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Measuring the Impact of Extreme Weather Phenomena on Total Factor Productivity of General Cropping Farms in East Anglia

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ABSTRACT

One of the main challenges of climate change on agriculture in UK is how to adapt to the potential changes to the availability of water. Changes in rainfall distribution may potentially lead to an increase in drought frequency, magnitude and duration. In this research a Data Envelopment Analysis (DEA) and a Malmquist Index (MI) are combined with a double bootstrap methodology to measure changes in Total Factor Productivity of general cropping farms in East Anglia. More specifically, the DEA technique was used to measure the year by year efficiency score for the farms in the sample and the MI and its components used to derive information on productivity over time. Data for the input – output models was obtained from the Farm Business Survey. Climate change is taken into consideration by using data for water cost as a proxy indicator of water consumption per farm. Results reveal changes in total, technical and scale efficiency and provide information on how the 2011 drought affect the TFP of the farms in the sample.

KEYWORDS

Agriculture, Bootstrapped Malmquist Index, Climate Change, DEA, Farm Business Survey, Malmquist Index, Sustainable Intensification, Technical Efficiency Change, Total Factor Productivity

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INTRODUCTION

Measurements of Total Factor Productivity (TFP) growth have been widely used in agriculture as a quantitative economic instrument to evaluate production performance of farming systems in subsequent periods (Melfou, Theocharopoulos, & Papanagiotou, 2013). The decomposition of TFP into the efficiency and technical index components and the observation of the trends in consecutive years contribute to the design of targeted policies aiming to improve agricultural productivity and sustainable development.

Two of the most important challenges for the future growth of agricultural systems globally are climate change and increased food demand. Global food demand is likely to increase by 70% by 2050 due to both population growth and changes in consumption patterns (Foresight Report, 2011). On the other hand, the impacts of climate change may vary globally and at a national level both in magnitude and nature (positive and negative effects) (Falloon & Betts, 2010).

Changes in rainfall and temperature may have a significant impact on agricultural production for the UK and hence they may influence the way that crops develop, grow and yield (Knox, Morris, & Hess, 2010; Murphy et al., 2009). Furthermore, there may also be indirect impacts such as the increased risk and spread of pests and diseases and the suitability of land for agricultural production, especially in parts of East Anglia due to saltwater intrusion and flooding from sea level rise (Knox et al., 2010).

Recent extreme weather phenomena in the UK during the period of 2007-2013, such as the floods of 2007, the drought periods of 2010 and 2011, and the subsequent floods of 2012 and 2013, had an impact on TFP recorded by the Department for the Environment, Food and Rural Affairs (Defra). Specifically, TFP in 2007 was at its lowest level during the aforementioned period (98.2) and fell by 2.9% for the period 2011-2012 (98.7) reaching the levels of 2007. According to Defra (2013), the main reasons for the variation in TFP estimates between years are factors outside the control of farmers such as extreme weather phenomena and disease outbreaks.

In the case of the East Anglian River Basin Catchment (EARBC), increased temperatures and reduced precipitation have direct impacts on the hydrological structure of the area (Defra, 2009; Environment Agency, 2008, 2011) due to increased water abstraction rates for agriculture and decreased water availability. Consequently, both climate change and the reduction in hydrological resources may affect the growth of TFP in the EARBC. Any desire for a secure food supply, efficient management of natural resources, and resilience to more frequent extreme weather phenomena requires the development of adaptation strategies for farmers and for prioritising the need for the sustainable intensification (SI) of agriculture (FAO, 2011; Foresight Report, 2011). Firbank, Elliott, Drake, Cao, and Gooday (2013) define SI at farm level as the process of increasing agricultural production per unit of input whilst at the same time ensuring that environmental pressures generated at a farm level are minimised. Thus, the main priority under the framework of SI is the increase in productivity of farming systems. In addition, according to Gadanakis, Bennett, Park, and Areal (2015), SI can be perceived as the trade-off between production efficiency and environmental efficiency and hence evaluated with the use of an eco-efficiency indicator.

Agricultural productivity depends on the ability of the farmer to take actions and develop strategies that contribute to the development of the farming system's adaptive capacity towards extreme weather phenomena and long-term adverse climatic conditions (Campbell, Thornton, Zougmoré, van Asten, & Lipper, 2014). This is required for responding effectively to climatic changes and to agricultural risks associated with increased variability of weather patterns (rainfall, temperature). Thus, the aim of the analysis here is to explore the impact of extreme weather phenomena in agricultural productivity for the most productive region in England (EARBC). Inward shifts of the production possibilities frontier will define undesirable changes in the global technology of the farming systems and therefore will direct policy makers and service providers to enhance actions towards building ecosystem services in agricultural systems that enhance resilience. In the framework of SI, this is translated as the development of management and farming practices that aim to the improvement of soil health to guarantee adequate nutrient and water resources for plant development. Moreover, it requires the adoption of technologies and crops that are more tolerant of heat, droughts, floods and salinity (Campbell et al., 2014) and to realise the advantages of the synergies between mixed crop and livestock systems. The analysis measures changes in agricultural productivity (TFP) for a period of 5 years using a Malmquist Index in the EARBC.

BACKGROUND

Productivity is defined as a measure of the rate of output produced given a unit of input used in the production process (partial productivity). However, TFP is a more comprehensive measure relying on the ratio of an index of aggregated outputs to an index of aggregated inputs. According to production theory, the determinants of the rate of output are based on the technology used, the quantity and quality of the production factors and the efficiency with which these factors are employed in the production function (Melfou et al., 2013). Thus, any divergence in TFP growth is the result of the net effect of changes in efficiency, shifts in the production frontier and the scale of production (Färe, Grosskopf, Lindgren, & Roos, 1992).

