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Klepacka, AM; Florkowski, WJ; Revoredo-Giha, C

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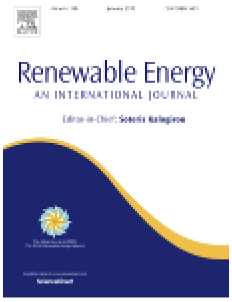

The expansion and changing cropping pattern of rapeseed production and biodiesel manufacturing in Poland

Author links open overlay panel Anna M.Klepacka[a]Wojciech J.Florkowski[b] CesarRevoredo-Giha[c]

[a] Department of Production Engineering, Warsaw University of Life Sciences, ul. Nowoursynowska 161, 02-787, Warsaw, Poland

[b] Department of Agricultural and Applied Economics, University of Georgia, Griffin Campus, 1109 Experiment Street, Griffin, GA 30223-1797, USA

[c] Scotland's Rural College (SRUC), Edinburgh, Scotland, UK

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Abstract

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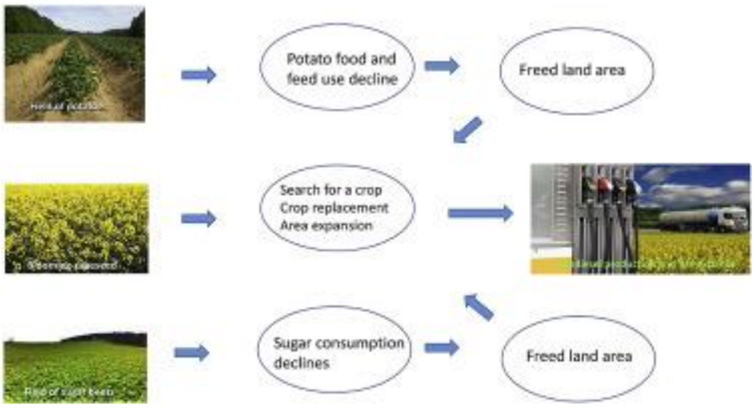
Graphical abstract



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Keywords

Rapeseed
Farm efficiency score
Sugar policy
Potato use
Spatial production variability

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Abstract

Poland depends on imports for its transportation fuel supply and EC renewable energy policy encourages rapeseed conversion into biodiesel. This paper discusses changes in winter rapeseed production following changes in sugar policy, decreased dependence on potato use as feed and food, and the EU 2007-2009 support program for production of oil seeds as biofuel feedstock. We examine whether farm cost efficiency scores differ across Poland's 16 regions between those growing rapeseed and all other farms using Farm Accounting Data Network (FADN) data. Farms growing rapeseed are more cost efficient in all regions, and while regions with long experience in growing rapeseed still dominate the production, rapeseed production is expanding into new areas. Subsidies offered under the EU support program likely initiated expansion and the expansion continues after the program expired. Less efficient farms can be encouraged to enter rapeseed production through farm outreach services and competitive prices in relation to other crops since the available land permits further expansion of this biodiesel feedstock production.

Keywords: Rapeseed, farm efficiency score, sugar policy, potato use, spatial production variability

1. Introduction

The European Commission (EC) mandate to increase the share of renewable feedstock in energy generation requires member-countries to reach the required level by 2020. The European Union (EU) directive obligates its member-countries, including Poland, to utilize renewable energy and reach a 15% share of renewable energy consumption by 2020 [1]. Additionally, the newly adopted, but not yet approved (by the European Parliament) goal aims at the share of renewable energy use at 32% by 2030 [2]. The share of renewable energy in total energy consumption amounted to 4.3% in Poland in 2013 [3] and Poland placed tenth among the world's largest biodiesel producers [4]. Biodiesel production reached about 0.8 million tons in 2016 [5] and increased to nearly 0.9 million tons in 2017 [6]. Poland is heavily dependent on imports of transportation fuels and expanding the domestic supply of biodiesel is consistent with renewable energy policies and increases energy security.

Biodiesel is the most important among the many types of biofuels produced and used in the European Union (EU) [7]. France and Germany lead among the EU countries in biodiesel production followed by Poland. EU countries manufacture biodiesel primarily from rapeseed *(Brassica napus* L.), which is the main oil seed crop in Poland, while the EU is the largest rapeseed producer (33% of world production) [8]. Biodiesel production is driven, among other reasons, by both EU agricultural, climate change, and energy policies. The various policy objectives have affected the global trade in biodiesel feedstock and are reflected in large EU imports of palm oil for the purpose of biodiesel production. The EU is the second largest palm oil importer and 45% of the global palm oil production was used in transportation (as biodiesel) in 2014 [9]. However, palm oil as a biodiesel feedstock was subject to severe criticism as the EC identified palm oil production as detrimental to the environment [9] due to, among other reasons, the effect of clearing land for palm oil plantations and was inconsistent with the desired indirect land use change (ILUC). The EC intention has been to eliminate palm oil as biodiesel feedstock after 2021 [10]. Such changes create additional demand for rapeseed, including rapeseed grown on Polish farms. Since Poland's accession to the EU, the number of farms producing rapeseed more than doubled and the rapeseed share in area planted increased from 4% to 9% in the period 2013-2015 [8]. The effect of expanding rapeseed production lowered the share of grains which is undesirable from an environmental standpoint.

Winter rapeseed is favored mostly in the southwestern and western parts of Poland as well as along the Baltic Sea coast. The spatial variability reflects biophysical factors including suitable soils and adequate moisture for proper plant growth, both conditions important in rapeseed production [11]. The crop is also sensitive to frost, but these regions tend to have mild spring weather. However, the production of rapeseed was also undertaken in neighboring regions, including Wielkopolska (located in west-central Poland), which has been traditionally recognized for its farmers' excellent management practices (Map 1). Rapeseed growers are familiar with regional agro-ecological conditions and have accumulated experience in managing rapeseed production risks. To meet the mandated renewable energy use will require that more rapeseed be planted in traditional and non-traditional production areas of Poland. Farmers in the non-traditional rapeseed growing areas are driven by competitive returns in undertaking rapeseed production, availability of new varieties, and government policy.

