Paper prepared for the joint 131st EAAE
and 21th Agrarian Perspective Seminar
"INNOVATION FOR AGRICULTURAL COMPETITIVENESS AND SUSTAINABILITY OF RURAL AREAS"
Prague, September 18-19, 2012

AGRARIAN PERSPECTIVES XXI.

STRUCTURAL CHANGE AND TECHNICAL CHANGE IN POLISH AGRICULTURE: AN ADJUSTMENT COST APPROACH WITH TECHNICAL AND ALLOCATIVE EFFICIENCY

Supawat Rungsuriyawiboon* and Heinrich Hockmann**

Faculty of Economics
Thammasat University, Bangkok 10200, Thailand
Tel +66-2-696-6140
Fax +66-2-224-9428
Email: supawat@econ.tu.ac.th

Leibniz Institute of Agricultural Development in Central and Eastern Europe (IAMO)
Theodor-Lieser-Str.2, D-06120 Halle (Saale)
Tel +49-345-2928-225
Fax +49-345-2928-299
Email: hockmann@iamo.de

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

The main purpose of the paper is to understand the influences of technical change on Polish Agriculture after the accession to the EU in 2004. EU membership offered several opportunities for Polish farmers. First the benefited stronger from monetary transfers provided by EU agricultural market and rural policies. This released probably existing credit constraints und increased investment possibilities of farmers. Furthermore, more intense integration into the EU market fostered competition with other EU members on the domestic as well the internal market. In turn, a higher competitive threat requires a restructuring of production and factor inputs. Moreover, since 2000 Polish economy experienced significant economic growth leading to higher pull factors regarding structural change. In sum, all these developments imply structural adjustment process including investment and changes in the production program to meet the requirements set by the changing economic and institutional environment. Moreover, it can expected that these restructuring processes will be accompanied by significant technical change, since technical improvement are usually implemented in new inputs, especially investment in new machinery and other equipment which in turn also require the use of appropriate and improved material inputs.

However, structural adjustment requires significant modifications of the production programs. This process usually occurs over several production periods. This implies that the estimation of a comparative static production frontier is inappropriate, instead, the representation of the technology has to take account of multiperiod decisions making processes. This feature is explicitly considered in the dynamic duality model of intertemporal decision making (Epstein and Denny 1983). The paper extends the adjustment costs model with allocative and technical efficiency 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 (labour, 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 behaviour. 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 behavioural value function of the dynamic programming equation (DPE) for a firm's intertemporal cost minimization behaviour. 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 behaviour can be addressed by characterizing firm investment behaviour 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 behaviour 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 behaviour 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 behaviour can be expressed as

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

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: The dynamic intertemporal cost model in the presence of the inefficiency

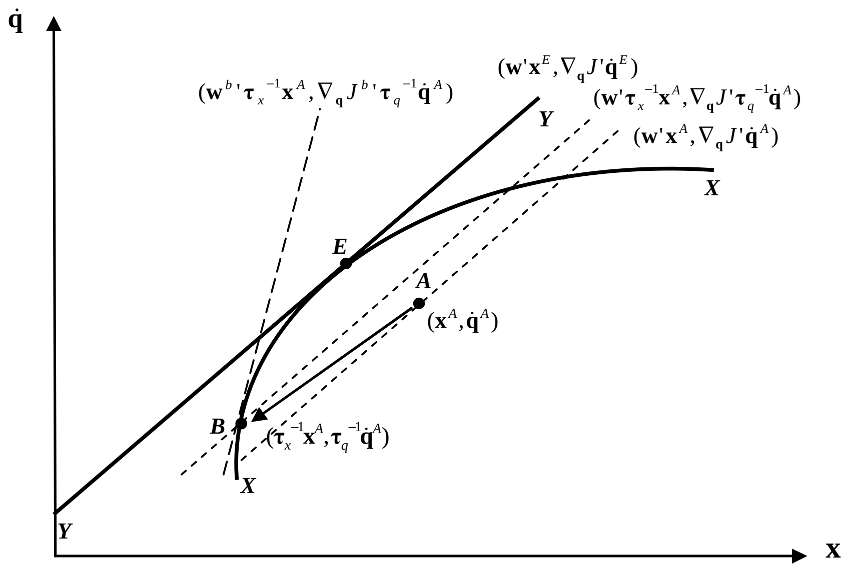

Figure 1 shows the bundle of variable and dynamic factors $(\mathbf{x},\dot{\mathbf{q}})$. The curve XX represents the isoquant. All curves to the southeast of XX represent higher output levels. Since $\nabla_{\mathbf{x}}F > 0$ and $\nabla_{\dot{\mathbf{q}}}F < 0$, it is downward sloping, moreover, $\nabla_{\mathbf{xx}}F < 0$ and $\nabla_{\dot{\mathbf{q}}\dot{\mathbf{q}}}F < 0$ implies that the function is concave. 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 $\nabla_{\mathbf{x}}\dot{\mathbf{q}} = -(\mathbf{w}/\nabla_{\mathbf{q}}J) = -(\nabla_{\mathbf{x}}F/\nabla_{\dot{\mathbf{q}}}F)$;; $\nabla_{\mathbf{q}}J < 0$.

