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DOI:
10.1111/1477-9552.12506

First published: 09/09/2022

Document Version
Peer reviewed version

The role of family life cycle events on persistent and transient inefficiencies in Less Favoured Areas

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Abstract: Family farms dominate Less Favoured Areas (LFA) within Europe, and family life-cycle conditions, such as succession and retirement, affects how these farms adapt to changing conditions. Past studies of on-farm technical efficiency have not directly addressed these conditions, but they may explain why some farms are more efficient than others, especially as the farm family model dominates most farming systems. Motivated by the UK's withdrawal from the EU and the debate around establishing replacement support policies we apply a multi-step model to measure both transient and persistent inefficiencies using a panel of LFA Cattle and Sheep farms in Scotland over the period 2003 to 2020. We find a greater prevalence of transient compared to persistent efficiency, which suggests that structural problems still exist. Farms with planned succession are found to have higher persistent efficiencies, whereas farmers nearing retirement have lower levels. Other factors, such as dependence on subsidy, off-farm activity and classification as severely disadvantaged tend to compound these lower efficiencies. We argue that life-cycle conditions should not be ignored in studies of farm technical efficiency. Within the scope of framing a new agricultural policy for UK administrations, these results inform the debate on support for Less Favoured Areas, as well as the promotion of support towards generational renewal to ease transition across farm family life-cycle events.

Keywords: Transient Efficiency, Persistent Efficiency, Less Favoured Area Cattle and Sheep farms, Scotland, life-cycle conditions and events.

JEL Classifications: C01, D22, D91, J26, Q12, Q18

1.0 Introduction

Cattle and sheep farms are significant contributors to the agricultural economy globally (e.g Hocquett et al., 2018). The bulk of these farms are situated in disadvantaged or less favoured areas (LFA) and considered a particularly fragile economic activity (Barbier and Hochard, 2018; Acs *et al.,* 2010; Williams *et al.*, 2021). These farms also support historic upland ecosystems, as well as the social benefit of maintaining populations in remote areas (Reed et al., 2009; Ruben and Pender, 2004; Acs et al., 2010; van Rensburg and Mulugeta, 2016). LFA cattle and sheep farms are likely to be family run with a high reliability on farm household labour (Weltin et al., 2017; Ashkenazy et al., 2018). As a consequence, low incomes are typical and reliance on subsidy support is high (Pérez *et al*., 2007; Gaspar *et al.,* 2009; Acs *et al*., 2010; van Rensburg and Mulugeta, 2016). The economic survival of LFA cattle and sheep farms is especially acute in the UK as the withdrawal from the European Union's Common Agricultural Policy at the end of 2020 has led to debate on the most appropriate replacement frameworks for agricultural support in the next decade (Hubbard et al., 2018; Vigani and Dwyer, 2018; Choi et al., 2018). Moreover, exposure to new trade deals, such as those with Australia and New Zealand, may lead to increasing pressures on the resilience of home-produced cattle and sheep meat (Choi et al., 2018; Arnott et al., 2021).

Technical efficiency (TE) is major indicator of farming performance as it reflects the use of inputs to outputs (Ren et al., 2019). Given the ubiquity of cattle and sheep systems within Europe their efficiency has been explored by a number of authors. The majority of these have not directly estimated the TE of farms in Less Favoured Areas but have tended to use an indicator variable to explain differences in efficiency with lowland systems. Hadley *et al*., (2006) and Barnes *et al.* (2008; 2010) applied the classic cross-sectional stochastic production frontier framework to sheep and beef farms within the UK. These studies found significantly lower efficiencies for farms in Less Favoured Areas. Martinez Cillero *et al*. (2018) studied cattle farms in Irish LFAs and found a similar lower TE for farms in severely disadvantaged compared to disadvantaged LFA classes. Ang (2019) examined Welsh sheep-meat productivity, the majority of which is produced in upland and Less Favoured Areas, and found that, whilst growth increased by around 2.3% per annum on average, this was not evenly distributed. This tallies with findings from Barnes (2020), who identified a great deal of heterogeneity in financial performance for LFA farms in Scotland. These two studies argued for a review of policies directed towards these sectors to ensure equity.

Several studies have inferred differences between upland and lowland production through the exploration of extensive compared to those intensive systems which would typically be observed in lowland regions. Theodoridis et al (2021) examined sheep-meat in the UK, Greece and France using the non-parametric data envelopment analysis approach, arguing that extensive farms need to intensify if they are to remain in a liberalised market and compete internationally. Applying a latent class stochastic frontier model to French beef farms Dakpo et al. (2020) found extensive beef farms to have higher productivity growth than those in their identified intensive class. Vigani and Dwyer (2020) examined a sample of English upland grazing livestock farms from 2010 to 2014, finding disparities in TE which were driven by altitude disadvantages.

An aspect of these farms which the above papers have not fully explored is the family household nature of these businesses (Weltin *et al*., 2017; Ashkenazy *et al*., 2018; Morgan-Davies *et al*., 2021; Arnott *et al*., 2021). The family farming model is ubiquitous globally and the role of farm family life cycle patterns have been extensively explored to assess the evolution and survival of these systems (Dubois and Carson, 2019; Boncinelli *et al*., 2018; Loizou *et al*., 2019; O'Rourke, 2019; Fuller *et al*., 2021). However, the role of farm family lifecycle factors as determinants of TE have been less well explored. Specifically, key events such as succession and retirement have been ignored in TE studies but have been found to be major causes of change in resource allocation on the farm (Potter and Lobley, 1996; Calus *et al*., 2008; Mishra and El-Osta, 2008; Sutherland *et al*., 2012; Suess-Reyes and Fuetsch, 2016; Bertoni *et al*., 2021).

We add to the literature in two ways. Firstly, no studies have directly examined succession and retirement as determinants of technical inefficiency. The changing pattern of decision-making towards investment, may change before or after a major event, such as handover or retirement, and this potentially results in a reallocation of resources with an associated change in observable TE (Chen and Holden*,* 2017; Wilkening, 2019; Wilson, 2008; Sutherland *et al.,* 2012; Barnes *et al*., 2016; Quemada *et al*., 2020). This offers lessons for other farming sectors as attempts have been made to support generational renewal through, for example farmer retirement schemes (Davis et al., 2009) but also to support successors and succession planning (Kimhi and Lopez,1999). This continues under present UK and EU agricultural policies which promote renewal of its workforce to support increased sustainable resource use efficiencies (Lobley et al., 2018; European Commission, 2020; Bhattacharyya *et al.,* 2020; Schebesta and Candel, 2020)

Secondly, we explore the extent of structural problems in the LFA cattle and sheep sector by disaggregating inefficiencies into transient and persistent components. Whereas transient inefficiencies occur due to random events or 'shocks' from the economic or biophysical environment, the presence of persistent inefficiency reflects a longer-term structural issue in the sector that can only be addressed by external intervention (Kumbhakar et al., 2014; Colombi et al., 2014; Badunenko et al., 2021). A small but growing literature is emerging on transient and persistent efficiencies in farming (Kumbhakar et al., 2014; Filippini and Greene, 2016; Manevska-Tasevska et al., 2017; Lien et al., 2018; Trnková and Žáková Kroupová, 2020; Baležentis and Sun,2020; Addo and Salhofer, 2022) but none have been applied to a UK farming context and only one study has included beef, as a part of an analysis of crop-livestock systems (Minviel and Sipiläinen, 2021). Accordingly, this analysis meets that gap by focusing on LFA farms to assess the magnitude of transient and persistent inefficiencies within these systems.