In the context of the pending renewable energy mandate imposed by the EC, the expected growing demand for biodiesel feedstock resulting from transportation needs, and restrictions on palm oil imports, this study examines policies adopted in Poland after the transition to a market economy in 1989 that indirectly and directly contributed to the growth of rapeseed area planted (Figure 1) and production. The consideration of changes in spatial variability accounts for various agro-ecological conditions and the overall management skills of farmers. The latter continually change, are difficult to measure, and are embedded in the observed changes in the crop area in this study. Additionally, biodiesel support program effects on rapeseed production are discussed. Next, we examine spatial differences in cost efficiency index values for all farms and, separately, for oil-seed producing farms using binary variables for each voivodship with Wielkopolskie Voivodship as the benchmark. Wielkopolskie Voivodship has been viewed as the leading region in terms of farm productivity and has been a traditional area of rapeseed production. Since growing conditions favoring rapeseed production vary across the country, regional analysis allows drawing inferences, such as what regions have relatively higher cost efficiency than Wielkopolskie Voivodship. The regional level of analysis supplements numerous studies evaluating biofuel policies in aggregate [12]. The study uses FADN data for the period 2004 to 2011, which included the 2008-2010 oil seed EU support program.

2. Methods

2.1.Spatial changes in crop area

Data used in the description of spatial changes in crop area in Poland were obtained from the Main Statistical Office (GUS). Several publications were used to obtain the series discussed in this study. The methodology of reporting was the same throughout the considered period.

2.2.Modeling cost efficiency

In general, improved input use or improved varieties make an inefficient farm more productive [13]. This study examines cost efficiency among farms producing oil seed crops and all farms to examine which of these two groups of farms is more cost efficient. The analysis is conducted at a regional level and accounts for spatial variability of winter rapeseed production. The available data and applied approach extend previous research that examined spatial aspects of rapeseed production from a country viewpoint [14].

Polish farms providing the information represent well the farms engaged in commercial agricultural production. Farms share details about their outputs, crops grown, and other details about farm operation using unified accounting principles. The monetary measures are converted from domestic currency to euros for countries outside the euro-zone such as Poland.

The study applies a stochastic cost frontier framework. The index of most efficient farms equals one and such farms are positioned on the frontier function. [15] proposed the fixed effects stochastic cost frontier model in

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

where i denotes farms and t the periods. The observed expenditure $\ln E_{it}$ is in the logarithm and the deterministic cost function, $\ln C(Q_{it}, W_{it}, \tau_t; \Omega)$ depends on the outputs Q_{it} , the input prices W_{it} , a deterministic trend τ_t that captures technological change, and a vector of parameters Ω in equation (1). Except the trend, all the variables are in logarithms. The statistical error, v_{it} , is with mean zero and variance $\sigma_v{}^2$. The inefficiency term u_i is positive and time invariant.

Prior to estimation, it is necessary to select the functional form for the deterministic part of the stochastic cost frontier (i.e., $\ln C(Q_{it}, W_{it}, \tau_t; \Omega)$). Following [16], this study applies a generalized multiproduct translog cost function. The latter imposes fewer a priori restrictions than alternative functional specifications. [16] note that in the context of multiproduct estimation, a farm may not generate a specific output causing the logarithm used in the translog function to produce an error. A Box-Cox transformation can then substitute for the logarithm of the output terms. This study applies $f(Q) = Q$ as a hybrid between the translog function and the quadratic function. The cost function for n inputs and m outputs is:

$$(2) \qquad \ln C(Q_{it}, W_{it}, \tau_t; \Omega) = \alpha_0 + \varphi_0 \tau_t + \varphi_0 \tau_t{}^2 + \sum_{j=1}^{n} \alpha_j \ln W_{jt} + \tfrac{1}{2} \sum_{j=1}^{n} \sum_{k=1}^{n} \beta_{jk} \ln W_{jt} \ln W_{kt}$$
$$+ \tfrac{1}{2} \sum_{j=1}^{m} \sum_{k=1}^{n} \delta_{jk} f(Q_{jit}) \ln W_{kt} + \sum_{j=1}^{m} \gamma_j f(Q_{jit}) + \tfrac{1}{2} \sum_{j=1}^{m} \sum_{k=1}^{m} \rho_{jk} f(Q_{jit}) \cdot f(Q_{kit}).$$

The stochastic cost frontier has to satisfy the properties of any cost function [31]. The imposition of price homogeneity and symmetry conditions in (2) followed from placing restrictions on the parameters (3):

$$(3) \qquad \sum_{j=1}^{n} \alpha_j = 1; \ \sum_{j=1}^{n} \delta_{jk} = 0; \ \sum_{j=1}^{n} \beta_{jk} = 0; \ \sum_{k=1}^{n} \beta_{jk} = 0; \ \sum_{j=1}^{n} \sum_{k=1}^{n} \beta_{jk} = 0; \beta_{jk} = \beta_{kj} \quad .$$

The inefficiency coefficient is assumed to be time invariant and was estimated using a fixed effects panel data model of a stochastic cost frontier estimation [15; 18; 19]. However, the use of a fixed effect model precludes the use of time invariant variables in estimation. To overcome this restriction, in the context of cost function estimation, the parameters linked to input prices are estimated from the cost share equations, where the inefficiency terms (i.e., the fixed effect terms) do not appear.

The equation to be estimated, with the intercept $\alpha_{0i} = \alpha_0 + u_i$ is:

$$(4) \qquad \ln E_{it} = \alpha_{0i} + \varphi_0 \tau_t + \varphi_0 \tau_t^{\,2} + \sum_{j=1}^{n} \alpha_j \ln W_j + \tfrac{1}{2} \sum_{j=1}^{n} \sum_{k=1}^{n} \beta_{jk} \ln W_j \ln W_k + \tfrac{1}{2} \sum_{j=1}^{m} \sum_{k=1}^{n} \delta_{jk} f\left(Q_{jit}\right) \ln W_k$$
$$+ \sum_{j=1}^{m} \gamma_j f\left(Q_{jit}\right) + \tfrac{1}{2} \sum_{j=1}^{m} \sum_{k=1}^{m} \rho_{jk} f\left(Q_{jit}\right) \cdot f\left(Q_{kit}\right) + v_{it}.$$

The dataset does not contain input prices for each farm, but it is common in cross section estimation to assume that all farmers face identical prices (e.g., [20]). However, in a cost function estimation applying panel data, prices are introduced under the assumption that all farmers face the same input prices within a year (i.e., across farms), while allowing prices to change over time. In a different context, similar assumptions can be found in the estimation of demand systems, where price elasticities are sometimes estimated from time series because of the lack of variability of prices in cross section datasets [14]. Table 1A reports the calculated elasticities of substitution among five input categories.

