Labour-use Eciency in the Italian Machinery Industry: a Non-parametric Stochastic Frontier Perspective

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A non-parametric stochastic frontier for the analysis of labour-use efficiency in the Italian machinery industry

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Summary: Firms' efficiency is a mainstream in the study of economic growth. Within this broad research area, the present work, conducted as part of the research activities of SOSE S.p.A., analyses the labour-use efficiency in the Italian machinery industry through the application of a non-parametric stochastic frontier model with the aim of suggesting new insights to better understand the recent dynamics of the Italian manufacturing system. An extended panel data of manufacturing Small and Medium Enterprises (SMEs) operating in the mechanical industry for the period 2002-2012 has been extracted (in anonymous form) from the Italian Ministry of Economy and Finance annual survey and used for the implementation of the proposed method. Results show the presence of a persistent level of labour-use inefficiency in the sample used for the analysis: this issue is particularly evident for the subset of firms using non standard jobs, while firms entitled to access to wage redundancy fund appear to have achieved higher levels of efficiency in labour input use on average. The analysis also shows that the inefficiency gap between the two subsets of firms tends to reduce in absolute terms over time.

Keywords: Labour-use efficiency; Stochastic frontier; SMEs; GAM; Splines.

1. Introduction

The measurement of productive efficiency and productivity growth has received increasing attention in the econometrics literature with particular emphasis on model estimation. Following this recent trend, the present research[1] aims at evaluating the different

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labour-use efficiency for a given set of Italian manufacturing firms through a stochastic frontier approach (Kumbhakar and Hjalmarsson, 1995).

Parametric stochastic frontier models introduced by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977) specify output in terms of a response function and a composite error term. The composite error term consists of a two-sided error representing random effects and a one-sided term capturing technical inefficiency. Since the introduction of this model, several attempts to improve the structure of the original specification have appeared in the literature (for extensive reviews of this topic, see: Kumbhakar and Lovell, 2000; Greene, 2008).

Despite its limited computational complexity, the stochastic frontier approach has an important drawback: the lack of flexibility. Indeed, the assumptions about the functional form of the frontier are often too restrictive and not always appropriated: this issue can introduce substantial bias and might lead to misleading conclusions about the actual relationship between inputs and output. To overcome this problem, we adopt in this paper a flexible estimation of the frontier modelled by a Generalized Additive Model (GAM), relaxing the linear assumption about the link between fitted values and the linear predictor (Vidoli and Ferrara, 2014).

The paper is structured as follows: in section 2, efficiency methods are discussed and the GAM stochastic frontier specification is introduced; in section 3, the results of the empirical application are presented; in section 4, the main conclusions from the study are drawn and the potential implications of the empirical findings and directions for future research in this area are provided.

2. The GAM Stochastic Frontier Specification

The determination of technical efficiency is based on the prior knowledge of the so-called "*production function*"; this preliminary information allows one to associate the production process of individual units to the *optimal* level of output. The measure of the distance of each unit from the frontier is the most immediate way to assess its efficiency (Farrell, 1957).

However, both the production function and the efficient frontier are generally unknown, while a limited set of information is available for each production unit. It is therefore essential to develop techniques to estimate the production frontier.

In literature, the specification and the estimation of production frontier functions are usually carried out through the two following approaches:

- Stochastic Frontier Analysis (SFA)(Aigner *et al.*, 1977; Meeusen and van den Broeck, 1977) - Deterministic Frontier Analysis (DFA) (Aigner and Chu, 1968);
- Data Envelopment Analysis (DEA) (Farrell, 1957; Charnes *et al.*, 1978) - Free Disposal Hull (FDH) (Deprins *et al.*, 1984; Grosskopf, 1996).

These two approaches are classified in the literature as parametric (DFA, SFA) and nonparametric (DEA, FDH) methods, respectively. In the first case the *a priori* specification of an explicit functional form for the boundary of the production set is required; on the other hand, the nonparametric analysis is characterized by the possibility to determine the relative efficiency of such units through linear programming, without specifying the functional form for the production function. In other words, unlike parametric techniques, the DEA-FDH approach allows the determination of the relative efficiency of each decision-making unit when relevant information on the production process is not available; however, when the marginal substitution rate between inputs is known, *value judgements* can be added into the optimization problem; in this context, Färe *et al.*(1989) have proposed a modification of the DEA model for estimating capacity utilization assuming constrained use of variable inputs.