We focus on Scotland which, as a devolved administration of the UK, is currently debating a replacement for the CAP. LFA cattle and sheep farming is the principal activity of the Scottish agricultural economy and an estimated 88% of all agricultural land is classified as LFA. As beef and sheep meat are principal exports of the Scottish economy future sustainable growth of the industry will be underpinned by resource use efficiencies within this sector (Moxey, 2016).

The paper is set out as follows. The next section outlines a conceptual framework for understanding farm family life cycles and transient and persistent inefficiencies. This is followed by a description of the data used, the input and output variables chosen and the methodology for the multi-step component model to estimate efficiencies. Then results are presented alongside a discussion against past literature. Finally, a conclusions section identifies the potential consequences for both policy and data and collection mechanisms.

2.0 Family life-cycles and transient and persistent technical efficiency

The recent literature on inter-generational handover has identified that when farmers inherit the business they will tend to be more entrepreneurial, more inclined towards diversification activities, and adopt a more environmental orientation (Zagata and Sutherland, 2015, Hamilton *et al*., 2015; Suess-Reyes and Fuetsch, 2016; Corsi, 2017). Creating a succession plan is commonly found to positively influence on-farm decision making for both production and environmental activities (Suess-Reyes et al., 2016; Barnes et al, 2016). A succession plan formalises the process of handover as well as the changing roles and responsibilities of family members (Bertoni et al., 2021; Bertolozzi-Caredio, et al., 2020; Coopmans et al., 2021; Rech et al., 2021). Accordingly, it would be expected to influence transient inefficiency, as the handover and acquisition of management skills may cause short term perturbations, but also address persistent inefficiencies as the above literature identify a long-term change in the farm's investment pattern post-handover.

A related aspect is the process of retirement. As the farmer approaches retirement then investment may increase after a farm successor has been identified, or disinvestment will occur if the farm has no successor (McConaughy and Phillips., 1999; Lobley and Bakker, 2012; Zagata and Sutherland, 2015; Bertoni *et al*., 2021). A retirement variable would explain the effect of increasing or decreasing persistent technical inefficiencies due to either investment increasing or being run down as the farmer withdraws from the business.

Farmer's age, as recorded within the Farm Account Data Network (FADN), has been used as a determinant to explain differences in technical efficiency studies, but this has generated mixed results (Bozoğlu, and Ceyhan, 2007; Martinez Cillero et al., 2018 Ahovi et al., 2021; Dakpo et al., 2021). Age may be considered a composite indicator for the effect of management ability, knowledge and skills acquisition, which may explain the mixed results found for this measure. Moreover, using principal decision maker's age ignores the farm family model where there will be different degrees of decision making within the family unit (Bowler et al., 1996; Hayden et al., 2021). Burton (2006) applies some scepticism to the use of principal decision-making age in measurement studies, and to overcome this, he produced a simple index of an average of family ages to reflect the joint decision-making structure within a farm. This would affect both transient and persistent inefficiencies as the level of skills acquisition will determine the management of short-term shocks in input management but may also reflect persistent inefficiency through joint decision making.

A further characteristic of the farm family lifecycle is the reliance on household, as opposed to hired, labour. Some studies in dairy and crop farming sectors have found that higher proportions of hired labour would relate to higher efficiencies (Zhu and Lansink, 2010; Barath and Ferto, 2015; Trnková and Žáková Kroupová (2020). The amount of labour present on the farm reflects an underlying resource to respond to short term shocks, but also the maintenance of persistent inefficiency which may be reflective of habitual decision-making and limited adaptation.

Notably only a small number of studies have focused on the determinants of transient and persistent inefficiency in the agricultural sector. Several have focused on the crop sector (Lien et al, 2018 Addo and Salhofer, 2022) whereas others have examined the livestock sector. Of these Manevska-Tasevska et al. (2017) looked at pig farms in Sweden, whereas Trnková and Žáková Kroupová (2020) and Baležentis and Sun (2020 both examined dairy farming. Minviel and Sipiläinen (2021) identified transient and persistent inefficiencies in mixed crop-livestock systems. Very few of these have explored determinants which would relate to any of the above family life cycle factors. Addo and Salhofer (2022) identified the influence of age on transient inefficiency for their study of Austrian crop farms, finding younger farmers would be expected to be more efficient. They added an additional squared term and found this to be inverse-U shaped whereby farmers would reach maximum efficiency at around 50 years of age and then efficiency would be expected to decline after that. Baležentis and Sun (2020) found the opposite effect of age on Lithuanian dairy farm transient inefficiencies, finding older farmers would be related to higher transient efficiencies. Another determinant explored by these studies is the effect of family to hired labour. Addo and Salhofer (2022) applied this to persistent inefficiencies, finding higher family labour share to be positively related to higher persistent efficiency. This led them to conclude that a more family run farm can manage occasional bad years more than farms with a mixed labour supply. Conversely Trnková and Žáková Kroupová (2020) explored hired labour as a determinant of transient inefficiency finding farms with a higher share of hired labour in the EU milk sector would be expected to have higher levels of transient efficiency.

The majority of these studies use national level FADN. This offers a rich resource to explore farm businesses over a long time period. National bookkeeping data in the form of the Farm Business Survey (FBS) provides more information around the family household factors than those collated centrally by the EU FADN. The next section outlines the data itself and the construction of variables to reflect some of these farm lifecycle factors, as well as a detailed methodology towards estimating their effect on transient and persistent inefficiencies.

3.0 Methodology

3.1. Data

National level data collected for the Scottish Farm Business Survey (SFBS) were used. These data are collected annually as part of annual recording within the EU's Farm Accountancy Data Network (FADN)[1]. These data were extracted for the years 2002/03 to 2019/20. This period represents a start time for the decoupling agenda of the CAP to be implemented and the year up to the UK's withdrawal from the EU. Ideally, in technical efficiency measurement we must attribute inputs to the same output activities, but this also needs pragmatism when applied to farming data as all farms will have a mixture of enterprise outputs. Less Favoured Area livestock farms are particularly prevalent in Scotland, these farms will have mixtures of sheep and cattle enterprises on their farms, and we merge the LFA Cattle and Sheep category with LFA Specialist Sheep and LFA Specialist Cattle[2] .