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 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 behaviour.

2.2. Derivation of Dynamic Efficiency Model

In the presence of inefficiency, the dynamic efficiency model with intertemporal cost minimizing firm behaviour 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 (behavioural) value functions of the DPE for the firms' intertemporal cost minimization behaviour. The behavioural 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 behavioural and actual value function.

Let $\mathbf{x}^b$ and $\dot{\mathbf{q}}^b$ denote a nonnegative vector of behavioural variable inputs and behavioural 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 behavioural variable input price and behavioural 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 $\mathbf{w}^b=\boldsymbol{\Lambda}_n\mathbf{w}$ $(n=1,...,N)$ 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 behavioural input prices and quantity, the DPE for the firms' intertemporal cost minimization behaviour 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 behavioural Lagrangian multiplier defined as the short-run, instantaneous marginal cost; $\nabla_t J^b$ is the shift of the behavioural value function.

Differentiating (2) with respect to $\mathbf{p}$ and $\mathbf{w}^b$ yields the behavioural 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 behavioural 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 behavioural demand function in (6) and (7), the value function in actual prices and quantities (5) can be written as

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

where $\nabla_t J^a = \nabla_t J^b$ implying a shift in the behavioural 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

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

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[1]. In our analysis, the production technology of Polish farm is presented by one output variable, four variable inputs (i.e. labour, 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[2]. Price indices for variable inputs were only available at the national level[3]. 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.

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.[4] 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.

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

[2] 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.

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

[4] 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.

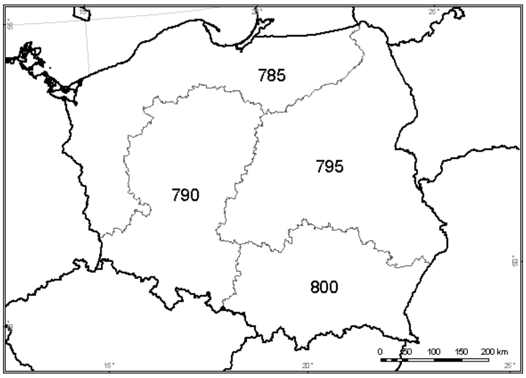
Table 1: Descriptive statistics of the variables, 2004-2007*

		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

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.

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

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 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 labour 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.

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 labour input is about the same in both regions, agriculture in Malopolska and Pogórze is more labour 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: 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

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.

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:

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

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

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

$$\begin{aligned} x^o = \boldsymbol{\tau}_x \boldsymbol{\Lambda}_n^{-1} &\begin{bmatrix} \mathbf{w}'(r\nabla_{\mathbf{ww}} J^b - r\nabla_{k\mathbf{w}} J^b (\nabla_{kp_k} J^b)^{-1} \nabla_{\mathbf{w}p_k} J^b - r\nabla_{l\mathbf{w}} J^b (\nabla_{lp_l} J^b)^{-1} \nabla_{\mathbf{w}p_l} J^b) \\ + r\nabla_{\mathbf{w}} J^b - \nabla_{t\mathbf{w}} J^b + \nabla_{k\mathbf{w}} J^b (\nabla_{kp_k} J^b)^{-1} \nabla_{tp_k} J^b + \nabla_{l\mathbf{w}} J^b (\nabla_{lp_l} J^b)^{-1} \nabla_{tp_l} J^b \end{bmatrix} \\ &+ \boldsymbol{\tau}_q \boldsymbol{\Sigma}_k^{-1}(rJ^b_k(J^b_{kp_k})^{-1} J^b_{\mathbf{w}p_k} - rJ^b_{kt}(J^b_{kp_k})^{-1} J^b_{\mathbf{w}p_k}) \\ (13) \qquad &+ \boldsymbol{\tau}_q \boldsymbol{\Sigma}_l^{-1}(rJ^b_l(J^b_{lp_l})^{-1} J^b_{\mathbf{w}p_l} - J^b_{lt}(J^b_{lp_l})^{-1} J^b_{\mathbf{w}p_l}) + J^b_{t\mathbf{w}} \\ &- \dot{k}^o \begin{bmatrix} \boldsymbol{\tau}_x \boldsymbol{\Lambda}_n^{-1}(J^b_{k\mathbf{w}} - J^b_{k\mathbf{w}}(J^b_{kp_k})^{-1}(J^b_{kp_k} - 1/r) + \boldsymbol{\tau}_q^{-1} J^b_{k\mathbf{w}}) \\ + \boldsymbol{\tau}_q \boldsymbol{\Sigma}_k^{-1}(J^b_{kk}(J^b_{kp_k})^{-1} J^b_{\mathbf{w}p_k}) \end{bmatrix} \\ &- \dot{l}^o \begin{bmatrix} \boldsymbol{\tau}_x \boldsymbol{\Lambda}_n^{-1}(J^b_{l\mathbf{w}} - J^b_{l\mathbf{w}}(J^b_{lp_l})^{-1}(J^b_{lp_l} - 1/r) + \boldsymbol{\tau}_q^{-1} J^b_{l\mathbf{w}}) \\ + \boldsymbol{\tau}_q \boldsymbol{\Sigma}_l^{-1}(J^b_{ll}(J^b_{lp_l})^{-1} J^b_{\mathbf{w}p_l}) \end{bmatrix} \end{aligned}$$