Despite the benefits in terms of flexibility and generalization, the main drawback of DEA (or FDH) is its deterministic nature. Indeed, this methodology does not allow one to assess whether efficiency gaps, namely the distance between observed and maximum possible output, are due to technical inefficiency or rather to disturbance effects of an accidental type (Greene, 2008). Therefore, it is not possible to determine whether inefficiency is due to factors that are independent of the entrepreneur actions(*e.g.* a dry season that has negative consequences on the performance of the farmers) or is rather explained by other reasons such as the lack of management skills.
The parametric model with stochastic production frontier (SFA) allows one to overcome some of the main drawbacks of the classical DFA by discriminating between the efficiency term and an error term which includes sources of inefficiency that are not directly attributable to the production function or disturbances of an accidental type; over against, the most important drawback associated with the SFA approach is the lack of flexibility associated with the specification of the production function.
In this paper, the above mentioned issues associated with parametric and nonparametric approaches are addressed by introducing a novel semiparametric specification based on a Generalize Additive Model (GAM) framework; the main benefit of this methodology is the possibility to avoid the choice of a particular specification of the production function.

Indicating L as the employment level (number of employees), Y as the production output (turnover), T as the trend variable (year) and K as the capital stock, the labour requirement function introduced by Kumbhakar and Zhang (2013) can be written as:

$$L = h(Y, K, T). \tag{1}$$

The relevant stochastic frontier model with panel data becomes, in general terms, as:

$$\ln(L_{it}) = h(\ln(K_{it}), \ln(Y_{it}), T; \boldsymbol{\beta}) + v_{it} + u_{it}, \tag{2}$$

where $h(\cdot)$ defines a frontier relationship for the labour input L, for firm i ($i = 1, \dots, n$) at time t ($t = 1, \dots, T$) and $\boldsymbol{\beta}$ is an unknown parameter vector to be estimated. The residual $\varepsilon_{it} = v_{it} + u_{it}$ is composed of a two-sided error term, where v_{it} represents noise and $u_{it} \geq 0$ is a one-sided error term reflecting technical inefficiency. In applications, the two-sided error term is generally assumed to be normally distributed $v_{it} \sim N(0, \sigma_v^2)$, while several assumptions have been made for the one-sided component (*e.g.* half-normal, truncated (other than at zero) normal, gamma and exponential). Following common practice, we assume that: (i) u is distributed as an half-normal on the non-negative part of the real number line ($u_{it} \sim |N(0, \sigma_u^2)|$) and (ii) v and u are identically and independently distributed (iid).

Regarding the production function, the most commonly used specifications in empirical studies are the Cobb-Douglas and the translog forms. These functions are widely diffused in economic theory and their properties lead to direct interpretability of the estimation results. However, their use can often generate overparameterized model specifications: in many cases, the specifications used are at best just convenient approximations of the unknown frontier function, and their adoption may lead to incorrect interpretations of the efficiency patterns.
The specification proposed in this paper considers a more flexible estimate of the frontier (2) by considering the relevant conditional expectation of $h(\cdot)$, namely $h_m(\cdot)$, as a Generalized Additive Model. In general terms a GAM specification for $h_m(\cdot)$, given a set of p covariates $X_1, X_2, \ldots, X_p$, may be written as:

$$h_m(X_1, X_2, \ldots, X_p) = \alpha + \sum_j f_j(X_j), \tag{3}$$

where the f_js are allowed to be arbitrary nonlinear functions of the set of covariates (Hastie and Tibshirani, 1990). Additive models retain most of the desirable properties of linear models, while increasing computational flexibility. One of the main benefits of linear models is that they are fairly straightforward to interpret: in order to know how the prediction changes in response to X_j, one only needs to know β_j while the partial response function f_j plays the same role in an additive model.
For the estimation of the stochastic frontier model (2) we consider the following two-step procedure as proposed by Olson *et al.* (1980):

1. estimation of the conditional expectation $h_m = E(L|Y, K, T)$ (i.e. the "mean" frontier) of the model (2) by means of GAMs (3);

2. estimation of the error term parameters (σ_v, σ_u) using the method of moments approach.