The descriptive statistics of the unbalanced panel are presented in Table 1. This shows 3,857 observations overall, which averages around 214 farms per year. We take total revenue less subsidies as the output variable, deflated by appropriate price indexes provided

[1] Detail on methodologies, definitions and data collection are available here: https://www.gov.uk/guidance/farm-business-survey-technical-notes-and-guidance

[2] Farms are classified based on having at least 2/3rds of their standard outputs from a particular activity. Previous to the 2010/11 period farms were classified based on 2/3rds of the standard gross margins.

by Defra in 2010 values. Subsidy payments during the majority of this period were based on an historic allocation related to activity between 2000-2002 (Sorrentino and Henke, 2016). Consequently, including subsidies within the output variable would lead to a significant distortion in output activity beyond these years and should be dropped to truly reflect input to output activity.

Labour consists of total hours worked on the farm. Intermediates consists of the main variable inputs into the production process deflated by their appropriate price indices, namely fuel and electricity, feed, veterinary, fertilisers, seeds, and other livestock costs. Capital is measured as the deflated closing value of total farm-based assets. Livestock were measured as grazing livestock units; this is to provide a common unit between cattle and sheep production. Notably, the SFBS does not identify the underlying systems of production, which is a constraint to the analysis. In Scotland, as with elsewhere, cattle producers could produce either animals, as the result of a suckler system, or beef meat, from finishing herds. Hence, this will not reflect the pure input of animals into the production process but does provide a metric for common inputs across cattle and sheep farms. More detailed approaches, using bespoke data collection may overcome this problem (see for example Aadland, 2004). Area refers to total adjusted area, this is adjusted for grazing feed intake given the extent of poor grazing land within the LFA regions[3]. To provide consistency of estimation all output and input series were normalised around the sample means (Trnková and Žáková Kroupová, 2020; Addo and Salhofer, 2022).

To mediate the production function, we include an altitude variable to account for heterogeneity in biophysical conditions that reflects the shift in production potential expected from farming at a higher altitude. This is categorised into three groups within the SFBS, with the latter group for farms above 600m. However, this only had a small number of observations (1.6% of the entire sample). Accordingly, we collapsed this into a binary variable and our altitude indicator reflects farms below and above 300m. We also include a farm type categorical variable to reflect whether they are considered specialist or mixed livestock enterprises. However, it is worth noting that classifying these farms as specialist farms is based on at least 2/3rds of their standard output coming from one enterprise. Hence, specialist LFA livestock farms will invariably have mixtures of cattle and sheep, albeit at lower proportions to mixed LFA livestock farms.

Table 1. Variables used within the production function and explanatory variables, descriptive statistics

[3] Adjusted utilised agricultural area comprises the utilised agricultural area with rough grazing in sole occupation converted to a permanent pasture equivalent.

Determinants of inefficiency

Within the SFBS questionnaire a section captures a number of characteristics which reflect farm family life-cycle factors. Firstly, for family members who work on the farm, their proportion of time worked is given, along with their ages. We took a simple average of age of family members weighted by hours worked on the farm, to indicate the amount of effort employed at the farm level. This develops Burton's (2006) metric further and reflects their level of engagement on the farm and, by inference, their influence on decision-making.

Farmers are asked whether a succession plan has been agreed and we take this as a binary variable, where 1 reflects a succession plan is in place. We would expect a succession plan to lead to a change in the decision-making structure on the farm which is reflective of the gradual handover of assets to the inheritor (Suess-Reyes *et al*, 2016; Barnes *et al*., 2016). Having a succession plan consequently reflects an improved ability to reduce the effects of long-term and short-term perturbations. Conversely, farmers are asked their approximate time to retirement within the SFBS. These are categorised as less than five years, less than 10 years, or less than 20 years. Whilst it would be useful to keep these fields and indicate the effect of a stated retirement time on performance, there were fewer observations in the earlier field. Consequently, we collapse these categories into a binary variable where 1 indicates whether the farmer has stated an intention to retire in less than 10 years. The SFBS has no indication of intention to exit the industry. Accordingly, whilst retirement planning has an influence on investment, we cannot say whether the intention to exit would affect transient or persistent inefficiencies.

Education is detailed in the SFBS in terms of the highest qualification level by type, i.e., agricultural, or non-agricultural, and level, i.e., school only, college, degree, or post-graduate. We take education as dummy variables to compare against a school-only education. Here we reduce all non-agricultural higher education into one category, and all agricultural higher education into another. This split will reflect the relationship between either a practical applied higher agricultural education, or a non-agricultural education and their relationship to transient or persistent efficiency. Problematically, there are no variables in the SFBS which directly ask for years of experience in managing the farm. As past studies have found years of experience to be positive based on bespoke surveys (Wilson *et al,* 2001; Manevska-Tasevska *et al*., 2017) it may be useful to know its influence, specifically with respect to new entrants but currently this is not available in the SFBS.

The amount of family labour as well as regular and seasonal hired labour in hours worked is declared in the SFBS. Accordingly, we take a ratio of family to total labour hours worked on the farm to infer the amount of household effort focused on the farm. This gives an indication of the allocation of family (farmer, spouse, other family members) labour to the enterprises (Veysset et al., 2019; Vigani and Dwyer, 2020).

Tenanted farmers are constrained by the requirements of their tenancy and also lack leverage for investment when compared to owner-occupiers (Hadley, 2006; Barnes, 2008; Vigani and Dwyer, 2020). It has been argued that tenanted farmers are more motivated to attain high levels of efficiency due to the economic necessity to fulfil rent demands (Zhu and Lansink, 2010; Trnková and Žáková Kroupová, 2020). The SFBS identifies full tenancies but also mixed tenancies, these are farmers who own a mixture of owned and tenanted ground, e.g., for grazing land, and the tenanted area is affected by the rights of the landlord. Hence, tenancy would be expected to influence long term persistent efficiency but, given the shorter nature of tenanted and mixed tenanted land agreements, would also influence transient efficiency as well.

As our farms are all within a Less Favoured Area, we examine those farms within disadvantaged compared to severely disadvantaged areas (SDA). Farms with the majority of land in SDA are limited by climatic, altitude, difficult topography and remoteness and National payment regimes are based on the severity of the disadvantaged land (Martinez Cillero et al., 2018; Rudinskaya et al., 2019; Barnes et al., 2020). We produce a dummy variable which reflects whether the land is classified as severely disadvantaged compared to disadvantaged. We would expect this indicator to have a negative effect on persistent inefficiency as it reflects underlying structural constraints.

Payment subsidies are a significant contributor to incomes in the LFA sector and this will affect technical efficiencies by influencing decision making (Serra et al., 2008; Zhu and Milán Demeter, 2012). Studies of beef and sheep farming across Europe find a mostly negative effect of subsidies on technical efficiency (Minviel and Latruffe, 2017). We take the level of subsidy as a ratio to total agricultural revenue, as predictor of the magnitude of the effect of subsidies on transient and persistent inefficiency (e.g., Lien et al., 2018, Addo and Salhofer, 2022).

