ARTICLE IN PRESS

JID: EOR [m5G;August 27, 2016;6:51]

European Journal of Operational Research 000 (2016) 1–7

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Interfaces with Other Disciplines

# Dynamic multi-directional inefficiency analysis of European dairy manufacturing firms

Magdalena Kapelko[a,*], Alfons Oude Lansink[b]

[a] Institute of Applied Mathematics, Department of Logistics, Wroclaw University of Economics, ul. Komandorska 118/120, 53-345 Wroclaw, Poland
[b] Business Economics Group, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands

A R T I C L E I N F O

*Article history:*
Received 20 October 2015
Accepted 2 August 2016
Available online xxx

*Keywords:*
Data Envelopment Analysis
Multi-directional inefficiency analysis
Dynamic inefficiency
Dairy manufacturing industry

A B S T R A C T

This paper extends the method of multi-directional inefficiency analysis to account for dynamics of firms' production decisions. The resulting approach – dynamic multi-directional inefficiency analysis – measures variable input- and investment-specific inefficiency using Data Envelopment Analysis. The empirical application focuses on panel data of large dairy manufacturing firms over the period 2005–2012 in three European regions (Eastern, Southern and Western). The results show that investments are the most inefficient factor for firms in all European regions, followed by labour and materials. However, the findings also suggest a high dispersion of investment-specific inefficiency scores within the sample. The paper also finds that the median dynamic inefficiency is changing rapidly in the years after the beginning of the financial crisis.



## 1. Introduction

The European dairy processing industry is the second largest sector within food manufacturing (after meat processing), accounting for 9% of employment and 16% of turnover in food manufacturing in 2011 (Eurostat, 2014). The sector is characterized by a strong regulation through the Common Agricultural Policy (CAP). At present, European Union (EU) liberalizes its dairy market, as exemplified by the recent abolishment of the dairy quota system which was introduced in 1983. At the same time, dairy markets are increasingly volatile in recent years. In particular, the European dairy sector experienced a period of high volatility of prices from 2007 to 2009. In 2007, the European and world dairy market prices were peaking, while in 2008 and 2009 the prices and producers' incomes substantially decreased partly as a result of the economic crisis (European Commission, 2010, 2012). The volatility of prices can affect technical inefficiency of firms through their impact on profitability and investments. In particular, the changes in prices will affect profitability of dairy firms, which in turn will influence firms investments (less profitable firms will tend to invest less), and eventually affect technical inefficiency. The events occurred in an era that is characterized by increasing market liberalization causing increasing competition from dairy manufacturing firms on world market. The developments described above could have a considerable effect on the structure of the European dairy manufacturing sector. For this reason, it is important to provide insight into the inefficiency with which these firms operate. Even more so, it is interesting to know whether the inefficiency differs between inputs employed by the firms.

The determination of inefficiency with regard to specific inputs is a theme that has drawn the attention of a large number of authors in the Data Envelopment Analysis (DEA) literature. Early attempts to input-specific inefficiency measurement were based on the concept of input subvector technical efficiency introduced by Färe et al. (1994) and applied elsewhere (for example in Oude Lansink, Pietola, & Bäckman, 2002; Oude Lansink & Silva, 2003; D'Haese, Speelman, Alary, Tillard, & D'Haese, 2009). Another stream of literature developed input-specific inefficiency measures based on the Russell measure (Färe & Lovell, 1978) or slacks-based measure (Tone, 2001) and directional slacks-based measure (Fukuyama & Weber, 2009; Färe & Grosskopf, 2010). The examples of studies that employed these measures to analyse input-specific inefficiency of different industrial sectors include, for example, Oude Lansink and Ondersteijn (2006) and Kapelko (2016). The extension of these measures to the assessment of environmental performance was explored in Skevas and Oude Lansink (2014), Zhou, Ang, and Wang (2012) and Wang, Zhou, and Zhou (2013a). Yet another stream of research on input-specific inefficiency measurement is based on the concept of multi-directional inefficiency analysis (MEA) (Bogetoft & Hougaard, 1999; Asmild, Hougaard, Kronborg, & Kvist, 2003). The advantage of MEA over other