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 behavioural value function. In addition, all inefficiencies must be specified to implement the estimation of all coefficient parameters of the behavioural value function. A quadratic behavioural value function assuming symmetry of the parameters can be expressed as[5]

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

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

[5] 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 $(\mathbf{w}^b, p_k, p_l)$.

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 asymptotically distributed as chi-square with as many degrees of freedom as 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[6] 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.[7] 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.

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

[7] 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

	Full Model		Restricted Model	
	Estimates	Std Err	Estimate	Std Err
β_{o}	-0.152***	0.022	-0.614***	0.082
β_{t}	0.015***	0.005	0.009**	0.003
β_{tt}	0.018	0.04	0.055	0.033
β_{w2}	0.320**	0.212	0.248	0.209
β_{w3}	0.289***	0.025	0.197*	0.142
β_{w4}	0.086***	0.021	0.187***	0.023
β_{pk}	0.209***	0.002	0.381***	0.002
β_{pl}	0.011***	0.004	0.081***	0.014
β_{k}	-0.800***	0.002	-0.180***	0.002
β_{l}	-0.027***	0.001	-0.267***	0.015
β_{y}	0.128***	0.002	0.430***	0.017
β_{w2t}	0.748	1.116	1.663***	0.475
β_{w3t}	-1.151	3.835	-2.399	3.528
β_{w4t}	-0.346	0.262	0.086	0.219
β_{pkt}	0.335	0.493	0.514	0.443
β_{plt}	1.895*	1.149	0.997	0.932
β_{kt}	0.642	0.49	1.322***	0.402
β_{lt}	0.605	0.406	-0.02	0.331
β_{yt}	-0.852*	0.453	-0.733**	0.368
β_{w2w2}	23.002***	3.296	13.905***	3.236
β_{w3w3}	1.280	14.762	-7.647	10.102
β_{w4w4}	0.764***	0.185	0.728***	0.186
β_{pkpk}	0.153***	0.004	0.152***	0.003
β_{plpl}	0.047	0.032	0.040	0.032
β_{kk}	-0.131***	0.005	-0.129***	0.005
β_{ll}	-0.021***	0.003	-0.022***	0.003
β_{yy}	0.120***	0.004	0.120***	0.004

	Full Model		Restricted Model	
	Estimates	Std Err	Estimate	Std Err
β_{w2w3}	5.757**	2.864	2.883	1.780
β_{w2w4}	-3.059	2.615	3.361**	1.449
β_{w2pk}	0.056	0.403	0.464**	0.236
β_{w2pl}	1.993*	1.107	0.480	0.539
β_{w2k}	0.131	0.436	0.789***	0.234
β_{w2l}	0.187	0.375	-0.704***	0.200
β_{w2y}	-0.294	0.427	-0.169	0.222
β_{w3w4}	1.013*	0.599	4.772	6.817
β_{w3pk}	-1.936	1.826	-0.989	1.337
β_{w3pl}	7.213	4.624	0.683	2.846
β_{w3k}	-8.368***	1.769	-4.940***	1.214
β_{w3l}	4.776***	1.502	1.503	1.009
β_{w3y}	1.072	1.702	1.755	1.125
β_{w4pk}	-0.961***	0.185	-1.188***	0.171
β_{w4pl}	-0.888*	0.528	-1.094**	0.534
β_{w4k}	-1.347***	0.218	-1.312***	0.22
β_{w4l}	0.139	0.201	0.091	0.202
β_{w4y}	0.709***	0.223	0.642***	0.224
β_{pkk}	83.897***	2.011	43.628***	0.313
β_{pky}	-9.681***	0.319	-9.714***	0.292
β_{pll}	36.798***	7.115	20.036***	0.78
β_{ply}	-1.499*	0.866	-2.050**	0.858
β_{ky}	-9.524***	0.379	-9.475***	0.379
β_{ly}	-1.791***	0.249	-1.908***	0.247