Lien et al. (2018) took off-farm hours as a ratio of total hours spent to estimate the influence of off-farm work on transient inefficiency. The SFBS only provides the amount of revenue from off-farm activities. Accordingly, we take off-farm revenue to total revenue as a proxy for off-farm activity in the absence of more detailed statistical measures.

The size of the farm, usually measured in Economic Size Units (ESU[4]), will also reflect the ability of the farm to manage resources more effectively. Most studies find that larger farms tend to have higher levels of efficiency (Zhu and Lansink, 2010). We take size as dummy variables using definitions from the SFBS, to compare medium (>=8 to <=16 ESU) farms and large (>16 ESU) farms with small (<8 ESU).

Lien et al (2018) argued that transient and persistent inefficiencies are reflected by diverse aspects of performance. This led Addo and Salhofer (2022) to apply different determinants in their estimation of transient and persistent inefficiency, stating that persistent inefficiency is determined by relatively stable indicators over time. However, other studies have used both sets of determinants to explain persistent and transient inefficiencies (Colombi et al., 2017; Lai and Kumbhakar, 2018). Accordingly, it would seem there is no robust conceptual basis for either approach, though we would argue a common set of indicators would capture any transient or long-term effects that may not have been considered by the analyst. We use the same set of determinants for transient and persistent inefficiency. To accommodate the non-time varying aspect of persistent inefficiency we take the individual farm level means for each determinant (except for dummies and categorical variables) following Lai and Kumbhakar (2018) and Addo and Salhofer (2022).

3.2. Method

We measure technical efficiency using the multi-step model (Kumbhakar *et al*. , 2014; Colombi et al., 2014; Tsionas and Kumbhakar, 2014). This approach decomposes efficiency into both persistent and transient components. The full equation is presented below, where *i=1,2..., n* is the n number of individual farms and *t* =1,2...T denotes the time periods in which these farms are observed:

$$y_{it} = \alpha_0 + f(x_{it}\,;\,\beta) + \delta_t t + \mu_i + \nu_{it} - \eta_{it} - u_{it} \qquad (1)$$

The dependant variable (y_{it}) is the output for each *i* farm at time *t*, $\alpha_0$is an intercept term, $f(x_{it};\,\beta)$ is the production technology, composed of a vector of x inputs). A time trend is also added to account for technical change (*t*). β and δ are corresponding parameters to be estimated. The remainder of equation (1) captures the changes in output not explained by input variations and are composed of: the parameter μ_i which depicts unobserved, time-invariant farm heterogeneity and ν_{it} a random noise term: the final two terms are non-

[4] Economic Size Units are measured as the standard gross margin/1200 euros (Eurostat, 2020)

negative random variables which capture persistent (time-invariant) technical inefficiency η_i and transient (time-varying) technical inefficiency u_{it} components, respectively.

Eq. 1 can be estimated through a random or fixed effects specification. There may be an omitted variable bias and the unobserved factors may correlate with the explanatory variables (Farsi et al., 2005). This is critical here as any time invariant component could be absorbed in the individual specific constant term (Filippini and Greene, 2016). To reduce this influence, it is common to include Mundlak's (1978) adjustment term to reduce the potential biases in the slope parameters and inefficiency term (Farsi et al., 2005; Filippini and Greene, 2016; Colombi et al., 2017; Addo and Salhofer, 2022), where we take the farm level mean of each input variable:

$$\overline{x_i} = \frac{1}{T}\sum_{t=1}^{T} lnx_{it} \quad (2)$$

Moreover, the level of inefficiency within these farms will be determined by a set of covariates and the model has been extended to explain heterogeneity of efficiency components (Lien *et al*., 2018; Colombi *et al*., 2017). To explain differences in inefficiency, we assume the variances of our time-invariant and time-varying technical inefficiency are conditioned by a set of determinants (*z*). Persistent inefficiency is now denoted $\eta_i(z_i)$ and is non-negative such that it has an expected value: $\mathrm{E}\big(\eta_i\,(z_i)\big) = m(z_i)\ \geq 0$ and transient inefficiency $\mu_{it}\,(z_{it})$ can be expressed as $\mathrm{E}\big(u_{it}(z_{it})\big) = g(z_{it}) \geq 0$. Equation 1 can be rewritten to include the Mundlak terms:

$$y_{it} = \alpha_0^* + f(x_{it}\,;\,\beta) + \xi\overline{x_i} + \delta_t t + \lambda_i + \varepsilon_{it} \quad (3)$$

Where $\alpha_0^* = \alpha_0 - m(z_i) - g(z_{it})$, $\lambda_i = w_i - \eta_i(z_i) + m_i(z_i)$, and $\varepsilon_{it} = v_{it} - u_{it}(z_{it}) + g(z_{it})$ (Addo and Salhofer, 2022). Following Robinson (1988), Lien et al. (2018) extracted the conditional expectation with respect to the determinants from both sides of the parametric component. These were estimated using a non-parametric constant kernel function. Addo and Salhofer (2022) combined the persistent with the transient component (z_i and z_{it}) and estimated a non-parametric linear kernel regression. We applied the same approach using the linear kernel function within Stata to extract the conditional means from both side of the equation. Once transformed a random or fixed effects specification can estimate the main parameters and allows consistent estimation of $\hat{\lambda}_i$ and $\hat{\varepsilon}_{it}$, which estimate persistent and transient inefficiency respectively (Kumbhakar *et al*., 2014; Lien et al., 2018; Addo and Salhofer, 2022). However, the Mundlak adjustment requires the random effects specification, and this is used here (Addo and Salhofer, 2022; Karagiannis and Sarris, 2005; Lien et al., 2018).

For transient inefficiency, we assume ν_{it} is iid $N(0,\sigma_v^2)$ (Greene, 2004) and inefficiency half-normal $u_{it}(z_{it})N^+(0,\sigma_u^2(z_{it}))$. After Battese and Coelli (1995), the expected value $E(u_{it}(z_{it})) = \left(\sqrt{2/_{\pi\ \sigma_u^2(z_{it})}}\right)$, which is estimated as a function of time varying exogenous parameters $\sigma_u^2 = e^{z_{it}'\vartheta}$, where σ_u^2 is the variance of the transient inefficiency, and ϑ the vector of unknown parameters to be estimated using standard stochastic frontier approaches, with $\hat{\varepsilon}_{it}$ as the dependant variable. Persistent inefficiency follows similar steps. We assume $\eta_i(z_i)N^+(0,\sigma_\eta^2(z_i))$, then the expected value $E(\eta_i) = \left(\sqrt{2/_{\pi\ \sigma_\eta^2(z_i)}}\right)$ can be estimated as a function of the time invariant exogenous determinants (z_i) as $\sigma_\eta^2 = e^{z_i'\theta}$. Where σ_η^2 is the variance of the persistent inefficiency, and θ the vector of unknown parameters to be estimated (Addo and Salhofer, 2022). Finally, using the Jondrow *et al.* (1982) procedure persistent technical efficiency (PTE) equates to exp $(-\hat{\eta}_i)$ and transient technical efficiency (TTE), equates to exp $(-\hat{u}_{it})$.Overall technical efficiency (OTE) is simply the product of PTE and TTE.

