0.676	0.695	0.703	0.706
AE(w_2)	0.752	0.746	0.736	0.723	0.900	0.895	0.895	0.892
AE(w_3)	0.600	0.599	0.587	0.563	0.691	0.695	0.675	0.655
AE(w_4)	1.398	1.322	1.292	1.300	3.156	2.513	2.074	2.151

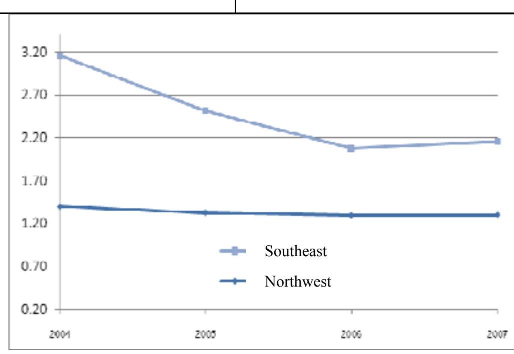
Figure 3. Plot of technical and allocative efficiency scores of dynamic and variable factor demands by region over the period 2004 to 2007.



A) Northwest region



B) Southwest region



C) Allocative efficiency of overhead input

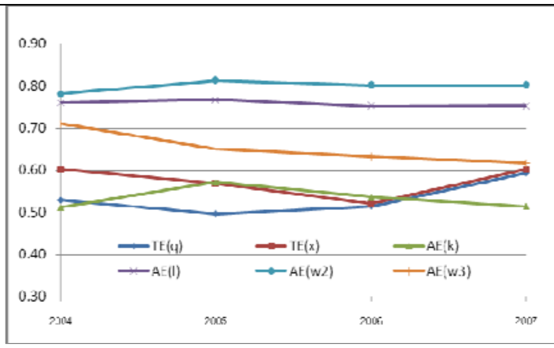
Turning to the role of adjustment costs in Polish farm, the partial adjustment coefficient of quasi-fixed factors is defined as $M_u = (r - (\beta_{qp_q})^{-1})$ where $q = k, l$ (Epstein and Denny 1983). Assuming a discount rate of 5%, the findings (table 4) show that the estimated adjustment rate of the quasi-fixed factor to its long-run equilibrium level is relatively low in both regions. In the northwest farms, the estimated adjustment rate is 4.0% per annum by capital and 3.6% per annum by land, or it may take capital approximately 25 years and labor approximately 28 years to adjust fully to its long-run equilibrium level. The southeast farms, however, takes much longer time to adjust both capital and land to their long-run equilibrium. The results indicate that in the southeast farms the estimated adjustment rate of capital and land is 3.7% and 3.4% per annum, respectively, or it may take capital and labor approximately 27 and 30 years respectively to adjust fully to their optimal level. These results imply that the sluggish adjustment processes exist in Polish agriculture. The findings are consistent with former analysis of farm size development in Poland (Goraj and Hockmann 2010).

Table 7. Average farm technical and allocative efficiency scores of dynamic and variable factor demands by farm production specialization, 2004-2007

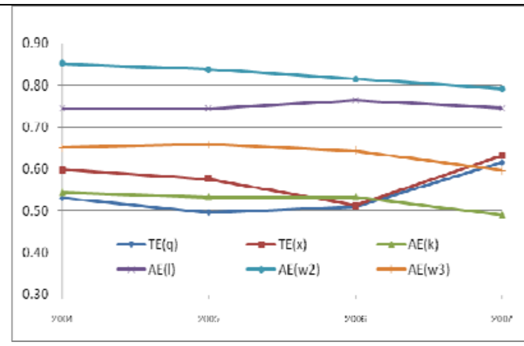
Efficiency scores	Field crops	Dairy cattle	Grazing livestock	Granivores	Mixed farms
TE(q)	0.540	0.545	0.565	0.585	0.527
TE(x)	0.577	0.586	0.614	0.628	0.568
AE(k)	0.592	0.589	0.611	0.538	0.504
AE(l)	0.794	0.778	0.756	0.757	0.741
AE(w2)	0.754	0.788	0.771	0.759	0.831
AE(w3)	0.641	0.615	0.638	0.553	0.636
AE(w4)	2.132	1.535	1.602	1.596	1.881