Costs and outputs by farm category were computed directly from the FADN data. Labor and land input prices were estimated from the FADN data. This data only presents input expenditures and not the prices paid for inputs (or their used quantities) needed for the cost function estimation. Therefore, Eurostat's input price indices data (base year 2005) were used for agricultural materials, energy, and capital as an estimate of those prices paid by farmers over the study period.

As shown in [15], the relative cost efficiency index (CEI_i) for a sample size N was computed as equation (5) based on the estimated fixed effect intercepts (i.e., $\hat{\alpha}_{0i}$), where for the most cost efficient producers it has a value equal to one:

$$(5) \qquad \mathrm{CEI}_i = \exp\left\{-\left(\hat{\alpha}_{0i} - \min_i\{\hat{\alpha}_{0i}\}\right)\right\} \qquad i = 1,\dots, N.$$

The results of the cost function estimations for two farm categories, i.e., those growing oil seed crops and for the whole sample provided insights into cost efficiency differences.

The estimation of the cost functions allowed not only produced efficiency scores but also factor substitution elasticities (Table 1A). All obtained elasticities are statistically significant at $\alpha = 0.01$ and, in general, have the expected signs. There appears to be a complementarity rather than substitution between energy and materials. This possibly results from the aggregate nature of the category “Materials”. Similar complementarity between land and energy could reflect the technology used on Polish farms, which are relatively small, especially if compared to farms in other EU countries.

The cost function was estimated for five inputs and three outputs (see Appendix) using Iterative Seemingly Unrelated Regression Equations (ISURE) to obtain the coefficients in the reduced model. Second, all the remaining parameters of the cost function, except the fixed effect terms (i.e., output terms not associated with prices) were estimated using the within estimator (ordinary least square applied to the variables expressed as deviations of the means by farm as in [21]. Finally, the fixed effect terms used in the construction of the relative cost efficiency indices were estimated by evaluating the function at the mean value of the variables by farm [15; 22; 23].[1] Finally, to identify regional differences in cost efficiency, scores of rapeseed producing farms were regressed on economic size of each farm and a binary variable indicating a specific region. The estimation applied the White heteroskedasticity-consistent regression.

2.3.Data

Data used in this paper are from the Farm Accounting Data Network (FADN) database, initiated in 1965. In the case of Poland, FADN data were available only since the 2004/05 production year (after the country's accession to the EU on May 1, 2004). The voluntary

[1] The farm level estimated fixed effects used to compute the relative cost efficiency indices were assumed to be constant over time due to the short period covered by the sample (in the best case, information was available for some farms for eight years) [22] 2003, p. 170).

participation of each farm causes some farms to drop from the panel and the available set is unbalanced panel data. The data are annual observations for the period 2004/05-2011/12. The unbalanced panel applied in this study included 19,455 farms, representing 93,916 observations. The study examines the cost efficiency of farms of all types included in the sample.

Table 1 shows the number of all farms and oil seed producing farms by voivodship in the FADN sample for the period 2004-2011. The number of all farms in the sample varies across years, but in eight voivodships reporting the largest area planted with rapeseed (Figure 2), the number of farms in the FADN sample increased over time (except in Wielkopolskie), i.e., Dolnośląskie, Lubuskie, Kujawsko-Pomorskie, Opolskie, Pomorskie, Warmińsko-Mazurskie, and Zachodnio-Pomorskie Voivodships (Map 1). The share of oil seed producing farms also increased in seven out of the eight voivodships with the largest area planted with rapeseed. The exception was Zachodnio-Pomorskie Voivodship, but in 2004 this voivodship reported the largest share of oil seed producing farms (45.2%). The observed tendency in the number of oil seed producing farms also characterizes the changes in the sample composition of the remaining voivodship stressing the increased interest in oil seed production in general in Poland.

3. Policies affecting rapeseed production

Rapeseed has been the primary oil seed crop in Poland prior to the transition to an open economy based on market mechanisms in 1989. Prior to 1989 the government relied on the state, cooperative, and private farm sectors to grow a crop subjected to unpredictable weather and dictated to state farms the area they had to dedicate to highly risky crop. The whole crop was sold at government procurement prices. The fixed price system, however, prevented any sustained supply response or change in demand. Rapeseed cake, a valuable co-product, provided a source of animal feed, but because the varieties grown at that time (before 1989) were characterized by different nutritional qualities than the current double-zero varieties, the cake was not well tolerated by some farm animals. Annual animal production targets faced by each state farm allocated by the government also reflected the importance of meat production. Any disruption of food production could lead to shortages on the domestic food market and social unrest [24].

The pressure to meet government assigned numerical goals resulted in contradictions between centrally allocated rapeseed production quotas, the reality of available arable land, and the unpredictable weather events during each growing season. But, varying weather patterns and soil quality, administratively driven production goals, and available technology shaped crop management skills that under the fixed price system had to focus on balancing costs and yields. The 1989 transition to a market economy eliminated the state monopoly on foreign trade. The immediate effect was the easing any food or agricultural input shortages including animal feed and feed concentrates. The imported feed quickly substituted the traditional feed of steamed potatoes mixed with crushed grains in the hog production. The open economy policy induced a near elimination of potatoes from the cropping pattern. Poland, which for decades belonged to the top potato-producing countries in the world, witnessed farmers choosing to purchase commercial feed and increasing the planting of grains. The area planted with potatoes amounted to 1.835 million hectares in 1990 [25]. In 2004, the year of Poland's accession to the EU, the area planted with potatoes was 713,000 hectares, a 61.1% decline since 1990. The rapidly decreasing use of potatoes as feed coincided with its declining consumption by households. Between 1990 and 2015, per capita consumption of potatoes decreased by 30.6% and continues to its decline [26; 27]. In 2015, the area planted with potatoes amounted to 300,000 hectares or 83.7% less than in 1990 [25].