We estimate a translog procedure, which has proven standard in the literature and superior to simpler forms such as the Cobb-Douglas (Sauer et al., 2006) as it captures both first and second order effects and accommodates non-linearities within the input variables[5]. Our translog production function has a single output, five production inputs, and 2 conditioning variables, namely altitude and farm type. We include the Mundlak adjustment, as well as a linear time trend and an interaction time term for inputs. Following Lien et al. (2018) and Addo and Salhofer (2022) we subtract the conditional mean from both sides, so that for equation 4,

$y_{it}\ is\ y_{it} - E(y_{it}|z)$, $x_{it}\ is\ x_{it} - E(x_{it}|z)$, and $\bar{x}_{it}\ is\ \bar{x}_{it} - E(\bar{x}_{it}|z)$.

[5] A likelihood ratio test strongly rejected the Cobb-Douglas in favor of the translog (388.8***). A test of residuals found negative skew (-0.252) and both a skewness test (D'agostino et al., 1990) and Coelli's (1995) M3T test confidently rejected the hypothesis of no skewness (-6.39). This supports the contention that the stochastic modelling approach is correctly formulated (Schmidt and Lin, 1984).

$$\ln(y_{it}) = \alpha_0 + \sum_{j=1}^{J} \beta_j \ln(x_{it}) + \frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{J} \beta_{jk} \ln(x_{jit}) \ln(x_{jit}) + \sum_{j=1}^{J} \xi_j \ln(\bar{x}_{it}) + \delta_t t + \sum_{j=1}^{J} \delta_{jt} \ln(x_{it}) t + \lambda_i + \varepsilon_{it} \quad (4)$$

4.0. Results and Discussion

Table 2 shows the results of the translog estimates. This has a strong fit with first order coefficients all positive, significant and less than 1 which satisfies monotonicity and diminishing marginal product conditions. A Wald test showed the results were significantly different from 1 (4366.2***). However, the altitude coefficient is not significant, reflective of the large number of farms operating above 300 metres in the sample. The farm type variable is significant indicating that, compared to LFA cattle and sheep, specialist sheep will have lower levels of output. The time trend is negative, indicating technical regress for the sector as a whole and, aside from capital and intermediate consumption, the remaining inputs are negatively related to the time variable.

Table 2. Estimates of the translog production frontier

Figure 1 shows the distribution of efficiency scores by transient and persistent efficiency components. Overall, it shows a much wider spread for persistent, compared to transient, efficiency across the farms. This reflects a great deal of variance in structural efficiency. Conversely a much tighter spread is found for transient efficiency within the farms. Minviel and Sipiläinen (2021) found similar distributions for their examination of mixed French farms.

Figure 1. Distribution of efficiency scores by overall (OTE), transient (TTE), and persistent (PTE) efficiency components

Figure 2 shows the trend in persistent, transient, and overall efficiency taken at the mean for each year. Persistent efficiency remains stable throughout the period, averaging 0.82. There are some perturbations in transient efficiency over time, but this averages around 0.90. At the mean persistent efficiency is consistently lower than transient efficiency which reflects the presence of structural problems (Kumbhakar et al., 2014). Overall technical efficiency is the product of transient and persistent efficiency, and the lower persistent efficiency score tends to depress this throughout the period, to an average of 0.73.

This is a relative efficiency measure and cannot be directly compared with other studies, however these results are similar to the findings of earlier periods in the UK across the same sectors (Hadley, 2006; Barnes, 2008) but lower than a recent assessment of upland cattle and sheep farms in England over the period 2010 to 2014, which averaged 0.84 (Vigani and Dwyer, 2020). Though we would expect Scottish LFA farms to have lower efficiencies given the dominance of LFA within Scotland compared to England.

Figure 2. Trends in overall (OTE), persistent (PTE), and transient (TTE) efficiency over time, 2003-2020

To explore the extent of structural problems further we calculated a ratio of persistent to transient efficiency (PTE/TTE). A ratio below 1 would indicate that PTE scores will be lower than TTE scores, and therefore provides a case for external intervention as structural, long-term, and persistent issues will be more prevalent than transient issues within the sector. We show this as a box plot in Figure 3 to illustrate the ratio of PTE/TTE at the median but also the wider distribution of ratios for the individual farms. This shows that for all years, the ratio is below 1 for at least 75% of all farms, indicating that persistent and not transient inefficiency is the main issue for this sector.

Figure 3. Ratio of persistent to transient efficiency, box plot with outliers (2003-2020)

Determinants of inefficiency

Table 3 shows the determinants of transient and persistent inefficiencies. A negative sign indicates a decrease in the variance of the inefficiency function and implies the determinant relates to higher efficiencies. The table also shows there are differences between how these determinants relate to transient and persistent inefficiency.

Table 3. Determinants of transient (TTI) and persistent (PTI) inefficiency

Having a succession plan is positively linked to higher persistent efficiency. Setting a succession plan has been found to have a positive effect on financial performance (Barnes et al., 2016; Bertoni and Cavicchioli, 2016; Barnes et al., 2020). Having a successor in place supports the farm planning process (Sutherland et al., 2012*;* Bertolozzi-Caredio et al., 2020), and tends to be reflected through increased investment which would lead to reduced persistent inefficiencies. The positive influence of succession planning on management efficiencies has been recognised by a number of farming agencies who have promoted the importance of a succession plan and have provided support for creating one[6].

Notably, our index of farm family age is insignificantly related to PTE and TTE. Martinez Cillero et al (2018) found the same result for non-cattle rearing enterprises as did Dakpo et al (2020) for extensive beef enterprises. Only Addo and Salhofer (2022) explored age within the multi-step model and found this to be negatively related to transient efficiency. However, these studies use principal decision maker age which may not correctly reflect the farm family lifecycle model in these LFA farms.

Age to retirement of the principal decision-maker was explored to capture the decision-making of farmers who may be planning to exit the industry. Although there is no effect on transient efficiency, a retirement age of less than 10 years has a negative effect on persistent efficiency. Bertoni et al., (2021) argued that retirement indicators may reflect both handover of the farm business and exit which could lead to opposing effects on investment. Accordingly, here we find that retirement may be more reflective of a running down of the business or the reduction of efforts as farmers near retirement age (Bretford et al.,2019; Brown et al.,2019).

The share of family to hired labour has mixed signs. Those farms with more hired to family labour would have higher transient efficiency. Conversely, a higher share of family labour leads to higher persistent efficiency. Trnková and Žáková Kroupová (2020) found a similar effect for transient efficiencies for EU milk producers that employ a higher share of non-family workers. Addo and Salhofer (2022) identified a higher amount of family to hired labour was positively related to the persistent efficiency of Austrian crop farms. They attributed this to the high levels of inheritance within the Austrian crop sector that provide an incentive to maintain farm efficiencies. Hence, it would seem our results tally with these previous studies and that for LFA livestock farms higher levels of hired labour supports management of short-term perturbations and, indeed, may be the consequence of a transient event. The longer-term and structural efficiencies of these farms are dominated by the family labour force and this could be considered a proxy for long-term knowledge of the farming business.