A series of studies have explored the TFP of the agricultural industry in the UK and are presented in Table 1. Defra releases an annual report on TFP of the UK agricultural industry based on the estimation of an ideal Fisher index, which is the geometric mean of the Laspeyres and Paache indices. Thirtle, Piesse, and Schimmelpfennig (2008) provided a TFP in UK agriculture from 1995-2005 based on a Tornqvist-Theil TFP index (Thirtle, Lin Lin, Holding, Jenkins, & Piesse, 2004) in an effort to explain the decline in TFP as a function of the lag in research and development (public and private) and to returns to scale. This index reveals almost 2% growth in TFP per year up until 1983; for the remaining 18 years studied this fell to 0.2%. Moreover, the level of TFP for the UK post-1983 had fallen behind the EU leading countries (Thirtle et al., 2008). The Tornqvist-Theil TFP index was also used by (Barnes, 2002) and was modified to include the environmental and social costs of agricultural productivity for the construction of a social TFP index. Furthermore, (Amadi, Piesse, & Thirtle, 2004) extended the work of (Thirtle, 1999) by constructing and measuring Tornqvist-Theil TFP indices for potatoes, oilseed rape, winter wheat and spring barley, as well as sugar for the East counties of the UK using data from 1970 to 1997. Renwick, Revoredo-Giha, and Reader (2005) also used the Tornqvist-Theil TFP index to measure changes in the productivity of farms in different regions of the UK due to reform of the sugar beet regime. This analysis showed a slight decrease in the productivity of individual farms during 1994-2002.

In addition, Hadley (2006) used farm level data for the estimation of stochastic frontier functions to measure differences in the relative efficiency of 8 different farm types in the UK for the period 1982-2002. The results illustrate that most of the farms are operating close to the technical efficiency frontier and that technical change has played a key role in the increase of efficiency over this 20-year period, especially in the most specialised arable farms. In a similar manner, Barnes, Revoredo, Sauer, and Jones (2010) made comparisons of technical efficiency for different farming systems across England and Wales, reporting a general upward trend in technical efficiency throughout the period. English and Welsh general cropping farms have a reported mean of technical efficiency of 0.74 although with considerable variation around the mean (Hadley, 2006). Earlier studies on technical efficiency include research by Dawson (1985), Wilson, Hadley, Ramsden, and Kaltsas (1998), and Wilson, Hadley, and Asby (2001).

The above-mentioned literature has not paid attention to the impact of extreme weather phenomena on farm level productivity in the way it is done in this analysis. Hence, this analysis contributes in the area by demonstrating how the decomposition of a TFP index such as the MI can be used to associate shifts of the frontier to extreme weather phenomena, and hence allow for future research in the area of spatial heterogeneity and agricultural productivity.

DATA AND METHODS

Data

Data for the empirical application of the model come from a representative sample of 41 General Cropping Farms (GCFs) over the period 2007-2011. The data have been obtained from the Farm Business Survey (FBS), which is a comprehensive and detailed database that provides information on the physical and economic performance of farm businesses in England. The selection of this subset of GCFs ensures that the sample is homogenous in terms of crop mix and environmental conditions and thus makes it possible to compare performances over time. The 41 GCFs selected over a 5-year period yield a panel dataset with 205 observations available for efficiency assessment. For the evaluation of the MI of TFP this provides 164 observations (since the analysis utilises data from two adjacent years at a time).

Table 1. Summary of Total Factor Productivity studies in the UK agricultural sector

Author	Year published	Title	Productivity Index	Period considered
Department of Environment Food and Rural Affairs	Annual report	Total Factor Productivity of the UK agricultural industry	Laspeyers and Paache indices: Annual statistics giving an indicator of the long-term performance of the UK agricultural industry.	Since 1973
Barnes, Revoredo, Sauer et al.	2010	A report on technical efficiency at the farm level 1989 to 2008	Stochastic Frontier Analysis	1989 - 2002
Thirtle, Piesse & Schimmelpfennig	2008	Modelling the length and shape of the R&D lag: an application to UK agricultural productivity	Tornqvist-Theil	1995 - 2005
Hadley	2006	Patterns in Technical Efficiency and Technical Change at the Farm-level in England and Wales, 1982–2002.	Stochastic Frontier Analysis	1982 - 2002
Renwick, Revoredo-Giha & Reader	2005	UK Sugar Beet Farm Productivity Under Different Reform Scenarios: A Farm Level Analysis	Tornqvist-Theil	1994 - 2002
Amadi, Piesse & Thirtle	2004	Crop Level Productivity in the Eastern Counties of England, 1970-97	Tornqvist-Theil	1970 - 1997
Thirtle, Lin, Holding, et al.	2004	Explaining the Decline in UK Agricultural Productivity Growth	Tornqvist-Theil	1953 - 2000
Barnes	2002	Publicly-funded UK agricultural R&D and ‘social’ total factor productivity.	Tornqvist-Theil	1948 - 1995

The production technology for the estimation of the MI of TFP was defined by the area farmed, crop costs (including fertiliser, crop protection, seed and other agricultural costs), other machinery costs, total labour input (hours per year), and water cost per farm including water for irrigation and water used for all agricultural purposes. The selection of inputs was based on the structure of the production system. Cash crop production systems demand heavy machinery as well as labour. Furthermore, since cash crops are sensitive to pests and diseases outbreaks, crop protection costs and fertilisers are having a significant impact to the total production cost expressed by the production technology. The outputs identified in the analysis are cash crop and cereal yield. Cash crop production is calculated through the FBS and is equal to the sum of potato and sugar beet production.

All inputs expressed in £/ha for the period 2007-2011 have been deflated, using indices based on 2005 published by the Department for Environment, Food and Rural Affairs (DEFRA) (API – Index of the purchase prices of the means of agricultural production – dataset (2005=100)). Specifically, the following indexes have been used: fertilisers and soil improvement index, seeds index, plant protection products index, farm machinery and installation index, and other costs index. The indexes have been selected according to the relevance of the data aggregated at a farm level through the FBS.