* Corresponding author. Fax: +48 713680334.
*E-mail addresses:* magdalena.kapelko@ue.wroc.pl (M. Kapelko), Alfons.OudeLansink@wur.nl (A. Oude Lansink).

http://dx.doi.org/10.1016/j.ejor.2016.08.009
0377-2217/

Please cite this article as: M. Kapelko, A. Oude Lansink, Dynamic multi-directional inefficiency analysis of European dairy manufacturing firms, European Journal of Operational Research (2016), http://dx.doi.org/10.1016/j.ejor.2016.08.009

input-specific approaches is that it is able to select benchmarks for inputs reduction which are not proportional to the actual production, but to the potential improvements related to each input variable separately. In addition, in differentiation to other measures, MEA ensures the characteristic of technological monotonicity (Bogetoft & Hougaard, 1999).

Several authors have analysed the technical efficiency of the dairy manufacturing sector. Shee and Stefanou (2015) analysed the efficiency of Colombian food manufacturers and found that average technical efficiency of dairy processors was reaching a level of 56%. Slightly higher efficiency values (66%) were reported by Kapelko and Oude Lansink (2013) in their study of dairy processing firms in Spain, whereas Ali, Singh, and Ekanem (2009) found an efficiency of 87% for the Indian sector. Doucouliagos and Hone (2000) undertook a study of dairy processing sector at the level of Australian states and their results showed that this industry exhibits a level of efficiency of approximately 90%. The studies discussed here have in common that they measured technical efficiency for all inputs simultaneously, assuming that all inputs can be contracted with the same percentage. None of these studies measured input-specific efficiency of the dairy manufacturing firms. Also, the existing studies have been conducted in a static context that is a context where production decisions are not interlinked over time. Recent contributions to the literature on inefficiency analysis (for example, Silva & Stefanou, 2003; Kapelko, Oude Lansink, & Stefanou, 2014; Silva, Oude Lansink, & Stefanou, 2015) suggest it is important to account for the presence of quasi-fixed factors of production in the measurement of inefficiency (that is, dynamic inefficiency).

In the light of the foregoing discussion, the present paper proposes an alternative approach to the measurement of input-specific inefficiency. The novel method extends multi-directional inefficiency analysis to allow for firms' production decisions to be linked over time through the capital adjustment. In particular, this paper applies the concept of dynamic inefficiency measurement to the MEA approach. And it is the first paper that extends MEA approach to the dynamic context. In the presence of adjustment costs in quasi-fixed factors of production traditional static MEA might not correctly reflect input-specific inefficiency of firms. The resulting method – dynamic multi-directional inefficiency analysis – is empirically operationalized in a Data Envelopment Analysis framework. A sample of large dairy processing firms operating in Europe over the period 2005–2012 is the focus of the empirical application. The application allows to consider inefficiency with regard to both variable inputs (materials and labour) and capital investments, providing insights for managers of dairy manufacturing firms and other stakeholders such as farmers and policy makers.

The remainder of this paper proceeds as follows. The next section introduces the multi-directional inefficiency approach in a dynamic context. The section to follow describes the dataset of European dairy processing firms, followed by the presentation of results. The last section provides concluding comments.

