Energy Economics 34 (2012) 930–941

Contents lists available at ScienceDirect

Energy Economics

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

Is energy intensity important for the productivity growth of EET adopters?

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ARTICLE INFO

Article history:
Received 4 June 2009
Received in revised form 9 May 2011
Accepted 14 May 2011
Available online 25 May 2011

JEL classification:
D2
D8
L2
L6
Q4
Q5

Keywords:
Energy efficient technologies
Productivity growth
Metafrontier

ABSTRACT

Energy Efficient Technologies (EET) have attracted strong interest because of their role in reducing environmental damage. Their adoption, however, remains rather low, while their impact on productivity is substantial and differentiating with respect to technological characteristics. Energy intensity, being such an obvious characteristic, could be employed to classify EET adopters thus giving rise to two heterogeneous technologies (i.e. those corresponding to firms of low and high energy consumption). Hence, this paper examines the impact of energy intensity on the productivity growth of firms adopting EET in varying time intervals through a metafrontier-based framework, while also decomposing that impact in terms of technical, efficiency and scale-efficiency changes. The analysis is complemented by examining the role of firm-specific characteristics on the productivity growth through linear regression.

1. Motivation

Although 'Energy Efficient Technologies' (EET) define an important option for reducing greenhouse gas emissions and environmental damage caused by other pollutants, the observed rate of EET adoption remains rather low. Despite several attempts to investigate the causalities linking the low rate of EET adoption to firms' behavior and characteristics (e.g. DeCanio, 1998; Jaffe and Stavins, 1994; Kounetas and Tsekouras, 2008), the impact of EET on firm's productivity remains a rather neglected issue. Still, initial findings by Jorgenson (1984) and Schurr (1983) leave little doubt about the importance of energy consumption on Total Factor Productivity (TFP).[1]

Since EET are available to a wide range of industrial sectors, estimating their impact on productivity requires a proper handling of technological heterogeneity. Moreover, it can reasonably be expected that the productivity effects arising from EET vary significantly with 'energy intensity' (i.e. the heavier the energy consumption of a firm the stronger the impact of EET adoption on TFP), thus signifying energy intensity as a fundamental factor of heterogeneity. Furthermore, different firms adopt EET in varying time intervals, therefore productivity growth must also examine 'time-based' heterogeneity. To the best of our knowledge, however, there exists neither a formal approach nor an empirical evaluation of EET's impact on the productivity of firms that are technologically heterogeneous with respect to energy consumption.

Hence this paper examines the role of EET on firms' TFP growth, when the following two conditions are simultaneously valid: (i) the firms have adopted EET and (ii) they are significantly technologically heterogeneous in terms of energy intensity. Although one could argue that the above imply a selection mechanism distinguishing the (EET) adopters from non-adopters, in the present paper we focus on the EET productivity effects on firms which have decided, through this latent decision making mechanism, to adopt EET (i.e., we do not examine this selection rule itself[2]). Thus, we aim solely at elucidating the role of EET on adopters' TFP growth.

Our methodological framework employs the notion of the *metafrontier*, which apart from estimating EET's impact on TFP under technological and time-based heterogeneity, allows us also to examine knowledge spillover effects and to investigate which of the TFP components are mostly affected by EET adoption. The latter is achieved not only by decomposing TFP into the components of technological change, technical efficiency change and scale efficiency change, but also by deriving 'metafrontier:frontier' ratios for each component to determine the difference of firms' performance within the restricted technology from

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[1] We may also refer to productivity gains reported from govermentally-funded programs (e.g. Worrell et al., 2003) and to empirical findings in Boyd and Pang (2000) and Murty and Kumar (2003) from energy-intensive sectors.

[2] This partial observability approach for productivity analysis has also been employed in Skuras et al. (2006).

0140-9883/$ – see front matter
doi:10.1016/j.eneco.2011.05.006

their performance within the metatechnology; it turns out that every such ratio is representable as a technical efficiency change (with respect to appropriately selected points). Last, firm-specific characteristics, possibly introducing additional heterogeneity, are also examined through linear regression in order to signify which such factors are relevant to EET's impact on firms' productive performance. Let us note here that, as Jensen and McGuckjn (1997) report, firms may differ along practically any observable dimension, such as technology, size, age, performance, job creation and destruction, investment patterns and innovative activities.

But which are the origins of the effects that the EET adoption may have on a firm's productivity? Normally, one should expect that the influence of EET on firms' productive performance is positively related to their energy intensity. This is easily deduced if we consider that EET, as any other form of biased technological progress, reduce average costs proportionally to the ratio of the required quantity of energy input per unit of produced output. However, it appears that EET are frequently embodied in an existing production technology not for reasons related to productivity improvements (DeGroot et al., 2001; Kounetas and Tsekouras, 2008); to the contrary, firms decide to adopt EET due to environmental regulations or due to business strategies that depart from cost-leadership behavior (Porter, 1991) and are developed on the grounds of corporate social responsibility, customer loyalty or rapid innovation (Lazonick, 2007). Such considerations are evidently more critical for energy-intensive firms.

In cases of a significantly negative impact of EET on productivity, EET adoption is indeed discouraged. The economic rationale for the possibly negative impact of EET adoption on firms' TFP growth may be traced to the internal cost of adjustment that the embodiment of a new technology may cause (Rohdin and Thollander, 2006; Seldon and Bullard, 1992). More specifically, that cost emanates from the organizational disorders implied by the use of the new technology (Damanpour, 1996), the replacement of equipment of low vintage with new ones (Geroski, 2000) and the fact that learning-by-doing effects are practically zero compared to the corresponding positive and often significant effects of the previous technology (Levinthal and March, 1993). Whether, in the EET case, such effects are more significant for energy-intensive firms is not straightforward to assess, although related policy implications remain crucial. Specifically, given that EET should become broadly adopted mainly for environmental reasons, a central authority should provide incentives (e.g. subsidies, tax deductions, public investment) that counteract internal costs of adjustment, possibly in a different scale per firm depending on its energy-intensity.