The reduction of potato area without exception in all regions of the country, released about one million hectares to grow other crops. Farmers sought crops that required fewer inputs and focused on grains. The change in cropping patterns is undesirable because planting grain after grain lowers yields and increases weed pressure [28]. Potato production required more inputs than grains. The consequence of the opening of the economy was a decrease in potato plantings allowing the expansion of rapeseed area for farmers seeking profitable although risky crops.

Similarly to other food products, sugar shortages were periodically experienced under the centrally planned economy in Poland prior to the 1989 transition. Following the transition to the market economy, initially the domestic sugar production continued relatively undisturbed. Growers received cash payment for deliveries and used leaves of beets as fodder, especially in dairy production. Additionally, many farms used beet pulp as feed for all types of livestock. The primary goal of higher yields under the centrally planned economy changed under the market conditions, when sugar processors tested deliveries and structured prices according to beet sugar content. The testing induced changes in cultural practices and plant varieties.

Still, in the mid-1990s, the sugar beet area dominated the share of industrial plant crops in Poland [28]. In managing cropping patterns, sugar beets played a crucial role. Sugar beet production limited planting grain after grain, maintaining soil quality. However, in 1994, Poland changed its policy with regard to the sugar industry. It implemented, long before the EU accession, sugar market regulations principally based on EU policy. The regulation involved quotas limiting the volume of sugar intended for domestic markets, subsidized exports, and exports at market prices. Sugar imports were subject to high import tariffs under the WTO arrangements. By 2006, when Poland already joined EU, policy changed again and relied on a strict quota and pricing system. As a result, the 26,718 farmers growing sugar beets in 981 counties (out of the total of 2478) lost sugar beet supply contracts [29]. The number of sugar beet factories rapidly declined. For example, in Dolnośląskie Voivodship (Map 1), the number of sugar processing plants declined from 9 in 2001 to 2 in 2011 [29].

The decline in the sugar beet planting area has been dramatic since the early 1990s. In 1996, the area planted amounted to 453,000 hectares and dropped by 154,000 (34.4%) in 2004, the year of EU accession [28]. In 2015, the area planted was reported as 180,000 hectares [27], a 60.2% decline since 1996. The domestic sugar production has been fluctuating around two million tons annually and has changed little over time. Improved processing technology and varieties substantially increased yield and quality of the raw commodity [28]. Per capita sugar consumption decreased by

8.4% between 1990 and 2015 [26; 27]. It appears that household consumption of refined raw sugar is decreasing, and the food industry is the primary sugar user in Poland.

The ecological consequences of limiting sugar beet production are significant because sugar beets produce a larger volume of oxygen than other agricultural crops [28]. There is the possibility of producing sugar beets for bioethanol and farmers in some other EU-member countries have contemplated that option [30]. However, bioethanol is produced mostly from corn in Poland and unless there is a noticeable increase in demand from bioethanol manufacturers due to investment in processing capacity farmers are unlikely to return to sugar beet production. Even the termination of the sugar quota system in September 2017 [31] may not lead to shifts in the cropping pattern in the immediate future.

3.1.Regional rapeseed production and the biodiesel support program in Poland

Rapeseed production has fluctuated in the past two decades (Figure 1). Following the transition to a market-driven economy in the late 1980s and early 1990s, rapeseed production remained high supplying the country with domestic food-grade plant oil. The area planted with rapeseed was decreasing until the accession to the EU in 2004. It appears farmers increased rapeseed areas in their planting decisions in the fall of 2003 in anticipation of the EU accession. It was not until 2004, that the Ministry of Agriculture and Food Economy permitted the production of 172,000 tons of methyl acetate from rapeseed. It was expected that in 2010 the total volume of diesel fuel used in Poland would contain 5% biodiesel [32]. To meet that goal required 400,000 tons of methyl acetate or an increase of rapeseed production by 1-1.2 million tons because Poland produces a negligible volume of other oil seed crops. The rapeseed production increase required an additional 400,000-500,000 hectares, while the area of arable land in Poland is estimated at 12 million hectares. The first biodiesel plant in Poland operated in Mochełko and processed up to 0.5 ton of rapeseed per hour. The largest biodiesel producer is Trzebinia Refinery in Małopolskie Voivodship. Biodiesel production capacity amounted to 1.269 million tons in Poland in 2013 [33].

The area planted showed rapid growth in 2008 (Figure 1), likely in response to the oil seed support program. Between 2007 and 2009, ARiMR (Agency of Restructuring and Modernization of Agriculture) and ARR (Agricultural Market Agency) implemented a financial support program for energy plant production [34]. The effects of that program are illustrated in Figures 1 and 2, recognizing that rapeseed is a winter crop planted in the fall and harvested in the summer the following calendar year. The rapeseed area peaked in 2010 and declined once the program expired. However, the tendency to increase the area planted resumed in 2012 and nearly reached the record level previously reported in 2010. Poland is the fourth largest rapeseed producer in the EU following France, Germany, and Great Britain.

The planted rapeseed varieties are only those allowed by Polish and EU regulations. They are characterized by two enhanced characteristics. Varieties have to have low erucic acid content (less than 1%) and low content of glucosinolates. Moreover, for biodiesel production, rapeseed oil must meet additional standards regarding the content of methyl acetate [35; 36]. Polish farmers can choose from 87 rapeseed varieties. It has been suggested that farmers focus on the total amount of fat produced per hectare. However, rapeseed buyers have not been paying for fat content except for buyers located near the border with Germany. The latter purchase rapeseed from Polish farmers, paying for fat content, and try to re-sell it in Germany.

3.2.Regional variation in rapeseed planted area

Figure 2 shows the changes in area planted with rapeseed in all voivodships. Those located in western, southwestern, northwestern, and northern Poland have been traditionally major rapeseed producers favored by weather patterns influenced by the Atlantic Ocean (Map 1). The oil seed production support program boosted the planted area, but its termination did not decrease the area in all voivodships. The initial decrease was mostly in voivodships with a large area planted in rapeseed, but in voivodships with small production, the area planted after 2010 increased in many instances. Because the area planted in voivodships showing an expansion of production was initially small, and those farmers had little experience in growing rapeseed, it is plausible that those who planted rapeseed were seeking novel but profitable crops and might have been encouraged by the support program. It is plausible that well-managed and productive farms tried rapeseed production in voivodships that saw little production in the past. For example, Łódzkie, Małopolskie, and Podkarpackie Voivodships have not been known as producers of rapeseed (Map 1), but appear to have expanded the area planted since 2004. Even farmers in Podlaskie Voivdoship, characterized by rather harsh climatic conditions, successfully learned how to grow rapeseed [37].