This approach allows one to smooth both firm and time effects, which are formally included linearly in the model; more specifically, we consider a penalized regression splines framework (Wood, 2003) where proper penalties are introduced to guarantee the smoothness of the fitted frontier. The unknown $h(\cdot)$ is modelled as a Generalized Additive Model according to an approach already been proposed by Vidoli and Ferrara (2014).

More specifically, the f_js smooth functions are represented using thin plate regression splines with smoothing parameters selected by the Generalized Cross Validation (GCV) criterion: $n * D/(n - DoF)^2$, where D is the deviance, n is the number of data and DoF are the effective degrees of freedom of the model. Following this approach, the knot placement issue of conventional regression spline modelling is specifically addressed (see Wood, 2006, for further details).

After obtaining the "mean" frontier $\widehat{E(Y|\boldsymbol{X} = \boldsymbol{x})}$, the estimated production function $h(\cdot)$ is obtained by shifting downwards the estimation of the conditional expectation by an amount equal to the average estimate of the expected value of the inefficiency term (Kumbhakar and Lovell, 2000).

Having obtained the pseudo maximum-likelihood estimates of the parameter σ_v and σ_u, the next step is to estimate the technical efficiency of each unit. In this context, Jondrow *et al.* (1982) propose to derive the conditional distribution of the component u with respect to the compound error $\varepsilon = v - u$ as follows:

$$f_{u|\varepsilon}(u|\varepsilon) = \frac{1}{\sqrt{2\pi}\sigma^*} \cdot \frac{\exp\left\{-\frac{(u-\mu^*)^2}{2\sigma^*}\right\}}{\left[1 - \Phi\left(-\frac{\mu^*}{\sigma^*}\right)\right]},$$

where $\mu_* = -\sigma_u^2\varepsilon/\sigma^2$ e $\sigma_*^2 = \sigma_u^2\sigma_v^2/\sigma^2$; consequently, a point estimator of u_i is:

$$E(u|\varepsilon) \quad = \quad \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{\phi(z)}{1-\Phi(z)} - z\right], z = \frac{\varepsilon\lambda}{\sigma}, \tag{4}$$

where $\lambda = \sigma_u/\sigma_v$ and $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$; as usual in frontier models, if the response is measured in logs, the relative estimates of technical efficiency for each unit are obtained by:

$$TE_i = \exp\{-\hat{u}_i\}. \tag{5}$$

Frontier models have a number of consistency properties: the most relevant assumptions about the underlying production function are monotonicity and concavity. In general, a multi factors - multi products production technology can be formulated with respect to the set of production possibilities, defined as the technically feasible combination set (Ψ) of (x, y). The most common assumptions on Ψ are:

1. Weak essentiality. This hypothesis requires positive amounts of input to be used in order to produce a positive amount of output. In other words, this hypothesis ensures that any non-negative level of input can produce at least a zero level of output and the production of positive output is impossible without at least one input $(x, 0_M) \in \Psi$, but if $y \geq 0 \Rightarrow (0_K, y) \notin \Psi$. This assumption is usually replaced by a stronger assumption in a situations where every input is essentially for production;

2. Ψ is a closed set. This assumption ensures the existence of at least one input and output efficient vector, since a closed set contains all points of its frontier;

3. Ψ is a non-empty set;

4. Scarcity. This ensures that a finite amount of input does not produce infinite quantities of output, formally implying that for each x, Ψ is upper bounded.