Table 2 presents a description of the sample used to build the input and output DEA models for the estimation of the MI of TFP. The final row provides information on the average percentage change in volumes of inputs and outputs for the 5-year period. The mean output for both cash crops and cereals grew by 11.33% and by 2.6% respectively. However, it is interesting to note that between 2010 and 2011, cereal yield dropped by 9% while the cash crop yield increased by 22%. The latter is related to the warmer conditions in 2011 which favour sugar beet and potato yield (when irrigation is available). Low yields have been observed for both cash crops and cereal yields during the harvest year of 2007 while during the 2009 harvest year yields reached the maximum value. Farmed area and the annual labour hours have a small variation across the 5-year period recording a 0.4% and 1.1% increase respectively. The input with the highest average increase in £/ha over the years is water; however, there is no difference in the variation during the years. The same conclusion can be drawn for machinery and crop costs that recorded an average increase of 5.9% and 3.8% over the years.

East Anglian River Basin Catchment (EARBC)

The climate in East Anglia is characterised by an annual rainfall around 620mm per year and includes some of the driest areas in the UK. Furthermore, the EARBC has been characterised as one of the most vulnerable areas in the UK in terms of climate change (Defra, 2009; Environment Agency, 2008, 2011). This mainly impacts both land suitability and productivity (yield and crop quality). In addition, projected reduced

Table 2. Descriptive statistics of the inputs and outputs used in the DEA linear programming model for the estimation of efficiency and the MI of TFP

	Farmed area (ha)	Labour (annual hours)	Water cost (£/ha)	Machinery cost (£/ha)	Crop costs (£/ha)	Cash crops (tonnes/ha)	Cereal (tonnes/ha)
Mean	331	8364	9	70	378	57	8
St. Deviation	467	13868	9	51	136	15	2
Minimum	23	960	0	5	203	20	3
Maximum	2204	67381	35	216	840	92	10
Average % change in mean per year	1.1	0.4	7.7	5.9	3.8	11.3	2.6

levels of rainfall and evapotranspiration would increase demand for supplemental irrigation, particularly in high value crops such as potatoes and sugar beet, and hence would increase the demand for water resources in an already over-abstracted catchment.

Methods: The Malmquist Index of Total Factor Productivity

A Malmquist Index (MI) of TFP is used to measure changes in productivity for the period 2007-2011. Focusing only on technical efficiency estimates and their distribution over the study period is not a sufficient method to provide complete information on changes in performance over years (Odeck, 2009; Simar & Wilson, 1999). The estimation of the Malmquist Index (MI) is more appropriate since it enables the explanation of changes in distance functions over years due to movements within the input or output space (efficiency change) and progress or backward movement of the production set over time (technological change). Specifically, attention is drawn to the periods 2007-2008 and 2010-2011 where floods occur in parts of the county and lower-than-average levels of rainfall were recorded, respectively. The decomposition of the MI into its components and especially the Technical Efficiency change index allows the estimation of the impact of drought in the EARBC (Piesse, Thirtle, & van Zyl, 1996). The MI is more complete than the Tornqvist-Theil method used in previous studies in the UK since it is possible to separate technical (the movement of the best practice frontier) and efficiency change (the distance of farms from the frontier). Thus, it is possible to identify if exogenous factors such as research and development or weather phenomena have an impact on the frontier or if technical changes were followed up by similar or not efficiency changes (Piesse & Thirtle, 2010). For example, it allows estimation of whether an outward shift of the technological frontier was followed up by farms, improving their efficiency and hence reducing their distance to the new frontier. Moreover, the MI offers the advantage that multi-input and multi-output technologies can be estimated even in the absence of price data. In addition, we use the methodology proposed by Simar and Wilson (1998b, 1999, 2000) to estimate and bootstrap Malmquist Indices in order to determine whether differences between two or more estimates are statistically significant.

The TFP measures were calculated using a Malmquist DEA TFP methodology which enables the decomposition of the MI into technical change, technical efficiency change, scale efficiency changes and a further decomposition of technical change proposed by Simar and Wilson (1999). The MI of TFP is further decomposed into technical and efficiency change as proposed by Färe et al. (1992). In addition, the index of efficiency change is disaggregated into pure efficiency and scale efficiency change which allows discussion of the importance of farm size and returns to scale over time. Moreover, Simar and Wilson (1998) have proposed the decomposition of the technical efficiency component of the MI into the pure technical and scale efficiency change that also allows the consideration of returns to scale when shifts of the best performing frontier are accounted for.

The Malmquist index (MI) of total factor productivity (TFP), introduced by Caves, Christensen, and Diewert (1982) and further developed by Färe et al. (1992), is based on the estimation of distance functions. For the purposes of the analysis an input orientation Malmquist index is adopted since farmers have more control over the adjustment and efficient use of inputs rather than the expansion of output (Kelvin Balcombe, Davidova, & Latruffe, 2008). Specifically, the MI between period t and $t+1$ is defined as the ratio of the distance function for each period relative to a common technology. Therefore, the MI based on an input distance function is defined as:

$$M_I^t = \frac{D_I^t\left(x^{t+1}, y^{t+1}\right)}{D_I^t\left(x^t, y^t\right)} \tag{1}$$

Equation (1) is expressing the ratio between the input-distance function for a farm observed at period $t+1$ and t, respectively, and measured against the technology at period t. Values of the $M_I < 1$ indicate negative changes in TFP, values of the $M_I > 1$ indicate positive changes in TFP while values of $M_I = 1$ indicate no change in productivity.