4. Results

The cost efficiency scores were estimated next, for all farms and rapeseed growing farms in the FADN sample. The visual evaluation of efficiency scores using histograms (available upon request) showed distinctly different pattern for all farms vs. oil seed producing farms. Figure 3 shows the observed differences after grouping the farms with scores falling in the same category. A larger share of the oil seed producing farms than all farms falls into categories with higher cost efficiency scores, although the numbers are not overwhelming. However, the results are consistent with the expectations that rapeseed producing farms tend to be more cost efficient than farms in general, likely implying skillful farm management.

4.1.Effects of location on all farm cost efficiency scores

Table 2 shows the results of regressing the efficiency scores on the economic size of the farm as defined in the FADN sample and dummies representing each voivodship. The link between the economic size and the efficiency score is justified by expectations that a highly productive farm must also be fairly cost-efficient. As expected, the economic size is statistically significant (Table 2).

Binary variables represent each voivodship. Wielkopolskie Voivodship represents the benchmark region allowing for comparison of potential differences across voivodships to the region commonly perceived as the most agriculturally productive. Coefficients of binary variables indicate that farms in all but three voivodships have lower efficiency scores. The three voivodships, which results suggest that the farm efficiency scores do not differ from those in Wielkopolskie, are

Śląskie, Zachodniopomorskie, and Lubuskie Voivodships (Map 1). Śląskie does not play a significant role in the country's agricultural production and its economy is based mostly on mining and industry. The binary variable coefficients of the remaining two voivodships, Zachodniopomorskie and Lubuskie, have negative signs and are marginally insignificant statistically. This is important because the regions are focused mainly on field crops rather than livestock production and farms are of a relatively large size. Overall, Wielkopolskie Voivodship and Warmińsko-Mazurskie farms tend to be more cost efficient than the majority of farms in other areas.

4.2.Effects of location on oil seed producing farm cost efficiency scores

The program favoring oil seed production for biodiesel production must account for differences not only in growing conditions (which can be offset by the development of improved varieties over time), but the implied differences in management skills of farmers. Otherwise, the realized yields may be low and despite the expansion of area planted, gains in crop volume are likely going to disappoint.

Results in Table 3 show that as compared to oil seed producing farms in Wielkopolskie, this type of farm in three voivodships, i.e., Zachodniopomorskie, Pomorskie, and Warmińsko-Mazurskie had a higher cost efficiency score. All three voivodships are large rapeseed producers and located in Northern Poland, where the climatic conditions are suitable for rapeseed production. Farms producing oil seeds in three other voivodships, namely Lubuskie, Opolskie, and Kujawsko-Pomorskie, do not differ in their scores from oil seed producers in Wielkopolskie (Map 1). Finally, oil seed producing farms in Śląskie Voivodship also are no different from Wielkopolskie, but the former plays a marginal role in oil seed production (Figure 2).

Results show that in the category of oil seed producing farms, Wielkopolskie faces tough competition from several other regions, although out of eight voivodships producing the bulk of the annual rapeseed crop, only three have been confirmed by statistical tests. It appears that farmers in those regions have been growing rapeseed for generations and have gained knowledge about the nuances of growing rapeseed and use it effectively.

5. Discussion

The observed increase in the area planted with rapeseed during that period (reflected in crop rather than calendar years because of the winter rapeseed growing requirements) occurred in traditional and non-traditional production areas. For farmers to continue growing rapeseed a key issue is the ability to recover production costs and outperform the returns to alternative crops, especially because of the crop growing requirements. Farms reporting growing oil seed crops (almost exclusively rapeseed in Poland) have been more cost-efficient than farms in general. The challenges associated with growing rapeseed might have initially led to a decrease in the area planted after the EU-funded support program was terminated, but in more recent years (after 2012) the expansion of the rapeseed area continued, including some non-traditional growing regions as farmers gained experience in growing the finicky crop.

In terms of regional participation in rapeseed production, the rapeseed support program resulted in increased production area in the traditional production regions, but also encouraged production in all other regions. The expansion of rapeseed use destined for biodiesel production requires substantial expansion of area planted. Attracting new rapeseed growers must involve less cost-efficient farms. That hypothesis was proven correct after the calculated cost efficiency scores were calculated for all farms and oil seed producing farms through the application of the stochastic cost function framework. Moreover, oil seed producing farms had higher efficiency scores than all farms in the sample (Figure 3).

Further, the gap in farm productivity was confirmed by regression results showing the effects of a region on cost efficiency scores for all farms and oil seed producing farms, where individual regional scores were compared to farm cost efficiency scores from Wielkopolska, widely viewed as having the most productive farms. Indeed, farms in all regions (except one) had lower scores than Wielkopolski Voivodship, but in the case of oil seed producing farms some heavy rapeseed-producing regions performed better than Wielkopolska. However, none of the regions attempting to increase rapeseed production was found to have more cost efficient scores. The result suggests that expanding rapeseed production may become costlier and require a continued subsidy offsetting higher farms costs or helping biodiesel plants pay for their feedstock. In the long term, the development of improved rapeseed varieties may reduce the risks faced by farmers. Other technological inventions can also increase rapeseed competitiveness as a feedstock for renewable energy production.

Statements of farmers from non-traditional rapeseed growing areas suggest that they have learned to manage cultural practices required by the crop. The timing of planting, for example, seems to be of major importance but it is highly variable because it depends on weather patterns specific to an area. Since some farmers find the crop profitable, the best policy to expand rapeseed production for biodiesel manufacturing may be to educate farmers in general. Regional agricultural extension centers are scattered throughout the country and experts with experience in growing rapeseed may participate in workshops and field days in other areas. Regional centers have been known for organizing field days and demonstration plots, which are essential in teaching novel crop growing techniques. Improved knowledge helps farmers to improve their individual cost efficiency. Examples of regional cooperative centers engaged in assisting farmers in growing rapeseed already exist [37]. Additionally, regional extension centers cooperate with agricultural input suppliers in some of their events. Such cooperation may be needed in the case of rapeseed grown for biodiesel because of the involved costs of producing the crop. Biodiesel manufacturers have an incentive to absorb the costs in the process of creating a regional supply base. Scattering the production across various regions reduces the risk associated with unfavorable weather events and assures that an adequate volume is produced year after year. Because of the highly concentrated processing capacity, it is also easier for the government to focus any biodiesel subsidy program on manufacturers and require them to pay for farmer education. Subsidies for biofuels would likely originate from a different government agency than additional funding for the regional agricultural centers.