The education variable has no relationship with transient efficiency but has a significant and positive effect on persistent efficiency. This holds for both specialist agricultural as well as non-specialist higher education qualifications. In summary, those farmers with post-school qualifications will have higher persistent efficiencies than those with school only qualifications. Educated farmers have been found to be more efficient and more adaptable

[6] See for example: https://www.nfumutual.co.uk/globalassets/farming/succession-planning/farm-handover-guide21.pdf

(Ahovi *et al*., 2021; Madau *et al.*, 2017) so it would dictate decision-making towards resource allocation. Addo and Salhofer (2022) found specialist agricultural education to be insignificant on persistent inefficiency for Austrian crop farms, as did Manevska-Tasevska *et al* (2017) for Swedish pig farms, though this latter study did not employ the full multi-step model.

We find subsidies are negatively related to both transient and persistent efficiencies, a similar result to Minviel and Sipiläinen (2021) for French mixed farms. Studies on beef and sheep farming which have not used the multi-step model have also found subsidies relate to lower efficiencies (Dakpo et al., 2020; Vagini and Dwyer, 2020). Only Martinez Cillero et al. (2018) observed a positive effect on Irish beef farm efficiency from the decoupled payments scheme.

The amount of off-farm to total revenue is negatively related to both transient and persistent efficiencies. A similar effect was found for the transient efficiency of Norwegian crop farms (Kumbhakar et al., 2014; Lien et al., 2018), but our finding argues that this determines lower long-term structural efficiencies as labour will be reallocated from the farm to an off-farm enterprise. Nevertheless, a long-term issue for LFA farms is the wider economic necessity of supporting farming incomes with off-farm jobs (Barnes et al., 2020; Vigani and Dwyer, 2020). Accordingly, if incomes in this sector remain low then the requirement to maintain off-farm activity may compound this structural inefficiency further.

For those farms in SDAs, compared to DAs, we find transient efficiencies will be lower. There is a similar relationship for persistent efficiency, but this is not significant. Martinez-Cillero *et al.* (2018) also examined the effect of SDAs and found the same influence on cattle rearing farms in Ireland. The severely disadvantaged indicator reflects increased biophysical constraints and triggers a higher tier of payment under the LFA payment scheme in Scotland. However, we do not find this to be a determinant of persistent, i.e., structural and long-term, inefficiency. This may reflect the findings of Barnes et al. (2020) who identified a diversity of financial performance irrespective of designation. They concluded that this called for further targeting of payments which are based beyond simple biophysical criteria.

Land management structures and farm tenure are prevalent barriers to investment (Graves et al., 2009, Borremans et al., 2018). Relative to owner-occupiers, those with mixed tenancies have lower persistent efficiency. Addo and Salhofer (2020) used an index of owned to rented land, finding higher proportions of rented land led to increased persistent efficiency. Trnková and Žáková Kroupová (2020) found a similar link for EU dairy farms. Compared to these studies we use a dummy variable to reflect the complexity of tenancy arrangements which may constrain efficient resource usage.

Farm size has positive effects on persistent efficiency. Addo and Salhofer (2022) found this determined transient efficiency but did not explore the effect on persistent efficiency. Conversely Trnková and Žáková Kroupová (2020) found farm size to be negatively related to persistent efficiency in their assessment of the EU milk sector. They argued this reflected a dairy sector which is less flexible to changing market demands. Nevertheless, a common finding in technical efficiency studies is that increasing farm size is positively related to efficiency (Madau *et al.,* 2017; Rada and Fuglie, 2019; Aragon *et al*., 2021).

5.0 Conclusions

Less Favoured Areas were established in 1975 to recognise the different physical and socio-economic characteristics that farmers face. Scottish LFA Cattle and Sheep farms are particularly vulnerable to variable production conditions, and we would expect high persistent inefficiencies. In addition, we would also expect high transient inefficiencies, given these farms' exposure to variable climatic and biophysical stressors. This is not the case here as transient efficiencies are high, which shows that these farms are managing short-term perturbations. However, persistent efficiencies have remained consistently low throughout the last 20 years and show little or no progress from interventions which have aimed to address these disadvantages. This period, 2003-2020, covers the whole of the Single Farm Payment scheme, where payments were based on historic activity, and the introduction of regionalised area based direct payments in 2015. Accordingly, we would agree with Ang (2019) and Barnes *et al.* (2020) for more targeting of support for these areas given the heterogeneity in observed performance. The determinants of higher persistent efficiencies found here provide a focus for this more targeted approach.

We find the influence of succession planning and retirement to be significantly related to persistent efficiency and this agrees with the large body of literature that recognises the influence of farm family life cycle events on performance (Potter and Lobley, 1996; Bika, 2007; Harris et al., 2012). These studies have explored different farm types and different regions, so we offer some consistency for this finding. For farmers nearing retirement, we observe lower persistent efficiencies which is reflective of running down of the business or limiting farm investment observed in other studies (Potter and Lobley, 1992; Bika, 2007). Early removal of farmers who plan to retire would negate these lower efficiencies and this has been the rationale behind a number of early retirement policies across the EU. However, the efficacy of these schemes has been questioned (Gilmor, 1999; Davis, 2011). This has been due to the compensation payment itself, but also the conditions imposed on the retirement payment, specifically the potential restrictions for family members to inherit the farm (Gilmor, 1999; Pietola et al., 2003; Bika, 2007; Davis, 2011). This will limit succession, so relaxing these conditions may make retirement more attractive but also incentivise succession planning and formal handovers to address the persistent inefficiencies identified here. As part of its agricultural transformation plan Defra have recently announced a lump-sum payment scheme for early exit from the industry (Defra, 2022), though there will be restrictions that constrain family members taking over that business. Scotland has not yet declared a similar scheme, but the evidence here would suggest the importance of a targeted approach to retirement which can also support succession. This may also address the finding that higher proportions of family to hired labour will lead to higher of persistent efficiencies. However, other factors such as the economic viability of the farm business to sustain family members but also the general economic prospects of rural regions themselves to will influence family members to remain within farming.

However, there was no significant effect of the farm family age indicator on transient or persistent inefficiency. A weakness of the current analysis is that farm account data does not identify years of experience in managing the farm. The addition of this variable would add more explanatory power to the results here and remove the need to using the age of the farmer to proxy these factors. In addition, previous studies which have estimated sheep and beef farm efficiency within a stochastic production frontier framework have not formally addressed the production conditions experienced by LFA farms, which should be handled as a separate technology set compared to lowland beef and sheep farms. The approach of Dakpo et al (2021) could be usefully extended to understand persistent inefficiencies. This could employ more criteria which infers different classes of disadvantage, e.g., soil type, altitude, as well as rural remoteness, to provide assessments which respect the unique disadvantages that LFA farms face.