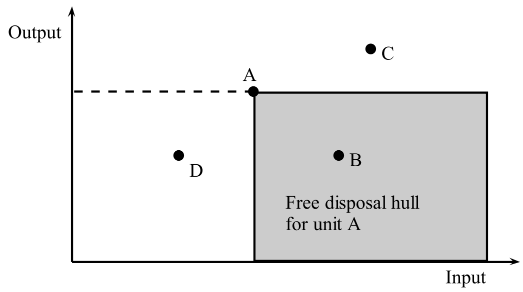
5. Input free disposal. This implies that it is possible to eliminate inputs without cost; formally if $(x_1, y) \in \Psi$ and $x_2 \geq x_1 \Rightarrow (x_2, y) \in \Psi$;

6. Output free disposal. It guarantees the possibility of an output reduction; formally if $(x, y_1) \in \Psi$ and $y_2 \leq y_1 \Rightarrow (x, y_2) \in \Psi$;

7. Ψ is a convex set.

Regarding monotonicity, properties (5) and (6) imply the existence of inefficient combinations of input and output. This assumption, in other terms, implies that if a productive unit is capable to transform a given amount of input into a given level of output, a greater amount of input will always lead to at least the same amount of output. Moreover, the monotonicity assumption implies that the optimal combination between inputs and between outputs can be achieved without cost: for this reason this hypothesis is usually also called *free disposal* (see Figure 1).

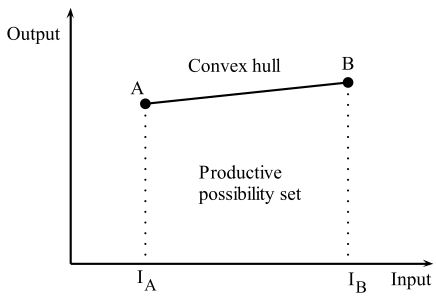
Figure 1. Free disposal hull



Although this hypothesis appears to be reasonable in several contexts, it does not necessarily hold in those production processes where congestion (even locally) is considerable (see *e.g.* Tone and Sahoo, 2004) or when the use of a greater amount of input negatively affects or slows the production process. Evidence of congestion is present for bigger Local Authorities when "*reductions in one or more inputs can be associated with increases in one or more outputs, or proceeding in reverse, when increases in one or more inputs can be associated with decreases in one or more outputs, without worsening any other input or output*" (Cooper *et al.*, 2000). Imposing assumption (5) and (6) the congestion factors are ruled out of the model assuming that *bad outputs* (such as pollutants or other products causing disutility in the production process) are not included in the set of production possibilities.

The convex assumption (7), instead, arises from the following question: given two different *DMU*, what can you say about the feasibility of the input-output combinations that lie between these two observations? In classical models this issue is addressed by assuming that the production possibility set is convex, implying that the convex hull of the two units lies in the set of production possibilities (see Figure 2).

Figure 2. Convex hull



The convexity assumption (7) is a consequence of decreasing marginal returns to scale in the theory of production and ensures that, in the whole production set, two or more input-output linear combinations are always possible.

As outlined by previous contributions proposed in literature about the two step procedures (Olson *et al.*, 1980; Fan *et al.*, 1996), the method here considered does not impose any constraints on the fitted frontier; this approach is consistent with the recent work of Kumbhakar *et al.* (2007) who proposed a nonparametric stochastic frontiers by a local maximum likelihood approach that does not assume monotonicity and concavity. Since monotonicity and concavity restrictions are not here closely considered, given that we have preferred to enhance a greater flexibility on the whole frontier, future research will possibly consider the estimation of GAM by backfitting algorithm; the basic idea behind backfitting is to estimate each smooth component of an additive model by iteratively smoothing partial residuals, thus imposing *a priori* constraints on the estimated frontier functions.