However, since the choice of period t or $t+1$ as the base year is arbitrary (i.e. the base year can be either period t or period $t+1$), Färe et al. (1992) defined the MI of TFP as the geometric mean of the t and $t+1$ Malmquist indices. Therefore, for each farm the input orientation Malmquist index is expressed as follows:

$$M_I^{t,t+1} = \left[\frac{D_I^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_I^t\left(x^t, y^t\right)} \frac{D_I^t\left(x^{t+1}, y^{t+1}\right)}{D_I^{t+1}\left(x^t, y^t\right)}\right]^{1/2} \tag{2}$$

where $M_I^{t,t+1}$ refers to the MI of TFP from period t to period $t+1$; $\left(x^t, y^t\right)$ is the farm input-output vector in the t^{th} period; $D_I^t\left(x^{t+1}, y^{t+1}\right) = max\left\{\theta > 0 : \left(x^{t+1}/\theta\right) \in P\right\}$ is the input distance from the observation in the *t+1* period to the technology frontier of the t^{th} period with $P\left(y^{t+1}\right)$ the input set at the $t+1$ period and θ is a scalar equal to the efficiency score. The indices are calculated with the use of the non-parametric DEA method in order to construct a piecewise frontier that envelopes the data points (Charnes, Cooper, & Rhodes, 1978). The technology assumption made to estimate the MI of TFP is CRS. Otherwise, the presence of non-CRS does not accurately measure productivity change (Grifell-Tatjé & Lovell, 1995). The main advantage of the DEA method is that it avoids misspecification errors and it enables the investigation of changes in productivity in a multi-output, multi-input case simultaneously (K. Balcombe, Fraser, Latruffe, Rahman, & Smith, 2008). Furthermore, the use of the DEA method for the estimation of the MI of TFP makes it easy to compute since DEA does not require information on prices.

In addition, the index in equation (2) can be decomposed into two components: efficiency change and technological change:

$$M_I^{t,t+1} = \underbrace{\frac{D_I^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_I^{t}\left(x^{t}, y^{t}\right)}}_{\Delta Eff} * \underbrace{\left[\frac{D_I^{t}\left(x^{t+1}, y^{t+1}\right)}{D_I^{t+1}\left(x^{t+1}, y^{t+1}\right)} \frac{D_I^{t}\left(x^{t}, y^{t}\right)}{D_I^{t+1}\left(x^{t}, y^{t}\right)}\right]^{1/2}}_{\Delta Tech} \tag{3}$$

The first part of equation (3) is an index of relative technical efficiency change (ΔEff) showing how much closer (or farther) a farm gets to the best practice frontier. It measures the "catch up" effect (Färe et al., 1992). The second component is an index of technical change (ΔTech) which measures how much the frontier shifts. Both components take values more, less or equal to unity as is the case of the MI of TFP indicating improvement, deterioration and stagnation respectively.

Statistical Inference for MI of TFP and Their Components

The TFP measures were calculated using a Malmquist DEA TFP methodology which enables the decomposition of the MI into technical change, technical efficiency change, scale efficiency change and a further decomposition of technical change proposed by Simar and Wilson (1999). Despite the significant advantages of DEA for the calculation of the MI of TFP we need to consider the fact that the estimates of productivity may be affected by sampling variation. In other words, it is possible to underestimate the distance functions to the frontier if the best performing farms in the population are excluded from the sample (K. Balcombe et al., 2008; Simar & Wilson, 1999). To overcome this shortcoming Simar and Wilson (1998, 1999) proposed a bootstrapping method for the construction of confidence intervals for the DEA efficiency estimates relying on smoothing the empirical distribution. The rationale behind bootstrapping is to simulate the true sampling distribution by mimicking the data generation process (DGP) (K. Balcombe et al., 2008). Through the DGP a pseudo-data set is constructed which is then used for the re-estimation of the DEA distance functions. Increasing the bootstrapped replicates (more than 2000 (Simar and Wilson, 1998b)) allows for a good approximation of the true distribution of the sampling.

Simar and Wilson (1999) adapted the bootstrapped procedure for the estimation of the MI of TFP in order to account for possible temporal correlation arising from the panel data characteristics (Balcombe et al., 2008a). Specifically, they proposed a consistent method using a bivariate kernel density estimate that accounts for the temporal correlation via the covariance matrix of data from adjustment years. The bootstrapped estimates of the distance functions allow the calculation of a set of MI of TFP which accounts for the bias and enables the estimation of confidence intervals. The latter are used for statistical inference of the MI of the TFP and its components.

A detailed presentation for the estimation and bootstrapping of MI is available in Simar and Wilson (1999).

Non-parametric tests such as the Kruskal Wallis and Mann-Whitney U tests were used to determine statistical difference between MI years and farm sizes.

Results

Changes in Productivity and Efficiency Over Time and Farm and its Decomposition into Pure Technical and Scale Efficiency Change

Table 4 reports the mean and standard deviation of the MI of Total Factor Productivity (TFP) per farm size between 2007 and 2011. In Table 3, values of the MI above unity indicate improvement in productivity, while values below unity indicate deterioration in productivity. In addition, the significance of these changes is reported for each farm in Table 3[1].

The MI results in Table 3 show that farm productivity was affected in periods with adverse climatic conditions (2007-08 and 2010-11). Only farm ID 6 improved productivity for the period 2007 and 2008 and only 3 farms (7%), farms ID 9, 22 and 23, have consistently been improving their performance between 2008 and 2011 (p-value < 0.10). The most important positive shift in MI is recorded between 2008 and 2009 where 71% of the farms in the sample significantly improved productivity followed by the period 2009-10 with 56% of farms improving their performance. In the period between 2010 and 2011, only 27% of farms improved their productivity, with the average MI of TFP being below unity indicating this general drop in farm productivity.

The effect of adverse climatic conditions affected the productivity of all farms in a similar way. Table 4 provides further information in relation to the TFP change per farm size and time. To explore any statistically significant differences between farm size and productivity changes, the Kruskall-Wallis (one-way analysis of variance by ranks) test was used. The null hypothesis of samples originating from the same distribution was not rejected for any period. This indicates that no significant differences exist between different farm sizes in each of the periods studied in relation to changes in productivity. However, statistically significant differences in TFP were found between all years with the exception of years 2008/09 and 2009/10[2]. Hence, it should be noted that during the two periods of extreme weather phenomena, the 2007/2008 floods (Pitt and Britain, 2008) and the 2010/2011 drought, productivity significantly deteriorated.