Nonetheless, even in the case where firms expect positive effects of the EET on their productivity, one should still consider the impact of the 'hidden' costs that are realized mainly in the post-adoption period. Hidden costs represent the most important and influential explanation for the low rate of EET diffusion (Sorrel et al., 2004, p. 65), while also explaining the short payback periods as a way to compensate them (Rohdin and Thollander, 2006). According to Sorrell et al. (2004), the most prominent types of hidden costs are (i) the general overhead costs of energy management, (ii) the costs that are specific to an individual EET investment or to the energy efficiency option and (iii) the potential loss in terms of performance associated with energy-efficient choices. In all such cases, the hidden costs are reflected on firms' TFP in the post-adoption period and should therefore be traced by analyzing productivity over medium-length time intervals. Overall, the firms' productivity differentials are determined by the size of both the adjustment costs and the EET benefits. However, we could further argue that both the adjustment costs, the biased, with respect to energy, technological progress and the resulting productivity gains, are all heavily dependent on a firm's absorptive capacity and strategic orientation as well as the existence and intensity of knowledge spillovers. Whether the absorptive capacity and the knowledge spillovers arise from the 'local' energy-specific technology or the 'global' metatechnology of all EET adopters remains a question to be addressed. Indeed, the methodological approach adopted here could be regarded as a solid step in that direction.

The rest of the paper is organized as follows. The methodological framework is presented in Section 2, while the application framework used is presented in Section 3. Our results are discussed in Section 4, while Section 5 contains some final remarks.

2. Methodology

A well-known approach for TFP estimation employs the Malmquist Productivity Index (MPI) of Caves et al. (1982) and is based on the estimation of a parametric or a non-parametric production frontier. The popularity of MPI arises from its rigorous mathematical documentation and its standard TFP decomposition into technical efficiency change, scale efficiency change and technological change. A plethora of papers employing MPI during the last decade share the assumption that all firms operate under the same technology, represented by a single frontier. In the case examined here, i.e. the role of energy intensity regarding EET's impact on TFP, the 'common technology' assumption appears unrealistic, i.e. a distinction between energy-intensive and non-energy-intensive firms becomes apparent, thus giving rise to two corresponding technologies.

Still, heterogeneity emerges also over time intervals, since observed changes among firms in the same industry could be uneven and idiosyncratic. Hence, it is reasonable to argue that time-related heterogeneity is present. Time heterogeneity is also the core of both the 'industry life-cycle' (Klepper, 1996) and the 'organizational ecology' (Caroll and Hannan, 2000) approaches. In the former approach, firms differ in terms of their innovative capabilities and timing of arrival and these differences are dynamically reflected by differential growth rates and firms' size. In the latter one, the unit of analysis is primarily different types of organizations, rather than individual firms and the goal is precisely to account for their relative diffusion within the industry over time. Such elements, being dynamic by their nature, may be considered as the notions (or vehicles) that convey issues of time-heterogeneity and link them with productivity.

To present our methodology, we follow closely the notation and work of Balk (2001) concerning the definition of productivity measures. Consider a firm as an entity transforming inputs into outputs and let $N=\{1,\ldots,n\}$ and $M=\{1,\ldots,m\}$ be the sets indexing the inputs and outputs, respectively. The input and output quantities can be represented as vectors of non-negative real values $x\in\mathbb{R}^n_+$ and $y\in\mathbb{R}^m_+$. Further, a technology S can be represented by the production possibility set as $S=\{(x,y): x \text{ can produce } y\}\ \mathbb{R}^{n+m}_+$, with the output sets defined as $P(x)=\{y:(x,y)\in S\}$.The (output-oriented) efficiency of a firm with respect to technology S can then be measured with respect to the output sets through the *direct output distance function*, defined as $D_O(x,y)=\inf\{\delta>0: y/\delta\in P(x)\}$.The output-oriented *frontier* F associated with technology S is the set of the output isoquants, i.e. $F=\{(x,y)\in S: D_O(x,y)=1\}$.For a particular technology S, define also the *cone* technology $\check{S}=\{(\lambda x,\lambda y):(x,y)\in S,\ \lambda>0\}$, i.e. technology $\check{S}$ exhibits *Constant Returns to Scale* (CRS). Output sets implied by $\hat{S}$, the associated distance functions and the frontier $\check{F}$ are defined accordingly.

Given k distinct technologies $S^1,\ldots,S^k$, the metatechnology set, denoted as S^M, is the smallest convex set containing all input–output feasible combinations (e.g. see O'Donnell et al., 2008). Formally, $S^M=conv.hull(S^1\cup S^2\cup S^K)$or $S^M=conv.hull\{(x,y):x\geq 0, y\geq 0, x$ can produce y in at least one of $S^1, S^2,\ldots, S^k\}$.The output sets $P^M(x)$ associated with the metatechnology are defined as for a single technology, while the corresponding distance function is $D^M_O(x,y)=\inf\{\delta>0: y/\delta\in P^M(x)\}$ where $D^l_O(x,y)\geq D^M_O(x,y)$, $l=1, 2,\ldots,k$. The definitions of cone metatechnology and associated distance functions are similar to the single-frontier case.

The current study involves two technology sets S^{le} and S^{he} that encompass firms of low-energy and high-energy consumption, respectively (or energy-intensive and non-energy-intensive firms). These