3. Analysing the recent trends of labour use efficiency in Italian SMEs: an application to the machinery industry

The model proposed in this paper has been applied to a balanced sample of 5821 SMEs extracted from the Italian Ministry of Economy and Finance annual survey (Studi di Settore) operating in the machinery industry during the 2002-2012 period: the choice of this sector is motivated by its key role in the Italian manufacturing system, considering that the engineering sector accounts for more than 42% of total manufacturing added value (Federmeccanica, 2006). The study of labour use efficiency appears to be particularly relevant in Italy, where, despite the efforts made by the national governments in the recent past, a number of legislative and institutional constraints still affect the efficient use of labour in several industries (for an extensive review of the topic, see Schindler, 2009): these weaknesses contribute to explain the structural gap in labour productivity existing between Italy and other advanced countries (Bassanini *et al.*, 2009). Despite the rigidities of the Italian labour market, the level of employment protection varies considerably across employee groups: in this context, a key role is played by the Wage Guarantee Fund (*Cassa Integrazione Guadagni*), a temporary lay-off scheme available to particular groups of firms that is used to counterbalance labour market rigidity and allocate the optimal level of labour after economic shocks. Aside from influencing the unemployment risk of permanent employees, this asymmetry across employment protection regulations has a potential positive impact on labour-use efficiency of the eligible firms. In this context, the study of employment use dynamics is particularly relevant to evaluate the speed of adjustment in the labour input use after the recent economic crisis and to assess the degree to which labour-use efficiency has varied among different groups of firms where employment protection was different. These issues have been addressed by evaluating the labour efficiency dynamics over time and relative to the use of Wage Guarantee Fund and relative to firms employing non standard workers.

Taking into account equation (1), the production output (Y) is measured in terms of turnover, labour (L) as the number of employees and capital stock (K) is proxied by the value of machinery and equipment. The financial variables included in the specification have been deflated using production price indices extracted from the Italian Bureau of Statistics (ISTAT) database.

Figure 3 shows the trend for the aggregate levels of capital K, labour factor L and production output Y of the sample. During the period considered in the analysis, the dynamics of factor K clearly appears to be anelastic with respect to the economic cycle, thus justifying the choice to treat this input as *quasi-fixed* in the subsequent part of analysis. Conversely, the significant decrease of Y during the double dip (2008-2010 and from 2012) appears to affect the dynamics of the labour factor only.

After estimating the model with GAM, the focus of the analysis is moved to the individual components contributions. The model has been estimated by using the `R` Environment (R Core Team, 2013) exploiting the `semsfa` package (Ferrara and Vidoli, 2015) which draws on the `mgcv` package (Wood, 2004).

Figure 4 shows contributions of the model terms to labour, that is the smooth terms associated to time, output and capital.

The dashed curves show pointwise approximate two standard error limits for the fitted curves. There is a strong evidence about the significance of all covariates.

Figure 3. Aggregate levels of Labour, Capital and Output per year (base = 2002)

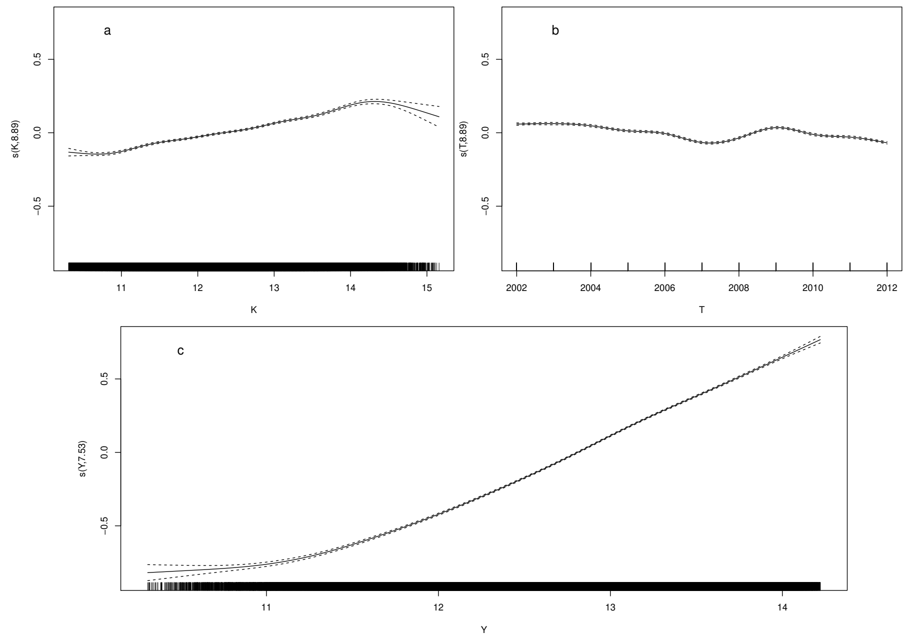
The median estimated values of labour-use efficiency obtained through the proposed procedure are reported in Table 1 (*Total*): during the time span considered, individual labour-use efficiency ranged from 24.2% to 97.3% with the mean value of 82.6%; therefore, on average, labour is overused by 17.4%. Overall, the inefficiency levels in the sample appear to be fairly stable over time.