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 labour (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

	Northwest Model (Pomorze and Mazury)		Southwest Model (Malopolska and Pogórze)			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_{w2w3}	0.444*	0.143	9.059**	4.398
β_{t}	0.065	0.726	0.011	0.008	β_{w2w4}	-0.682*	0.385	0.477	0.422
β_{tt}	0.052	0.062	-0.030	0.06	β_{w2pk}	0.074	0.058	-0.113*	0.063
β_{w2}	0.154	0.329	0.243	0.319	β_{w2pl}	0.269	0.165	0.098	0.177
β_{w3}	0.521***	0.213	0.410***	0.224	β_{w2k}	0.068	0.066	-0.134*	0.069
β_{w4}	0.069***	0.017	0.085***	0.017	β_{w2l}	0.195***	0.062	0.189***	0.053
β_{pk}	0.179***	0.003	0.201***	0.003	β_{w2y}	-0.172***	0.064	0.234***	0.061
β_{pl}	0.103	0.224	0.016**	0.007	β_{w3w4}	2.891*	1.580	0.600	1.714
β_{k}	-0.579***	0.002	-0.789***	0.003	β_{w3pk}	-0.027	0.228	-0.789***	0.274
β_{l}	-0.125***	0.011	-0.326***	0.028	β_{w3pl}	0.331	0.703	1.063	0.738
β_{y}	0.136***	0.003	0.137***	0.002	β_{w3k}	-0.597***	0.261	1.137***	0.268
β_{w2t}	0.099	0.168	0.026	0.174	β_{w3l}	0.710***	0.251	-0.066	0.213
β_{w3t}	-0.069	0.572	-0.099	0.584	β_{w3y}	0.120**	0.024	0.673***	0.241
β_{w4t}	-0.056	0.039	-0.011	0.043	β_{w4pk}	-0.087***	0.026	-0.149***	0.031
β_{pkt}	0.001	0.007	-0.002	0.008	β_{w4pl}	-0.153**	0.076	-0.110	0.093
β_{plt}	0.034**	0.017	-0.013	0.019	β_{w4k}	-0.146***	0.032	-0.112***	0.036
β_{kt}	0.009	0.007	-0.010	0.008	β_{w4l}	-0.013	0.030	-0.008	0.031
β_{lt}	0.021***	0.006	-0.009	0.006	β_{w4y}	0.093***	0.033	0.046	0.036
β_{yt}	-0.021***	0.006	0.021***	0.007	β_{pkk}	97.651***	2.256	75.465***	2.137
β_{w2w2}	31.428***	5.152	10.493**	5.143	β_{pky}	-0.114***	0.004	-0.128***	0.004
β_{w3w3}	4.591	4.136	5.259	7.622	β_{pll}	71.542**	17.382	61.018**	13.256
β_{w4w4}	0.808***	0.275	1.284***	0.301	β_{ply}	-0.031**	0.013	-0.038***	0.014
β_{pkpk}	0.163***	0.004	0.170***	0.005	β_{ky}	-0.098***	0.005	-0.123***	0.005
β_{plpl}	0.080*	0.047	0.033	0.053	β_{ly}	-0.030***	0.004	-0.025***	0.003
β_{kk}	-0.137***	0.007	-0.159***	0.006					
β_{ll}	-0.039***	0.005	-0.020***	0.004					
β_{yy}	0.138***	0.006	0.157***	0.006					

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 labour (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.

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 for further discussion of results.