We further examine the performance of Polish farms associated with farm production specialization. Table 7 reports average farm technical and allocative efficiency scores of dynamic and variable factor demands by types of farm production specializations during 2004 to 2007. The estimated value of the technical efficiency by farm production specialization does not differ significantly between dynamic and variable factors ranging from 0.527 to 0.628. Granivores exhibits the highest average technical efficiency score, followed by Grazing livestock farms, dairy cattle, Field crop and mixed farms, respectively. Average allocative efficiency of net investment in capital demand is 0.592 for field crops, 0.589 for dairy cattle, 0.611 for grazing livestock, 0.538 for granivores and 0.504 for mixed farms. Grazing livestock farms exhibited the highest allocative efficiency of net investment in capital demand. On the other hand, average allocative efficiency of net investment in land demand by production specialization ranges from 0.741 to 0.794. Field crop farms have the highest average allocative efficiency of net investment in land demand, followed by diary cattle, granivores, grazing livestock and mixed farms. Turning to the allocative efficiency scores of variable inputs, the estimates indicate that field crop farms have the highest degree of over-utilization in crops relative to labor, followed by granivores, grazing livestock, dairy cattle and mixed farms. The average allocative efficiency of livestock demand ranges from 0.553 to 0.641. Granivores exhibited the highest degree of over-utilization in livestock relative to labor, followed by dairy cattle, mixed farms, grazing livestock and field crops. Average allocative efficiency of overhead demand amounts to 2.132 for field crops, 1.535 for dairy cattle, 1.602 for grazing livestock, 1.596 for granivores and 1.881 for mixed farms. The findings also indicate that field crop farms have the highest degree of under-utilization in overhead relative to labor, followed by mixed farms, grazing livestock, granivores and dairy cattle. Figure 4 illustrates plots of technical and allocative efficiency scores of dynamic and variable factor demands by types of farm production specializations over the period 2004-2007. Plots of Grazing livestock and Granivores (Section C and D in figure 4) show that efficiency scores vary considerably over time while change in efficiency scores by mixed farms (Section E) is relatively stable over the period after the accession. The findings also show that change in allocative efficiency of overhead input by each type of production specialization (Section F) is decreasing over the period.

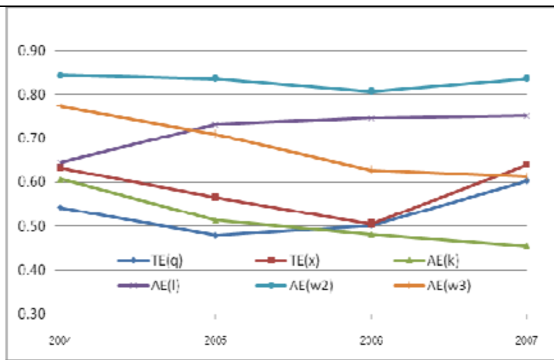
Figure 4. Plot of technical and allocative efficiency scores of dynamic and variable factor demands by farm production specialization over the period 2004-2007