Acknowledgements

This work was supported by the Scottish Government as part of the Rural Affairs, Food and the Environment (RAFE) Strategic Research Programme 2022-2027 SRUC-B3-1 - Ensuring positive behavioural change for farmers towards best practice for clean growth: economic and behavioural investigations.

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Table 1. Variables used within the production function and explanatory variables, descriptive statistics

		LFA Cattle and Sheep Farms (n=3,857)			
	Variable	Mean	*S.D.*	Min	Max
	Production function				
y	Agricultural Revenue (£ 000)	96.3	78.1	1.8	806.3
x_m	Intermediate Consumption (£ 000)	58.5	45.6	2.8	379.7
x_l	Hours Worked (Hours)	3,906.1	2,112.0	105.0	15,797.0
x_k	Farm-based Assets (not including livestock) (£ 000)	55.7	36.3	2.1	277.7
x_{lu}	Grazing Livestock Units	169.8	112.8	13.0	947.0
x_a	Total agricultural area (adjusted ha)	186.2	188.6	20.0	2,363.0
t	Time (1=2003, 18=2020)	9.3	5.1	1.0	18.0
k_1	Altitude (0=Below 300m, 1=Above 300m)	0.2	0.4	0.0	1.0
k_2	Farm Type (0= LFA Cattle and Sheep, 2= LFA Sheep,3=LFA Cattle)	1.2	0.9	0.0	2.0
	Determinants	Mean	*S.D.*	Min	Max
z_1	Succession plan in place (0=No, 1=Yes)	0.50	0.50	0.00	1.00
z_2	Average of family member age	56.5	11.6	24.0	97.0
z_3	Average of family member age^2	3,330	1,340	576	9,409
z_4	Household labour to total labour (ratio)	0.81	0.26	0.00	1.00
z_5	Education (0=school only, 1=higher education, 2=education in an agricultural school)	1.03	0.88	0.00	2.00
z_6	Share of Off farm to total revenue	0.20	0.21	0.00	0.97
z_7	Retirement planning (0 = will not retire in 10 years; 1= will retire in next 10 years)	0.16	0.37	0.00	1.00
z_8	Share of subsidies to total agricultural revenue	0.31	0.15	0.00	0.95
z_9	LFA level (0=Disadvantaged; 1= Severely Disadvantaged	0.84	0.36	0.00	1.00
z_{10}	Tenure (0=Owner Occupied, 1=Tenanted, 2=Mixed/Partnerships)	0.87	0.85	0.00	2.00
z_{11}	Size Dummy (0=Small, 1=Medium (, 2=Large*)	1.15	0.66	0.00	2.00

*where small is <8 ESU, medium is >=8 and <16 ESU, large >=16 ESU. ESUs are calculated as standard gross margin/1200

Table 2. Estimates of the translog production frontier

	Estimates	Sig.	Std. err.
β_{m} (*intermediates*)	0.301	***	0.030
β_{l} (*hours worked*)	0.072	**	0.023
β_{k} (*farm-based assets*)	0.058	*	0.026
β_{lu} (*livestock units*)	0.341	***	0.042
β_{a} (*agricultural area*)	0.106	***	0.027
$\beta_m*\beta_m$	0.097	***	0.026
$\beta_m*\beta_l$	0.0003	-	0.031
$\beta_m*\beta_k$	-0.080	*	0.034
$\beta_m*\beta_{lu}$	-0.145	*	0.058
$\beta_m*\beta_a$	0.078	*	0.036
$\beta_l*\beta_l$	0.024	*	0.010
$\beta_l*\beta_k$	-0.055	*	0.025
$\beta_l*\beta_{lu}$	0.025	-	0.043
$\beta_l*\beta_a$	-0.006	-	0.021
$\beta_k*\beta_k$	-0.004	-	0.016
$\beta_k*\beta_{lu}$	0.088	*	0.042
$\beta_k*\beta_a$	0.009	-	0.021
$\beta_{lu}*\beta_{lu}$	0.046	-	0.040
$\beta_{lu}*\beta_a$	-0.066	-	0.046
$\beta_a*\beta_a$	-0.009	-	0.019
$\xi_{\bar{m}}$	0.339	***	0.053
$\xi_{\bar{l}}$	0.007	-	0.045
$\xi_{\bar{k}}$	0.356	***	0.043
$\xi_{\overline{lu}}$	-0.311	***	0.071
$\xi_{\bar{a}}$	-0.125	**	0.042
t	-0.004	***	0.001
$t*\beta_m$	0.009	***	0.002
$t*\beta_l$	-0.005	**	0.002
$t*\beta_k$	0.005	**	0.002
$t*\beta_{lu}$	-0.004	-	0.003
$t*\beta_a$	-0.006	**	0.002
Farmtype (reference: LFA Cattle and Sheep			
γ_{sheep}	-0.097	***	0.021
γ_{cattle}	0.010	-	0.015
Y_{alt}	-0.009	-	0.025
σ_u	0.276		
σ_e	0.191		
ρ	0.677		
R^2			
Within	0.370		
Between	0.850		
Overall	0.851		

* sig. at 0.05; **sig at 0.01; ***sig at 0.001

Table 3. Determinants of transient (TTI) and persistent (PTI) technical inefficiency

		TTI			PTI		
		Estimates	Sig.	Std. err.	Estimates	Sig	Std. err.
z_1	Succession plan in place	0.077	-	0.103	-0.324	***	0.089
z_2	Average age of family members	0.002	-	0.029	0.026	-	0.026
z_3	Family Age^2	0.000	-	0.000	0.000	-	0.000
z_4	Household labour share	0.499	*	0.220	-0.557	**	0.161
z_5	Education (reference: School Only)						
	Higher non-agricultural	-0.105	-	0.130	-0.297	**	0.108
	Higher agricultural	-0.088	-	0.125	-0.380	***	0.101
z_6	Off-farm revenue	0.513	***	0.056	0.394	***	0.035
z_7	Age to retirement	0.074	-	0.138	0.259	*	0.114
z_8	Share of subsidies	0.614	***	0.068	0.683	***	0.069
z_9	LFA Severely disadvantaged	0.576	***	0.148	0.084	-	0.182
z_{10}	Tenure (reference: owner occupied)						
	Full tenanted	0.138	-	0.123	-0.109	-	0.105
	Mixed	0.058	-	0.119	0.495	***	0.095
z_{11}	Farm Size (reference: Small)						
	Medium	0.034	-	0.140	0.114	-	0.112
	Large	-0.159	-	0.173	-0.822	***	0.153
	Constant	-4.007	***	0.878	-2.384	**	0.745

* sig. at 0.05; **sig at 0.01; ***sig at 0.001

Figure 1. Distribution of efficiency scores by overall (OTE), transient (TTE) and persistent efficiency (PTE) efficiency