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 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 labour 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 labour 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 5: Technical and allocative efficiency over time and by specialization

Efficiency scores	Northwest region (Pomorze and Mazury)				Southwest region (Malopolska and Pogórze)			
	By year							
	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	0.64	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

Efficiency scores	Northwest region (Pomorze and Mazury)					Southwest region (Malopolska and Pogórze)				
	By specialisation									
	Field crops	Dairy cattle	Grazing livestock	Grani-vores	Mixed farms	Field crops	Dairy cattle	Grazing livestock	Grani-vores	Mixed farms
TE(q)	0.555	0.563	0.568	0.616	0.564	0.470	0.459	0.447	0.443	0.508
TE(x)	0.572	0.583	0.603	0.636	0.580	0.606	0.578	0.563	0.548	0.540
AE(k)	0.633	0.636	0.649	0.576	0.626	0.392	0.401	0.394	0.413	0.423
AE(l)	0.817	0.803	0.778	0.781	0.801	0.684	0.684	0.685	0.700	0.703
AE(w2)	0.721	0.761	0.755	0.723	0.741	0.908	0.908	0.905	0.922	0.891
AE(w3)	0.624	0.602	0.623	0.512	0.581	0.723	0.735	0.766	0.714	0.667
AE(w4)	1.306	1.344	1.405	1.26	1.339	3.103	2.328	2.399	2.192	2.125

[*] 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 5 presents average the estimated efficiency scores. 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 over time range from 0.468 to 0.622 with an average of 0.536 whereas those of variable inputs range from 0.45740 to 0.623 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). The estimates further show that technical efficiency is slightly improving over times. This holds for both regions. Moreover, the average differences between the specialisation within the regions are pronounced. What matters is the regional effect while the specialisation effect appears to be marginal.

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 labour 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 labour 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 labour 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 labour input. The 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 labour input while they are under-utilizing overhead relative to the labour 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 labour while they indicate a lower degree of under-utilization in overhead relative to labour.

Table 6 gives information about the impact of technical change on total cost and individual input use. The figures are calculated using the parameter estimates of the behavioural value function (2) and the input demand equations given (3) and (4):

$$(15) \qquad \frac{\partial \dot{\mathbf{q}}^b}{\partial t} = r\nabla_{\mathbf{p}t} J^b (\nabla_{\mathbf{qp}} J^b)^{-1}$$

$$(16) \qquad \frac{\partial \mathbf{x}^b}{\partial t} = r\left[\nabla_{\mathbf{w}t} J^b - \nabla_{\mathbf{wp}} J^b (\nabla_{\mathbf{qp}} J^b)^{-1} \nabla_{\mathbf{p}t} J^b\right]$$

These expression provide the impact of technical change in absolute terms. The relative changes ae estimated by dividing (15) and (16) by (3) and (4), respectively. Besides the bias we are interested in the effect of technical change on total cost of production (in relative terms). This is estimated by $\partial \ln J^b / \partial t$ where J^b is given by (14).

Table 6: Impact of technical change

		Northwest Model (Pomorze and Mazury)	Southwest Model (Malopolska and Pogórze)
Total cost reduction	2004	0.01%	-0.07%
	2005	0.03%	-0.12%
	2006	0.05%	-0.17%
	2007	0.07%	-0.22%
Bias of technical change	Crop input	0.29%	0.08%
	Animal input	-0.22%	-0.28%
	Overheads	-0.17%	-0.03%
	Capital	0.01%	-0.02%
	Land	0.02%	-0.02%

The impact of technical change on production, the overall effect as well as its bias, are rather low in both regions. It appears that only the Southwest could benefit from technical change in the period under investigation. Farms in the Northwest experienced a (marginal) reduction of the production possibilities. The impact on variables inputs had a similar structure between the two regions: crop input using and animal and overhead input saving. However, the sign for the quasifixed inputs are opposite for the regions. In the northwest technical change was factor using while in the Southeast is had a factor saving characteristics.

On the one hand these results are consistent with the parameter estimates shown in Table 4 and the technical change indicators follow the parameter differences. Moreover, the estimates also provide that almost none of the parameters for technical change is significant, implying that that the impact of technical change on the production structures in the period under investigation can be disregarded. However, this result is rather astonishing, since other studies investigating a similar period report significant positive influences of technical change (Goraj and Hockmann 2010).

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.

We estimate a rather low impact of technical change. Moreover, the effects differ between the regions not by size but only by direction. Given other studies on Polish agriculture, these results appear quite suspicious. This suggests that we have to improve the estimate procedures, probably by using different estimation techniques. This strategy is inevitable since the present estimates provide rather unexpected results the regarding allocative efficiencies. Since Polish agriculture belongs to the most labour intensive in the EU, an overuse instead of an underuse of labour is expected. Since allocative inefficiency is inter alia determined by the shape of the isoquants it has to be checked whether the curvature conditions regarding the behavioural value function are satisfied and whether restrictions have to be applied that guarantee that the value fnction behaves well.

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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