Considering the estimates of labour-use efficiency are firm and time specific, the results can be examined in further detail by focusing on those firms that have used Wage Guarantee Fund during the time span considered. The results of the estimates (Table 1 and Figure 5) show that this subset of firms have achieved a higher level of labour-use efficiency during the 2005-2012 period[2]: therefore, the empirical evidence suggests that this policy measure has been effective in mitigating the negative effects associated with the demand shocks experienced during the recent economic crisis, limiting the rigidities of the Italian labour market.

Finally, the focus of the investigation on labour-use efficiency is moved to the subset of firms that have not used standard forms of employment such as part-time, casual, fixed-term, temporary agency workers namely "No Employees": this analysis is particularly relevant as it provides empirical evidence to inform the ongoing debate about the medium and long run effects of the labour market reforms introduced in Italy between

[2] Information on Wage Guarantee Fund is not available in our database before 2005. However, the use of this policy tool was rather limited between 2002 and 2004 (Congia *et al.*, 2012).

Figure 4. Contributions of the model terms to labour L with respect to capital K (a), time T (b) and output Y (c).



the end of the 1990s and the beginning of the 2000s.

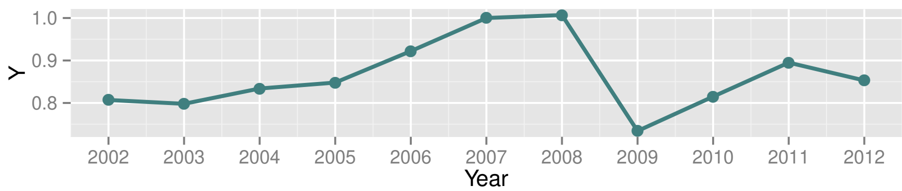
The implementation of this set of reforms has resulted in a significant decrease in the strictness of regulation, increasing the share of non standard typologies of contracts and stimulating job creation within the Italian economic system (De Stefanis and Fonseca, 2007). However, a number of works have raised concerns over the potential side effects generated by the reforms in terms of stagnating labour productivity (Boeri and Garibaldi, 2007; Lucidi and Kleinknecht, 2010): according to these contributions, the slowdown in productivity experienced by the Italian economic system during the last two decades could be partly explained by the increased presence of less productive workers who are often employed with non standard contracts. Indeed, the wage gap existing between these type of workers and regular employees (Picchio, 2006) reduces the incentive for firms to invest in both labour-saving innovative activities and limits the motivation of employees to accumulate human capital and increase their skills, hampering the chances of cooperative relationships between management and employees and resulting in lower productivity levels among workers employed with non standard contracts.
In this context, comparing the labour-use efficiency levels of those firms employing

Table 1. Median labour-use efficiency in the Italian machinery industry, time span 2002-2012.

	efficiency by year			efficiency by year, index values (base year = 2007)	
Year	Total	Firms using Wages Guarantee Fund	Firms using Non standard jobs	Firms using Wages Guarantee Fund	Firms using Non standard jobs
2002	0,849	.	0,779		0,984
2003	0,851	.	0,780		0,985
2004	0,848	.	0,783		0,989
2005	0,853	0,880	0,789	0,975	0,996
2006	0,848	0,890	0,782	0,986	0,987
2007	0,854	0,903	0,792	1,000	1,000
2008	0,845	0,885	0,783	0,980	0,989
2009	0,854	0,884	0,793	0,979	1,001
2010	0,849	0,874	0,803	0,968	1,014
2011	0,851	0,882	0,811	0,977	1,024
2012	0,848	0,883	0,804	0,978	1,015

The efficiency estimate for firms using non standard jobs in year 2006 is affected by a methodological change in the fiscal system; therefore this data it's not reported in Figure 5.