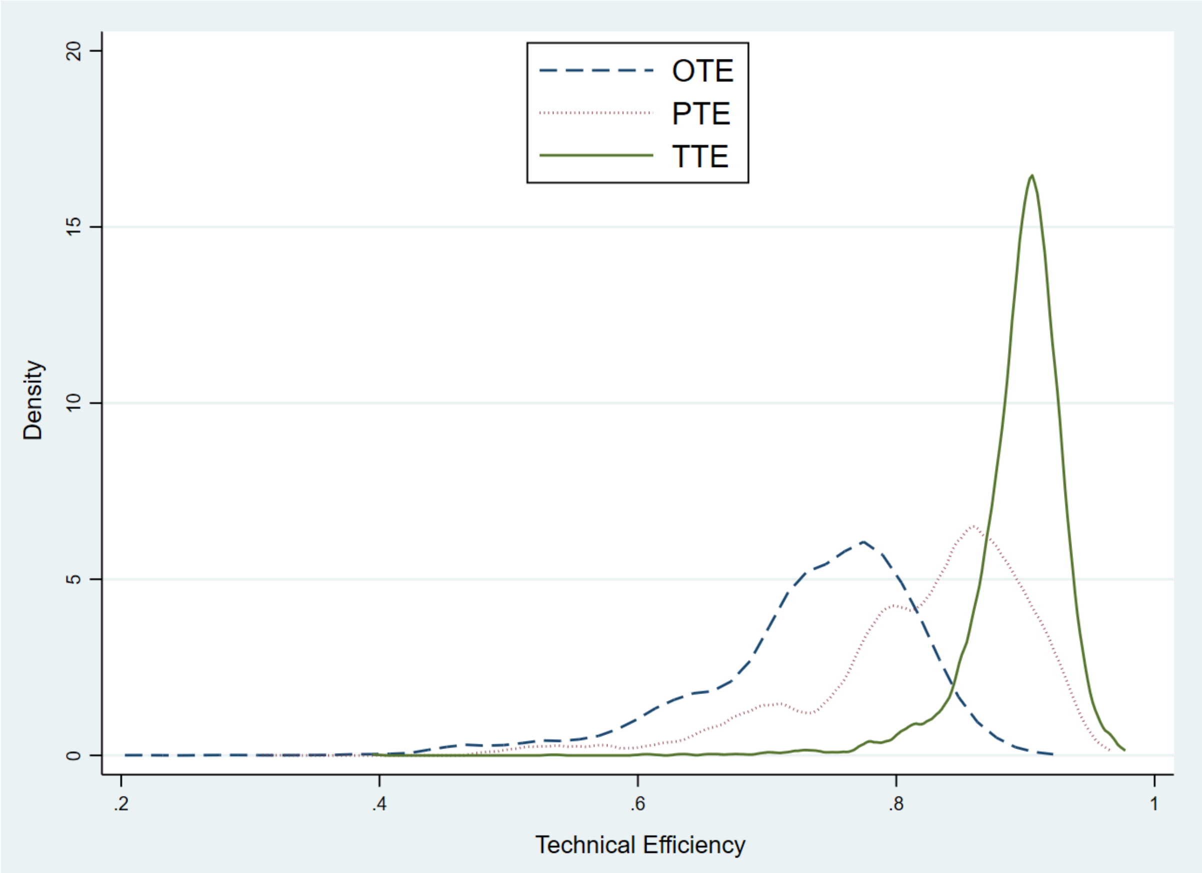

Figure 2. Trends in overall (OTE), transient (TTE) and persistent efficiency (PTE) efficiency over time, 2003-2020

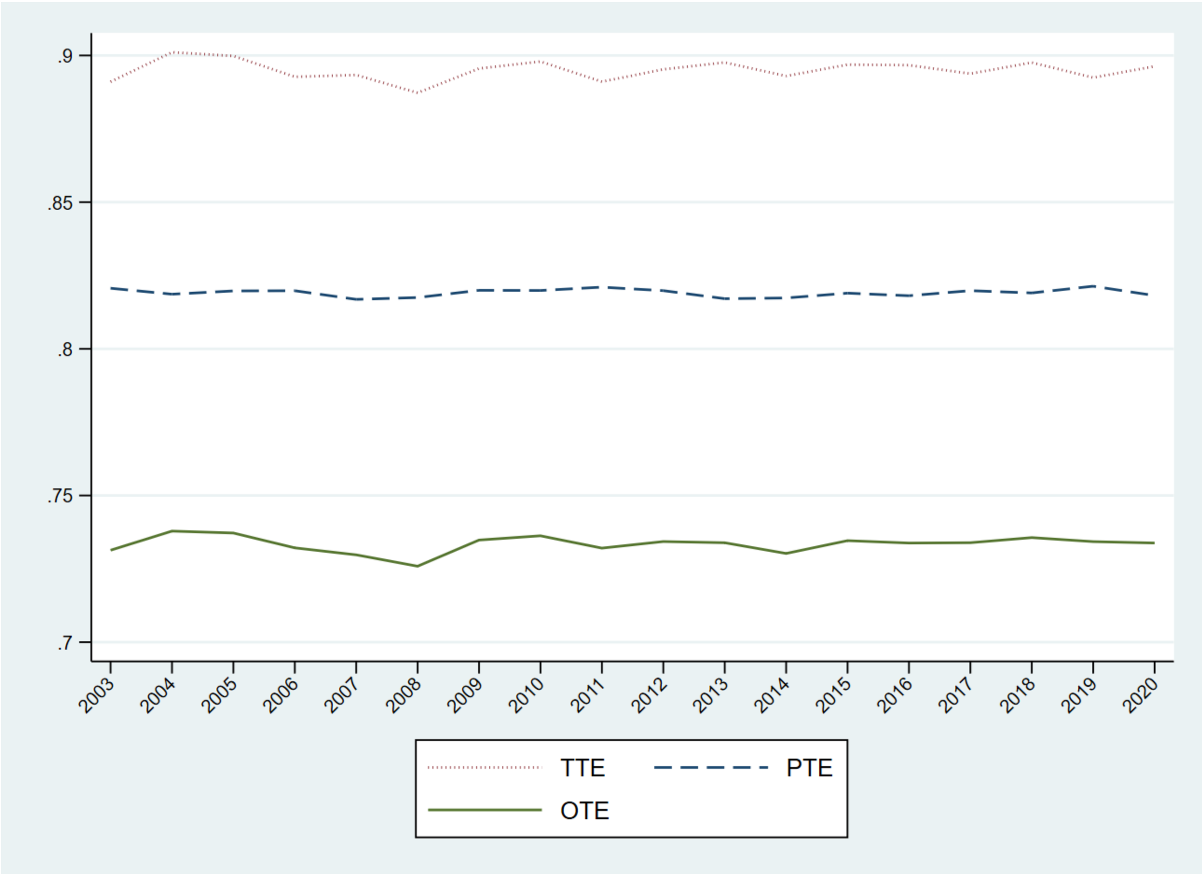

Figure 3. Ratio of persistent to transient efficiency, box plot with outliers, 2003-2020