Productivity over the whole period of the study has slightly deteriorated for all farm sizes. The average MI for the 5-year period for the large, medium and small farms is 0.99, 0.97 and 0.96 respectively. Year 2007 is considered the base year for the calculation of the MI. All averages are reported as geometric means. During the periods 2007 and 2008 the TFP deteriorated (MI<1) for all farm sizes. On the other hand, significant improvement (MI>1) is recorded for the 2008/2009 and 2009/2010 periods for both medium and large farms while for the period between 2010 and 2011 where drought conditions were prevailing the MI is less than unity, identifying deterioration in TFP for the two farm sizes. The farm size most affected from the

Table 3. Statistical significance of the MI of TFP per farm per period

Farm ID	Malmquist total factor productivity index			
	2007-2008	2008-2009	2009-2010	2010-2011
1	0.796***	1.186***	1.249***	0.898
2	0.695***	1.547***	0.880***	1.069**
3	0.679***	0.848***	1.724***	0.769***
4	0.867***	1.205***	0.893***	0.994
5	0.834***	1.608***	1.546***	0.599***
6	1.063***	1.003	1.408***	0.644***
7	0.801***	1.096*	0.983	0.984
8	0.698***	0.543***	1.579*	0.764***
9	0.665***	1.185***	1.071***	1.096***
10	0.819***	2.242	0.497***	0.819***
11	0.840***	0.935***	0.928***	1.008
12	0.669***	1.343***	1.525***	0.859***
13	0.791***	1.235***	0.915	0.696***
14	0.757***	1.278***	0.791***	1.650***
15	0.733***	1.416***	0.924**	1.056**
16	0.796***	1.362***	0.630***	1.156***
17	0.785***	0.560***	1.630**	1.174***
18	0.872***	1.270***	0.946	0.871***
19	0.856***	0.664***	1.547***	0.669***
20	0.743***	0.285***	5.227**	0.934
21	0.631***	1.091***	1.121	1.035
22	0.691***	1.048***	1.117*	1.081***
23	0.871***	1.193***	1.044***	1.111***
24	0.719***	1.452***	1.154***	0.712***
25	0.618***	1.446***	1.062	0.958*
26	0.789***	1.159***	1.175***	0.966
27	0.829***	0.978	1.130**	0.961
28	0.939*	1.098***	1.074***	0.978
29	0.945***	1.034***	1.133***	1.013
30	0.872***	1.115**	0.959***	1.124
31	0.919***	0.938	1.142***	1.007
32	0.930*	1.089*	0.973	0.935**
33	0.689***	0.981	1.226***	0.858***
34	0.560***	1.322***	0.976**	0.988
35	0.728***	1.106**	1.116	0.985
36	0.809***	1.279***	1.104***	1.035
37	0.946	0.920	1.530**	1.157***
38	0.761***	1.444***	0.953	1.202**
39	0.647***	1.144***	0.945	1.320
40	0.782***	1.037*	1.212***	0.779***
41	0.765***	1.271***	0.936***	1.072***

* Significantly different from unity at 0.1 level,
** Significantly different from unity at 0.05 level
*** Significantly different from unity at 0.01 level

weather conditions in 2010 and 2011 is the small size farm with an average of MI=0.96 for the 2010/2011 period. In addition, the MI for the small size farms is below unity for all paired years with an exception for the period 2009/2010 where a significant improvement in productivity is indicated. This large increase in the MI for the small

Table 4. The MI of TFP per year and per farm size

Farm Size	Malmquist Index[1]							
	2007/2008		2008/2009		2009/2010		2010/2011	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Large	0.78	0.12	1.16	0.37	1.11	0.32	0.95	0.23
Medium	0.78	0.07	1.14	0.19	1.02	0.19	0.97	0.15
Small	0.73	0.02	0.81	0.40	1.53	1.66	0.94	0.19

[1]Since the Malmquist index is multiplicative, these averages are also multiplicative (i.e. geometric means)

size farms is mainly due to a single farm (farm 20) which in the period 2009/2010 had MI=5.227, identifying a large improvement in technical efficiency when decomposing the MI into technical and efficiency change. If this farm is excluded from the sample then the curve becomes smoother with an average of MI=1.188.

The MI consists of two components: a) Efficiency Change (e.g. management change) and b) Technical change (production technology). Detailed presentations of the efficiency and technical change estimates are presented in Table A.1 and Table A.2 in Appendix A. Färe et al. (1994) decomposed efficiency change further into two more components: a) Pure efficiency (under the assumption of variable returns to scale) and b) Scale efficiency.

Table 5 provides further information on the decomposition of the MI for the sample presenting information for the geometric means of the farms for the 5-year period. The efficiency change component of the MI of TFP is related to distance functions measuring shifts of the farms in the sample towards the frontier. It estimates whether a farm is getting closer (catching up effect) or farther from the frontier (Färe et al., 1994) and is therefore a measure of technical efficiency change. On the other hand, the technical change index provides a representation of the shifts to the frontier of the sample based on each farm's observed input mix during the study period. It is therefore possible with this decomposition to isolate the effect of technical efficiency (catching up to the frontier) from outward or inward shifts of the frontier. In addition, the product of efficiency and technical change should by definition be equal to the MI of the period and it is possible that these components are moving in opposite directions. For instance, farm 1 had the capacity to improve productivity over the 5-year period and its geometric mean of MI was 1.015. The index of efficiency change (1.082) indicates an improvement of efficiency, and therefore, indicates an improvement in input savings by 8.2% while the index of technological change (0.937) implies that the farm failed to maintain input saving technology. However, this lagging performance in technological change did not outweigh significantly the improvement in efficiency change and thus the overall productivity was improved by 1.5% in the observed period. It is therefore concluded for farm 1 that the improvement in productivity is mainly due to efficiency improvements rather than technological changes. The same is concluded for the majority of the farms in the sample when the geometric means for the MI and its components of efficiency and technical change are considered. Specifically, the