Cake is a by-product of rapeseed processing that has been used in animal feed. Because the varieties grown in Poland have an improved nutritional profile, the cake can be fed to all farm animals. An increase in rapeseed production implies larger domestic supplies of cake adding to stability of animal feed prices. Stabilizing feeding costs improves animal farmers' returns, while also enhancing the competiveness of meat processors. Consequently, rapeseed farmers, biodiesel producers, animal farms, and meat processors have a mutual interest in increasing demand for the crop. The dramatic elimination of two crops, potatoes and sugar beets, traditionally essential for farm revenues, led to the expansion of grain production beyond what is desirable from the standpoint of maintaining soil productivity and weed control. If the rapeseed area expands, the planted grain area will likely decrease without hampering the supply of feed grains in the country. Currently, the grain area is too large from the standpoint of an optimal cropping pattern and may be lowering soil productivity. Moreover, although some of the land has permitted an increase in production of corn used in making bioethanol, this biofuel is produced on a limited scale in Poland, whereas biodiesel manufacturing steadily increases.

A program that would allocate additional area away from grains to rapeseed production could benefit soil fertility, improve environmental quality, contribute to sustainability, supress weeds, provide additional feedstock for biodiesel manufacturing, and increase the domestic supply of cake for animal feed in Poland and the EU. A mechanism to induce such reallocation of land, however, is not obvious and unlikely to occur as a broad agricultural subsidy program because of the desire to eliminate farm support policies. Polish consumers continue to enjoy an abundant supply of edible vegetable oil despite the growth in biodiesel production, while from a global perspective additional supplies of oil from Poland can be highly desirable. In the case of Poland, creating regional rapeseed processing capacity could establish a local biodiesel supply net making biodiesel accessible. Perhaps, if combined with a system of discounts for rapeseed growers, farmers themselves would be the primary users of biodiesel. An alternative is to find additional users of cake and by stimulating the demand for the by-product encourage farmers to grow more rapeseed. [37] suggested additional incentives, not directly linked to rapeseed growing for example, but to a water management scheme or low cost local feedstock. In contrast to the past, food security has not been an issue in Poland since the transition to an open economy.

6. Conclusions

Rapeseed has been traditionally grown in Poland to supply edible oil, but has also become a feedstock for biodiesel production in recent years. Biodiesel production has been stimulated by the EC mandate to increase renewable energy utilization. A program supporting rapeseed production was implemented in Poland between 2007 and 2009 before its termination by the EC, which also funded the program in full. Prior to the program, eight voivodships were the primary rapeseed producers, exploiting the suitable climatic conditions, but also the knowledge and management skills of their farmers.

A series of changes in trade policy and sugar policy led to a decrease in potato and sugar beet production. The search for alternative crops to replace potatoes and sugar beets led to an increase in grain area and contributed to a gradual expansion of rapeseed area planted with new “double 00” varieties and better adapted to growing conditions.

To expand rapeseed plantings requires the continued development of new varieties better adapted to the regional growing conditions. New improved varieties will alter cost efficiency of farms and their relative regional competitive position. The traditional family farm producing a mix of plant and animal outputs is being replaced by increasing specialization, especially in field crops. This shift in farming is dictated by the recently occurring employment opportunities outside agriculture and demographic changes (many retiring farmers) potentially favor rapeseed area expansion. New regulations regarding land ownership and purchase introduced in 2016 may slow changes in farm size, but will not likely reverse the trend of mixed farms moving to focused field crop farms because of irreversible demographic changes.

Conflict of Interest

The authors declare no conflict of interest

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Table 1. Total number of farms and share of oil seed producing farms in the FADN sample of each voivodship for the period 2004-2011.

Voivodship	2004		2005		2006		2007		2008		2009		2010		2011	
	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms
Łódzkie	1036	8.5%	1001	8.1%	1005	8.4%	969	11.7%	924	12.1%	946	12.8%	841	13.8%	828	14.3%
Mazowieckie	1851	7.0%	1808	7.4%	1822	9.0%	1781	11.4%	1637	11.5%	1654	11.9%	1509	12.6%	1505	12.3%
Małopolskie	479	2.7%	469	2.8%	486	4.1%	473	3.8%	494	5.7%	466	6.2%	427	7.5%	385	6.8%
Śląskie	302	22.2%	304	22.0%	294	22.8%	283	29.0%	312	33.3%	294	32.3%	274	36.5%	273	31.1%
Lubelskie	1116	15.9%	1094	16.9%	1093	19.9%	1082	23.2%	1042	23.5%	982	24.6%	867	26.1%	849	26.4%
Podkarpackie	292	12.7%	307	14.0%	316	16.8%	284	21.1%	284	23.2%	267	21.7%	249	23.7%	233	21.5%
Świętokrzyski	317	12.6%	312	11.5%	331	14.8%	329	15.2%	339	17.4%	343	19.5%	316	16.5%	300	17.7%
Podlaskie	938	1.9%	930	1.7%	929	2.5%	933	4.2%	928	3.9%	928	4.0%	832	5.3%	834	5.8%
Wielkopolskie	1835	13.4%	1822	12.1%	1831	14.1%	1887	16.9%	1966	18.1%	1982	19.9%	1777	21.4%	1764	21.9%
Zachodniopo-morskie	330	45.2%	348	40.5%	386	44.8%	419	48.9%	457	47.3%	484	48.8%	430	49.3%	436	39.0%
Lubuskie	182	27.5%	163	22.1%	175	25.1%	216	26.9%	237	31.6%	254	33.9%	225	36.9%	231	37.2%
Dolnośląskie	513	41.5%	535	42.2%	533	48.0%	579	57.2%	634	58.2%	621	55.2%	557	60.0%	551	58.6%
Opolskie	413	41.2%	417	41.5%	418	48.1%	449	53.0%	506	57.7%	514	59.1%	465	61.5%	467	63.2%
Kujawsko-Pomorskie	1097	32.6%	1138	33.1%	1133	34.9%	1195	38.7%	1308	42.7%	1370	48.7%	1227	48.9%	1236	47.7%
Warmińsko-Mazurskie	471	21.7%	473	18.8%	475	21.7%	493	23.5%	527	24.7%	596	24.7%	548	24.5%	549	23.0%
Pomorskie	557	26.4%	569	27.1%	574	30.5%	609	32.5%	608	33.1%	657	37.0%	585	36.8%	586	35.2%

Source: Own calculations based on FADN data.