Figure 5. Median labour-use efficiency by type of firm and production output (base = 2007*)*



flexible workers and those relying solely on standard forms of employment is expected to provide new insights to enhance a more comprehensive evaluation of the effects of the labour market reforms briefly discussed above. The results of the estimates show that labour input use, holding capital and output constant, is lower than average among the subset of firms using non standard forms of employment. although the gap tends to decrease over time.

As far as the dynamics of the aforementioned gap is concerned, Figure 5 shows that the reaction to the sharp decrease in production experienced by the sector since 2009 has been substantially different among the two subsets of firms analyzed in this paper. The downturn was preceded by a period of moderate growth (2002-2007) characterized by a generalized increase in labour-use efficiency. In 2008, all firms experienced a significant contraction of labour-use efficiency, motivated by the difficulty to quickly readjust the labour input to the demand shock in the short term. However, during the following years firms using non standard jobs were capable to react to the crisis by increasing their labour use efficiency; on the other hand, the ability of other firms to readjust their use of the labour input appears to have been limited during the crisis.

According to these results, the diffusion of non standard jobs following the introduction of the labour market reforms in Italy between the end of the 1990s and the beginning of the 2000s, appears to have supported the entrepreneurs in the optimal allocation of the labour input, thus generating benefits in terms of labour use efficiency in addition to those associated with employment growth. However, a potential trade-off may exist between these desirable effects and the lower productivity of this type of employees, as the recent literature has highlighted. This considered, further research to address this potential issue is certainly needed.

4. Conclusions

This work provides a novel framework to evaluate labour-use efficiency of Italian manufacturing firms, in an attempt to partially fill the existing gap in the relevant literature due essentially to the lack of firm level data.

The model proposed in this paper aims overcome the main drawbacks associated with the preliminary specification of a particular form for the production function: the higher degree of flexibility in the new approach is the consequence of the limited set of assumptions specified for the model. Nevertheless, these simplifications do not affect the additivity and separability assumptions, as well as the hypothesis regarding the independence between noise and efficiency. However, monotonicity and concavity restrictions have been ruled out of the model: therefore, future research will consider the estimation of GAM by backfitting algorithm. The basic idea behind backfitting is to estimate each smooth component of an additive model by iteratively smoothing partial residuals: by this way one can impose some constraints on the estimated smooth functions.

This flexible procedure has allowed us to find new insights associated to the labour-use efficiency dynamics of Italian manufacturing firms in the recent past. Results show the presence of a persistent level of labour-use inefficiency in the sample used for the analysis: this issue is particularly evident for the subset of firms using non standard jobs, while firms entitled to access to wage redundancy fund appear to have achieved higher levels of efficiency in labour input use on average. Therefore, the study shows that this policy measure was effective in mitigating the negative effects associated with the demand shocks experienced during the recent economic crisis, limiting the rigidities of the Italian labour market.

The analysis also shows that the inefficiency gap between the two subsets of firms tends to reduce in absolute terms over time: this trend appears to be the result of the increased efficiency in firms using non standard jobs, possibly associated with the higher possibility to rapidly readjust the labour input during the negative phase of the economic cycle. According to these results, the diffusion of non standard jobs following the introduction of the labour market reforms introduced in Italy between the end of the 1990s and the beginning of the 2000s appears to have supported the entrepreneurs in the optimal allocation of the labour input, thus generating benefits in terms of labour use efficiency in addition to those associated with employment growth. However, a potential trade-off may exist between these desirable effects and the lower productivity of this type of employees, as the recent literature has highlighted. This considered, further research to address this potential issue is certainly needed.

Other possible directions for future research include the implementation of alternative specifications of the inefficiency component u_{it}, integrating internal and external factors associated with tangible and intangible factors such as R&D, human capital, public infrastructure and degree of internalisation. Furthermore, the analysis could be moved forward by estimating the employment elasticity with respect to the covariates with particular regard to time: according to Kumbhakar and Zhang (2013) this component can be interpreted as technical change.

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