Table 5. Geometric mean of MI components per farm and farm ranking with respect to MI

Farm ID	MI	Efficiency Change	Technical Change	Pure Efficiency Change	Scale Efficiency Change	Ranking with respect to MI[1]
1	1.015	1.082	0.937	1.000	1.082	10
2	1.003	1.006	0.997	0.994	1.012	15
3	0.935	0.950	0.984	1.000	0.950	34
4	0.981	0.986	0.995	0.991	0.995	19
5	1.056	1.139	0.927	1.098	1.037	4
6	0.992	1.048	0.946	1.052	0.997	18
7	0.960	1.000	0.960	1.000	1.000	29
8	0.822	0.889	0.925	0.921	0.965	41
9	0.981	1.000	0.981	1.000	1.000	20
10	0.930	1.000	0.930	1.000	1.000	35
11	0.926	0.985	0.940	0.939	1.048	36
12	1.041	1.077	0.967	1.015	1.061	7
13	0.888	1.000	0.888	1.000	1.000	39
14	1.060	1.118	0.948	1.051	1.063	2
15	1.003	1.002	1.001	0.988	1.015	14
16	0.943	0.956	0.986	0.962	0.994	32
17	0.958	1.000	0.958	1.000	1.000	30
18	0.978	1.008	0.969	1.077	0.936	23
19	0.876	1.000	0.876	1.000	1.000	40
20	1.008	1.000	1.008	1.000	1.000	13
21	0.945	1.000	0.945	1.000	1.000	31
22	0.967	0.943	1.025	0.892	1.058	27
23	1.048	1.022	1.025	1.000	1.022	5
24	0.962	1.065	0.903	1.051	1.013	28
25	0.976	0.977	1.000	1.034	0.945	24
26	1.009	1.055	0.957	1.006	1.048	12
27	0.969	1.000	0.969	1.000	1.000	26
28	1.020	1.139	0.895	1.091	1.044	9
29	1.029	1.096	0.939	1.035	1.058	8
30	1.012	1.045	0.968	1.030	1.015	11
31	0.998	1.050	0.950	1.041	1.009	16
32	0.980	1.000	0.980	1.000	1.000	22
33	0.918	0.967	0.950	0.969	0.997	38
34	0.919	0.928	0.991	0.923	1.005	37
35	0.970	0.980	0.990	0.986	0.994	25
36	1.043	1.129	0.924	1.096	1.030	6
37	1.114	1.100	1.013	1.104	0.996	1
38	1.059	1.139	0.930	1.085	1.050	3
39	0.981	1.006	0.975	0.992	1.014	21
40	0.936	1.000	0.936	1.000	1.000	33
41	0.994	1.027	0.968	0.991	1.037	17

MI: Malmquist Index, Note: All indices are geometric means

geometric mean of the MI of TFP for the 5-year period is 0.98, while for efficiency change it is 1.03 and 0.96 for the technical change. Hence, the deterioration in estimated productivity was mainly due to fall back of the frontier rather than a reduction in technical efficiency of the farms. In other words, although farms have improved their management performance in order to shift efficiency upwards, other exogenous factors such as extreme weather phenomena (2007/2008 floods, 2010/2011 drought) and increased input market prices (fertilisers and soil improvements in 2009) resulted in less technological change.

Table 6 provides further information of the geometric means for the efficiency and technical change per year and per farm size. No significant differences are found between farm sizes. However, it is rather significant that the deterioration of the MI as it has been observed in Table 3 and Table 4 for the 2007-2008 and 2010 – 2011 periods is mainly driven from technical change rather than efficiency change. Specifically, the reduction in MI for the 2007 – 2008 period was on average 20% as a result of the extreme flood events and on average by 6% during the drought of 2011.

In addition, the component distance functions in the technical change index of the MI of TFP are used to identify farms responsible for the frontier shift (Färe, Grosskopf, Norris, & Zhang, 1994). During the period between 2007/2008 no farm caused any shift to the frontier since technical change was less than unity for all farms. The farms that caused the frontier to shift in the remaining three pairs of years were farm 13 in the 2008/2009 period, farms 32 and 33 in the 2009/2010 period and farms 4, 16 and 35 in the 2010/2011 period. According to Färe et al. (1994) these farms can be identified as the "innovators" of the sample.

The efficiency change index can be further decomposed into pure efficiency and scale efficiency change isolating in that way the impact of farm scale to efficiency change. Table 7 reports the distribution of pure and scale efficiency estimates for the consecutive years. Estimates of pure and scale efficiency per farm are presented in Table B.1 and Table B.2 in Appendix B. The results for 2009/2010 indicate that the scale efficiency index has improved for more than 71% of the farms; however the pure efficiency index deteriorates for 51% of the farms in the sample. This adjustment in scale might be the reason for the deterioration in efficiency since farms need to adapt their management requirements into the new conditions and scale of operation. Figure 1 illustrates these changes, in which scale efficiency deteriorates after the 2008/2009 period. In addition, the improvement in efficiency for the 2007/2008 period is mainly due to improvements in pure efficiency while it has an adverse impact to the next period causing efficiency to deteriorate. However, pure efficiency is the main factor in the improvement of the efficiency change index for the 2010/2011 period.