Table 2. Regression results of cost efficiency scores for all farms in the sample (n=13,462).

Variable name	Coefficient	Std. error	t-statistic	Prob.
Intercept	0.0222	0.0013	17.42	0.00
Economic size	0.0000	0.0000	14.23	0.00
Łódzkie	-0.0021	0.0008	-2.74	0.01
Mazowieckie	-0.0046	0.0007	-6.94	0.00
Małopolskie	-0.0060	0.0010	-5.79	0.00
Śląskie	0.0010	0.0012	0.80	0.42
Lubelskie	-0.0058	0.0008	-7.31	0.00
Podkarpackie	-0.0050	0.0011	-4.49	0.00
Świętokrzyskie	-0.0032	0.0014	-2.21	0.03
Podlaskie	-0.0041	0.0006	-6.51	0.00
Zachodniopomorskie	-0.0028	0.0019	-1.47	0.14
Lubuskie	-0.0026	0.0016	-1.58	0.12
Dolnośląskie	-0.0042	0.0015	-2.81	0.00
Opolskie	-0.0042	0.0015	-2.77	0.01
Kujawsko-Pomorskie	-0.0019	0.0006	-2.98	0.00
Warmińsko-Mazurskie	-0.0042	0.0008	-5.04	0.00
Pomorskie	-0.0022	0.0009	-2.52	0.01
R-squared	0.5945			
Adjusted R-squared	0.5940			

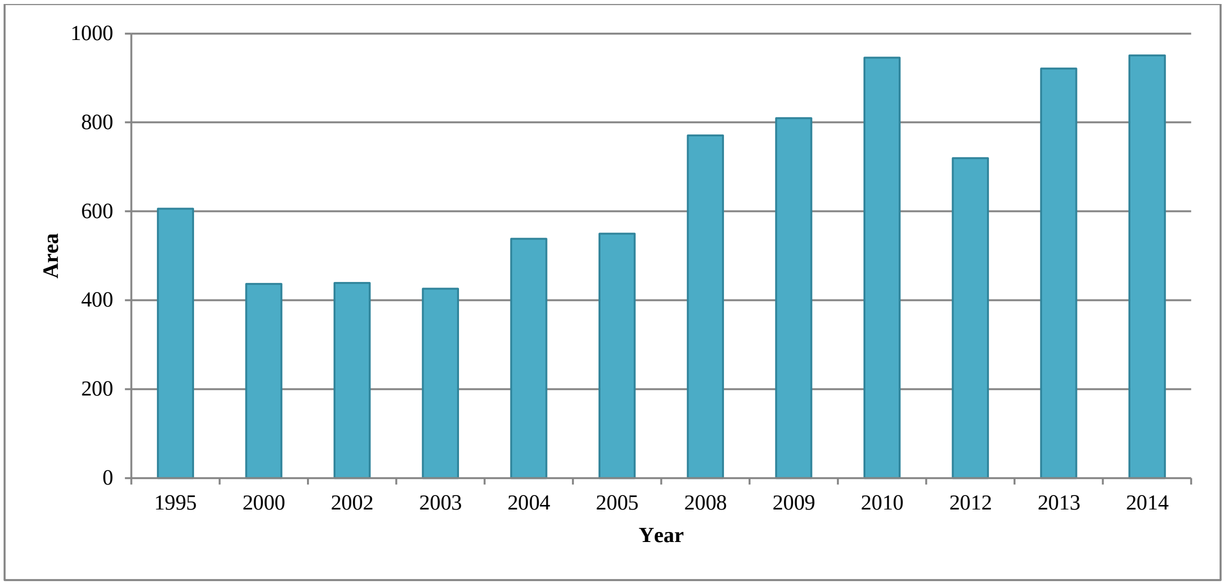
Note: The benchmark for the regional dummy is Wielkopolskie Voivodship. Estimation applied the White heteroskedasticity-consistent regression.

Table 3. Regression results of cost efficiency scores for oil seed producing farms in the sample (N=5,993).

Variable name	Coefficient	Std. error	t-statistic	Prob.
Intercept	0.0426	0.0022	19.78	0.00
Economic size	0.0000	0.0000	8.18	0.00
Łódzkie	-0.0078	0.0029	-2.68	0.01
Mazowieckie	-0.0096	0.0023	-4.13	0.00
Małopolskie	-0.0071	0.0056	-1.27	0.20
Śląskie	0.0042	0.0029	1.45	0.15
Lubelskie	-0.0164	0.0023	-7.12	0.00
Podkarpackie	-0.0092	0.0038	-2.43	0.02
Świętokrzyskie	-0.0109	0.0033	-3.32	0.00
Podlaskie	-0.0011	0.0047	-0.24	0.81
Zachodniopomorskie	0.0209	0.0043	4.90	0.00
Lubuskie	0.0045	0.0043	1.04	0.30
Dolnośląskie	-0.0039	0.0024	-1.62	0.11
Opolskie	0.0049	0.0031	1.60	0.11
Kujawsko-Pomorskie	0.0004	0.0025	0.18	0.86
Warmińsko-Mazurskie	0.0215	0.0045	4.79	0.00
Pomorskie	0.0187	0.0036	5.23	0.00
R-squared	0.4138			
Adjusted R-squared	0.4122			