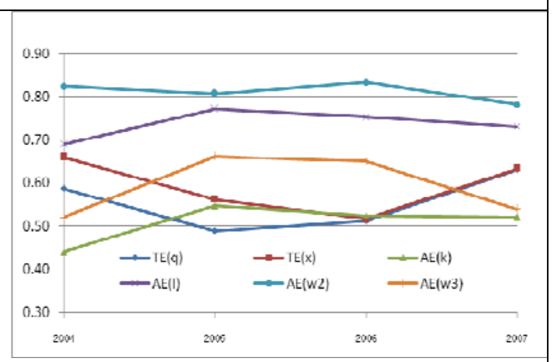
A) Field crops



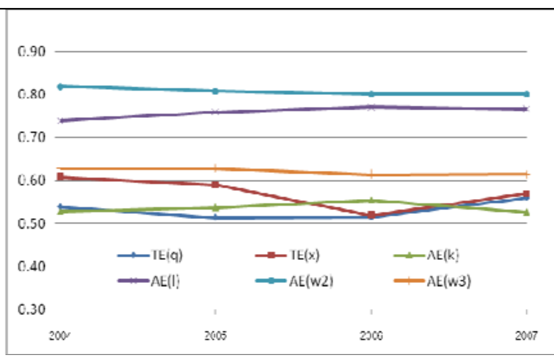
B) Dairy cattle



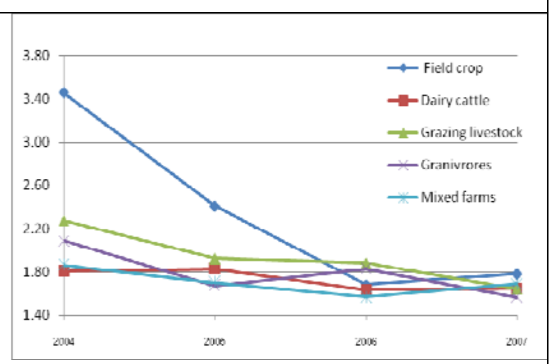
C) Grazing livestock



D) Granivores



E) Mixed farms



F) Allocative efficiency of overhead input

Table 8 reports average farm technical and allocative efficiency scores of dynamic and variable factor demands by types of farm production specialization for each region. Compared to other specialization in the northwest, field crop farms have the highest allocative efficiency of net investment in land but the lowest technical efficiency of dynamic and variable factors. They have the highest degree of over-utilization in crop relative to labor. Grazing livestock farms have the have the highest allocative efficiency of net investment in capital but the lowest allocative efficiency of net investment in land. They have the highest degree of under-utilization in overhead relative to labor. Granivore farms exhibit the highest technical efficiency of dynamic and variable factors but the lowest allocative efficiency of net investment in capital. They also have highest degree of over-utilization in livestock relative to labor. Turning to the southeast farms, mixed farms exhibit the highest technical efficiency of dynamic factors and the highest allocative efficiency of net investment in capital and land. In addition, they also exhibit the highest degree of over-utilization in crop and livestock relative to labor while field crop farms have the highest degree of under-utilization in overhead relative to labor.

Table 8. Average farm technical and allocative efficiency scores of dynamic and variable factor demands by production specialization for each region, 2004-2007

Efficiency scores	Northwest region (Pomorze and Mazury)				
	Field crops	Dairy cattle	Grazing livestock	Granivores	Mixed farms
TE(q)	0.555	0.563	0.568	0.616	0.564
TE(x)	0.572	0.583	0.603	0.636	0.580
AE(k)	0.633	0.636	0.649	0.576	0.626
AE(l)	0.817	0.803	0.778	0.781	0.801
AE(w2)	0.721	0.761	0.755	0.723	0.741
AE(w3)	0.624	0.602	0.623	0.512	0.581
AE(w4)	1.306	1.344	1.405	1.260	1.339
	Southwest region (Malopolska and Pogórze)				
TE(q)	0.470	0.459	0.447	0.443	0.508
TE(x)	0.606	0.578	0.563	0.548	0.540
AE(k)	0.392	0.401	0.394	0.413	0.423
AE(l)	0.684	0.684	0.685	0.700	0.703
AE(w2)	0.908	0.908	0.905	0.922	0.891
AE(w3)	0.723	0.735	0.766	0.714	0.667
AE(w4)	3.103	2.328	2.399	2.192	2.125

6 Conclusions

Over the past two decades, Polish agriculture has undergone profound transformations. This paper deals with the astonishing observation that farm restructuring in Poland is rather sluggish and there is no indication that this will change in the next few years. Contrarily, farm size appears to be rather small, even the agricultural sectors is facing significant internal and external threats like increasing competition in agriculture with other EU countries or increasing the demand for labour from other sectors of the overall economy.

This paper analyses this phenomenon by developing and estimating a dynamic frontier model using the shadow cost approach. The dynamic cost efficiency model allows considering the impact of allocative and technical efficiency, as well as adjustment costs resulting from the change of quasi-fixed input use. The model presented in this paper extends the theoretical literature insofar as not only one but multiple quasi-fixed factors are considered. In this paper, the model is analysed using two quasi-fixed inputs (i.e. land and capital). The data set used for estimation was provided by the Polish FADN agency. It includes detailed information on production and input use. However, the data has to be supplemented by information on product and factors prices. These were provided by national statistics and EUROSTAT. We estimated the dynamic cost efficiency model for two rather distinct FADN regions (i.e. Northwest and Southeast). The first is characterized by, for the Polish situation, larger farms, while in the Southeast smaller farms are dominated.

The shadow cost approach does not given information for individual firms, however, it allows a detailed information of average technical and allocative efficiencies of the variable and quasi-fixed inputs. The results show that adjustment costs are a relevant phenomenon in Polish agriculture. Moreover, they have confirmed the observation already made from the data that adjustment processes are very sluggish. It takes up to 30 years until Polish farms moved to the optimal level of capital and land input. Furthermore, the estimates provide that technical efficiency is a relevant phenomenon in both regions for all inputs. Moreover, the efficiency scores for both variable and quasi-fixed inputs were rather similar, with slightly higher figures in the Northwest. In general, both inputs could possibly be reduced by about 50% while still producing the same level of output. Moreover, there is neither significant indication that technical efficiency varies over time nor largely differs among farm specialisations. The last two conclusions also hold for allocative efficiency. However, allocative efficiencies for land and capital are higher in the Northwest than in the Southeast, implying that those farms replying more intensively than the smaller farms in the Southeast. Furthermore, the estimates provide that labour is overused in relation to overheads, but underused in relation of crop and animal inputs. This holds for both regions, however, overuse is more pronounced in the Northwest, while overuse is prominent in the Southeast.

Acknowledgment

The authors gratefully acknowledge financial support by the Thailand Research Fund (TRF), the Commission on Higher Education (CHE), Ministry of Education (Thailand) and the Leibniz Institute of Agricultural Development in Central and Eastern Europe (IAMO). Usual disclaimer applies.

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