Factors affecting the frontier such as the extreme weather phenomena observed in the 2007/2008 and 2010/2011 periods have a significant impact on technical change and consequently on productivity for the GCFs in the EARBC. The decomposition of

Table 6. Efficiency and technical change per farm size and per period

Farm Size	2007-2008		2008-2009		2009-2010		2010-2011	
	Efficiency change	Technical change	Efficiency change	Technical change	Efficiency change	Technical change	Efficiency change	Technical change
Large	1.02	0.76	0.99	1.17	1.10	1.01	1.02	0.93
Medium	0.98	0.79	1.11	1.03	0.93	1.10	0.98	0.99
Small	1.00	0.73	1.01	0.81	1.05	1.46	1.02	0.93

Table 7. Distribution of the efficiency change decomposition

Distribution	2007/2008		2008/2009		2009/2010		2010/2011	
	Pure	Scale	Pure	Scale	Pure	Scale	Pure	Scale
<0.6	0	0	0	0	0	1	1	0
0.6≤ Eff <0.8	2	1	3	1	5	2	0	2
0.8≤ Eff <1	11	14	7	14	16	4	8	20
Eff=1	16	7	13	2	12	5	15	3
1< Eff <1.2	9	17	11	21	6	20	14	15
1.2≤ Eff <1.4	2	1	6	2	0	5	2	1
Eff>1.4	1	1	1	1	2	4	1	0
Improvement	29%	46%	44%	58.5%	19.5%	71%	41%	39%
Deterioration	32%	36.5%	24%	36.5%	51%	17%	22%	54%
Geometric Mean	1.04	1.02	1.01	1.02	1.03	1.01	1.05	0.98

Figure 1. Changes in efficiency change index and its components

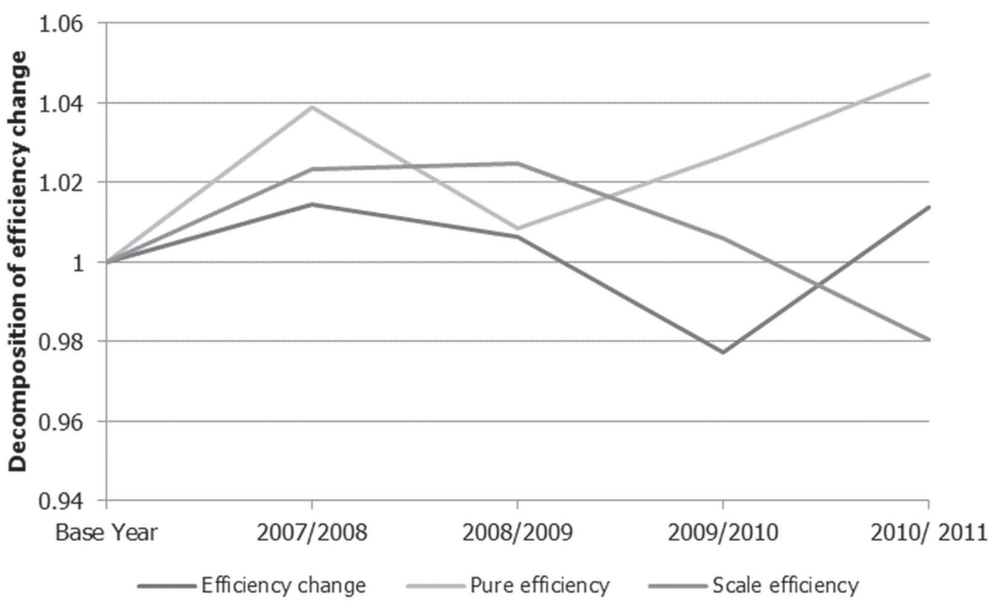


Table 8. Distribution of the technical change decomposition

Distribution	2007/2008		2008/2009		2009/2010		2010/2011	
	Pure	Scale	Pure	Scale	Pure	Scale	Pure	Scale
<0.6	1	0	1	2	0	0	2	2
0.6≤ Eff <0.8	7	0	2	0	0	3	5	14
0.8≤ Eff <1	7	11	4	10	8	23	18	11
1< Eff <1.2	0	3	21	24	21	9	6	5
1.2≤ Eff <1.4	0	0	7	1	3	1	2	2
Eff>1.4	0	1	2	0	4	0	1	0
Not feasible to compute	26	26	4	4	5	5	7	7
Improvement	0%	10%	73%	61%	68%	63%	61%	25%
Deterioration	37%	27%	17%	29%	20%	24%	22%	17%
Geometric Mean	0.75	1.00	1.10	0.98	1.13	0.95	0.91	1.05

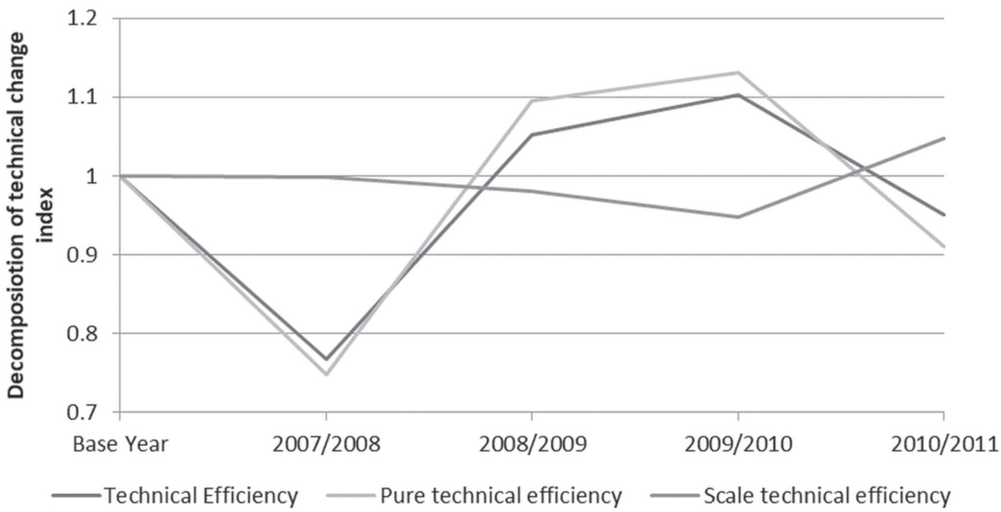
technical change proposed by Simar and Wilson (1999) was used in order to isolate the impact of farm scale in the technical change component of the MI of TFP. Tables C.1 and C.2 in Appendix C provide a detailed presentation of the pure technical, scale technical changes and the product of the latter with the scale efficiency component of efficiency change[3]. Figure 2 illustrates the technical change index. Shifts in the frontier are mainly driven by the pure technical efficiency index rather than the scale of operation of the farms in the sample. Thus, Table 8 shows the distribution of the two components of technical change, pure and scale, during the 5-year period.