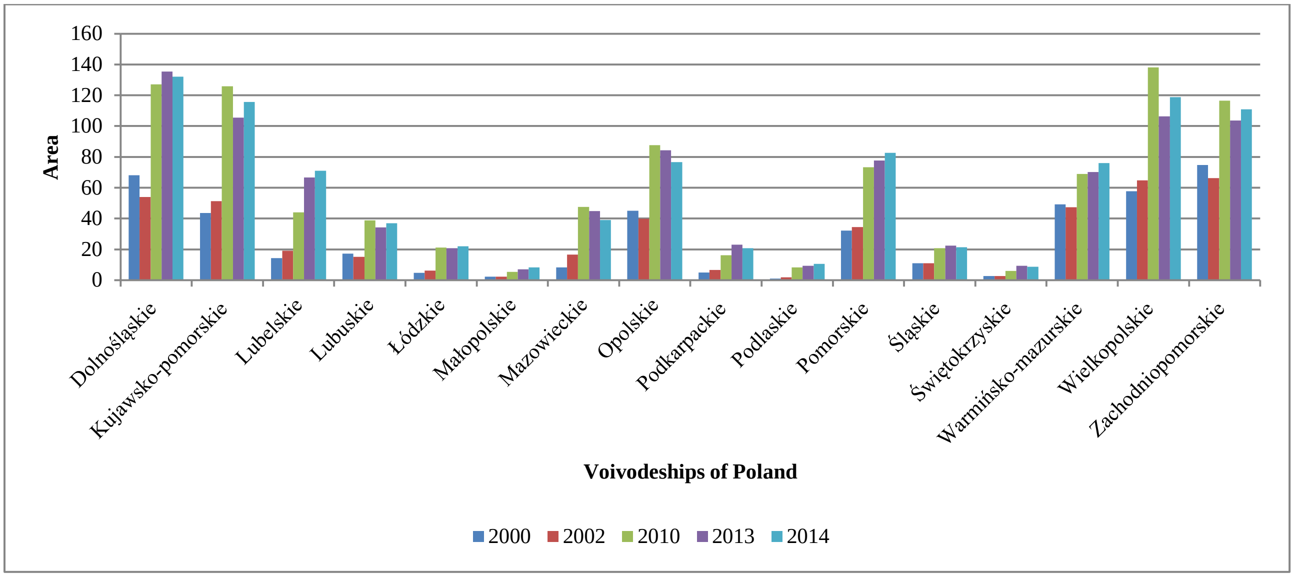
Note: The benchmark for the regional dummy is Wielkopolskie Voivodship. Estimation applied the White heteroskedasticity-consistent regression.

Figure 1. Area planted with rapeseed in Poland, selected years, in thousand hectares.



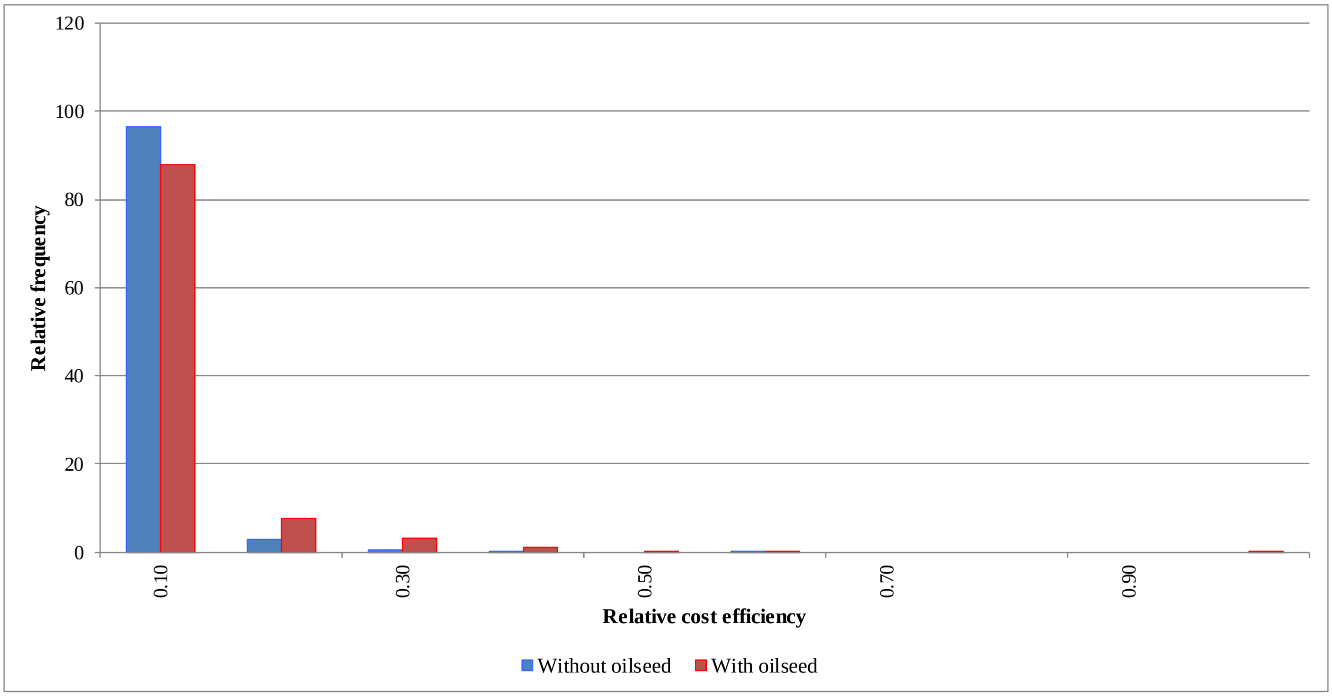
Source: Based on GUS [16; 38].

Figure 2. Spatial variability in area planted with rape seed/canola by voivodship in Poland, selected years, in thousand hectares.



Source: Based on GUS [26; 38].

Figure 3. Percent of all farms and oil seed producing farms by calculated cost efficiency score category.



Map 1. Location of 16 voivodships within Poland.

Source: Prepared by authors.

Appendix

Table A1. Estimated elasticities of substitution for Polish farms in FADN sample for the period 2004-2011.

Input	Elasticities				
	Materials	Energy	Labor	Land	Capital
Materials	-1.069	-0.275	0.536	0.667	0.870
	(-34.29)	(-4.72)	(30.13)	(18.54)	(29.76)
Energy		-1.368	0.404	-0.247	0.376
		(-3.37)	(15.54)	(-4.09)	(4.88)
Labor			-1.354	0.459	0.454
			(-62.34)	(14.41)	(31.11)
Land				-12.207	0.354
				(-123.92)	(10.21)
Capital					-1.744
					(-49.38)

Note: t-statistics in parentheses.
Source: Own calculations.