## 2. Dynamic multi-directional inefficiency measurement

This section develops the MEA approach to account for the dynamics of firms' production decisions. The approach developed builds on the conventional (static) MEA approach of which the foundations were developed by Bogetoft and Hougaard (1999). In short, their measurement of efficiency is based on the potential improvements and separates the issue of benchmark selection from the issue of efficiency measurement; these two steps are usually undertaken simultaneously in the efficiency literature. However, MEA was first coined some years later by Asmild et al. (2003) who proposed a DEA approach for determining an inefficiency index representing potential improvements. The MEA approach was further elaborated by Bogetoft and Hougaard (2004), Asmild and Pastor (2010), Asmild, Baležentis, and Hougaard (2016) and Baležentis and De Witte (2015), and applied in different contexts, such as the works of Holvad, Hougaard, Kronborg, and Kvist (2004), Asmild and Matthews (2012), and Wang, Wei, and Zhang (2013b). Conventional MEA model treats all inputs as variable and does not take into account the investments in capital. Essentially, the MEA framework is based on two sequential steps. In the first step the input coordinates of an ideal point are determined by solving linear programmes for each input separately. The ideal reference point expresses the largest possible reduction in each input. Then, in the second step with an ideal point determined, a single linear programme needs to be solved of which the outcome is used to compute a vector of input-specific inefficiencies.

In the sequel, this paper focuses on an input-oriented MEA. An input-oriented MEA selects the input reduction benchmark according to the improvement potential with regard to each input separately. [1] This section builds on the conventional MEA model by linking it to dynamic inefficiency measurement in the line of research developed by Silva and Stefanou (2003, 2007) and extended by Serra, Oude Lansink, and Stefanou (2011), Kapelko et al. (2014) and Silva et al. (2015).

Consider a set of $j=1,\dots,J$ firms using a vector of $N$ variable inputs $x=(x_1,\dots,x_N)$, a vector of $F$ gross investments in quasi-fixed inputs $I=(I_1,\dots,I_F)$, a vector of $F$ quasi-fixed inputs $k=(k_1,\dots,k_F)$ and producing a vector of $M$ outputs $y=(y_1,\dots,y_M)$. The dynamic production technology transforms variable inputs and gross investments into outputs at a given level of quasi-fixed inputs and is defined as (see Kapelko et al., 2014; Silva et al., 2015):

$$P=\{(x,I,y,k):\ x,I \text{ can produce } y, \text{ given } k\} \quad (1)$$

The properties of the dynamic production technology are described in Silva and Stefanou (2003). In particular, $P$ is a closed and nonempty set, has a lower bound, is positive monotonic in variable inputs, negative monotonic in gross investments, is a strictly convex set, output are freely disposable and increase with the stock of capital and quasi-fixed inputs.

The first step in the dynamic MEA is to find an ideal reference point with regard to variable inputs $x_n^*$ for the DMU$^0$ under analysis $(x_n^0, I_f^0, y_m^0)$. Hence, for each variable input $n(=1,\dots,N)$, the following linear programming model needs to be solved using DEA:

$$\begin{aligned}
x_n^* = \min_{x_n,\lambda^j} & \ x_n \\
\text{s.t.} & \\
& \sum_{j=1}^{J}\lambda^j y_m^j \ge y_m^0, && m=1,\dots,M \\
& \sum_{j=1}^{J}\lambda^j x_n^j \le x_n \\
& \sum_{j=1}^{J}\lambda^j x_{-n}^j \le x_{-n}^0 && -n=1,\dots,n-1,n+1,\dots,N \\
& \sum_{j=1}^{J}\lambda^j (I_f^j-\delta^j k_f^j) \ge I_f^0-\delta^j k_f^0 && f=1,\dots,F \\
& \lambda^j \ge 0 && j=1,\dots,J
\end{aligned} \quad (2)$$

where $(x_{-n}^0)$ is a vector of all variable inputs except input $n$, $\lambda^j$ are intensity weights to form the linear combinations of $J$ observed

[1] Please note that MEA approach can also select benchmarks with regard to each output separately. Hence, it can be also used to analyze output-specific inefficiency. This paper, however, focuses on input-specific inefficiency, hence the focus is on the MEA approach for the estimation of input-specific inefficiency, that is an input-oriented MEA. In addition, it is worth pointing out that MEA approach can be also generalized to the full input-output space.

Please cite this article as: M. Kapelko, A. Oude Lansink, Dynamic multi-directional inefficiency analysis of European dairy manufacturing firms, European Journal of Operational Research (2016), http://dx.doi.org/10.1016/j.ejor.2016.08.009