Considering both pure technical and pure efficiency change in the 2008/2009 period, GCFs in the EARBC have successfully improved their management performance and were able to maintain this input-saving technology during the remaining periods (2009/2010, 2010/2011) (Figure 2) while pure technical efficiency drops significantly in the 2010/2011 period, pushing productivity below unity.

DISCUSSION

Comparison of the results obtained from the MI of TFP revealed deterioration in productivity for the GCFs in the EARBC over the study period 2007-2011 for all farm sizes. Furthermore, the decomposition of the MI of TFP into its components enabled a disaggregation of the effects of technical efficiency (catching up to the frontier) and outward or inward shifts of the frontier. Hence, deterioration in productivity is mainly due to fall back of the frontier rather than reduction in technical efficiency of the farms. Farms on the efficient frontier are becoming more efficient due to improvements in the pure efficiency index rather than technical change. Specifically, productivity falls for the 2007/2008 and 2010/2011 periods due to a fall in the technical change index which reflects the impact of the extreme weather phenomena for 2007 (floods) and 2011 (drought). The more frequent these extreme weather phenomena occur, the more

Figure 2. Changes in technical change index and its components



the need for adapting to these changes is. Farm performance is very sensitive to such changes in weather conditions leading to underperformance. All farms' productivity, regardless of their size, are affected by weather. Hadley (2006) has similarly showed that technical change is the factor with the most significant role in the increase of efficiency in a period of 20 years (1998-2002). Furthermore, in a more recent study by Barnes et al. (2010), a general upward trend in technical efficiency was also reported throughout the period. On the other hand, the most important improvement in MI is recorded between 2008 and 2009 where 73% of the farms are indicated with a significant improvement in TFP. Generally, 15% of the farms have been consistently improving TFP over the study period while the remainder of the sample has been fluctuating above and below unity, thus improving efficiency in some years and decreasing in others.

In addition, scale efficiency change (Figure 2) for the years between 2008 and 2009 drops below unity. This is mainly explained by the change in the proportion between large, medium and small farms in the sample compared with previous years. The average farm size in 2011 is lower than 2009 (medium and small size farms have doubled). However, the technical scale efficiency change is increasing for the same period, implying that farms operate closer to the point of a technically optimal scale under the VRS assumption. According to (Coelli, Perelman, & Van Lierde, 2006) the fall in scale efficiency might be caused from the faster rate that larger farms improve productivity when compared to medium and small farms. Therefore, the performance gap between the different sizes of farms is widening and is depicted by the technical scale efficiency.

CONCLUSION

The challenge of sustainable intensification of agricultural production and the need to meet increasing food demand requires farming systems to improve their productivity. In the case of GCFs in the EARBC, the potential risk of increasing summer droughts and temperatures due to climate change is also a challenge that should be considered. We have shown the effects of weather conditions on farm productivity.

The analysis of TFP of the GCFs in the EARBC, based on the measurement of the MI and its components, has shown that extreme weather phenomena have a negative impact on productivity. During the 5-year study period, both efficiency and productivity fell due to the floods in 2007 and the drought period between 2010 and 2011. However, pure efficiency change has been positive, indicating that farmers are improving their management skills and are adopting input-saving technologies. On the other hand, pure technical efficiency deteriorates and is the main reason for the lowering of productivity of the GCFs in the EARBC. In addition, the bootstrap of the MI of TFP and its components provides a correction for the inherent bias in non-parametric distance functions and allows statistical inference for the results. Hence, it is possible not only to indicate changes in the MI of TFP but also to indicate if these changes are statistically significant.

Finally, the analysis of returns to scale and scale efficiency change allows the identification of farms operating closer to the point of the technically optimal scale as well as the identification of the optimal scale for farms in the sample. Furthermore, distinguishing between PTE and OTE permits the development of strategies for reducing inputs or scale adjustment in the short and long run respectively.

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ENDNOTES

[1] Confidence intervals (CIs) were calculated for 10%, 5% and 1% levels of significance. The majority of the MI estimates are significantly different from unity at the 99% or 95% level. Hence, a farm is reported to have experienced significant progress between the two time periods if its confidence interval lower bound is greater than unity, it has significantly regressed during the period if its upper bound is less than unity and there is no statistically significant change if unity is included in its confidence interval.

[2] Mann-Whitney U test was used to test for TFP difference between periods.

[3] It should be noted that in some cases the computation of pure technical change or scale efficiency based on distance functions between the two time periods is not feasible to compute due to the linear programme constraints.

Yiorgos Gadanakis research interests are Agricultural Economics, Agri-Business management and Environmental Economics. In the past he has worked on: Evaluating sustainable agri-food systems and rural development in the Mediterranean Partner Countries (MPCs); Ex-post and ex-ante evaluation of rural development and regional plans strengthening innovation capacity and sustainability in agricultural sector; Establishing common models of integrated sustainable monitoring, planning and management of high environmental value areas to control natural resources degradation" Research topic "Lefka Ori, the Greek case study"; Measuring the impacts of distortions in the European Union cotton sector. My most recent research focuses on Sustainable Intensification of Agricultural Systems in the UK, measures of Total Factor Productivity and Technical Efficiency of farming systems. Francisco Areal is an Associate Professor in Environmental Economics at the School of Agriculture, Policy and Development, University of Reading. He was appointed Lecturer of Environmental Economics at University of Reading in 2011. Previously he worked at the Joint Research Centre – Institute for Prospective Technological Studies in Seville, Spain and at the Central Science Laboratory in York (currently known as the Food and Environment Research Agency –FERA-). Francisco research has recently focused on four areas: efficiency analysis, performance of genetically modified (GM) crops and evaluation of coexistence policies, sustainability, and food security. Francisco has worked on a wide number of nationally and internationally funded projects.