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Exporting and Environmental Performance: A Firm-level Productivity Analysis

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1. INTRODUCTION

OVER the last decade the literature on firm heterogeneity and firm-level globalisation strategies (sometimes called 'new trade theory') has increased considerably. One dimension to receive particularly close attention is the relationship between firm-level productivity and entry to, as well as survival in, export markets (Greenaway and Kneller, 2007). In this line, several models have focused on explaining the heterogeneity of firm and industry productivity, with exports as a key factor, which is often empirically analysed using probabilistic methods to estimate export premia as an exogenous factor (e.g. Clerides et al., 1998; Bernard and Jensen, 1999; Aw et al., 2000; Bernard et al., 2003; Helpman et al., 2004). Although these studies have provided useful insights into the relationship between productivity growth and exports in recent years, some questions remain. For example, the analysis of the impact of environmental performance on this relationship has received scant attention, especially at firm level.

The impact of environmental policy on international trade has frequently been analysed from the traditional comparative advantage perspective (e.g. Tobey, 1990; Jaffe et al., 1995). In the standard Heckscher–Ohlin (HO) framework (sometimes called 'old trade theory') comparative advantage is determined by factor endowment differentials. One assumption is that environmental policy can affect standard factors, such as differences in resources endowments (e.g.

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specialised workers) or technology, thus influencing trade patterns (Copeland and Taylor, 2003; Ederington and Minier, 2003). Nevertheless, the empirical literature has been inconclusive on this issue (e.g. Brunnermeier and Levinson, 2004).

Cole and Elliott (2003a) examine the impact of environmental regulation on trade patterns from both aforementioned perspectives, i.e. 'old' (Heckscher–Ohlin–Vanek) and 'new' trade frameworks. Although, as these authors state, the answers provided by these models are different, their findings offer an extensive view of implications on exports of environmental regulations at country and industry levels.

In the international economics literature we can also find other links between the two trade perspectives, particularly related to productivity issues. Harrigan (1997) and Davis and Weinstein (2003) develop a simple general equilibrium model, in which general technology as reflected in total factor productivity (TFP) and factor supply differences can jointly determine patterns of production and exports. Recently developed models on firms' productivity differences have renewed interest in factor endowment (e.g. López, 2004; Yeaple, 2005; Bernard et al., 2007a). They state that export orientation is the determinant of resource endowment and the adoption of new technology, and so the within-industry heterogeneity of firms may also be explained endogenously. In empirical studies, for example, authors such as Alpay et al. (2004) for the food industry in Turkey, and Managi and Karemera (2005) for agri-food trade in the US, carried out several empirical analyses based on the above-mentioned approaches to determine the relevance of environmental factors to exporting. At firm level, Cole et al. (2006) also analysed the relationship between several environmental performance measures and firm-specific characteristics in Japan, showing a positive influence of exports.

The contributions of this paper are two-fold. First, we analyse the effect of export orientation on firm productivity differences, considering several components: technological change, efficiency change and environmental productivity, which is interpreted as a measure of environmental performance. Second, we analyse the implications of these components on export performance, particularly including environmental indicators as factors of firms' specialisation and technology proficiency. Considering analyses based on traditional and new trade models, the main aim is to offer extensive empirical findings on the relationships between exporting and environmental variables at firm level.

The Spanish food industry constitutes the reference for this analysis, which uses a panel data of firms for the period 1994–2005. On average, over 55 per cent of the production of these firms is exported, and fellow European Union (EU) member countries are the main markets for their produce.

Traditionally, environmental performance in the Spanish and European food industry has received scant attention. There are a number of factors that explain the lack of studies on this sector, including the limited technological improvements, the nature of operations with diffuse pollution in comparison with other industries (e.g. the chemical industry or certain manufacturing sectors), and the recent incorporation of environmental programmes and the fact that many of these are voluntary, among others (Swinton et al., 1999; Galdeano-Gómez, 2008). Nowadays, however, environmental quality and food safety, and the pollution generated by agri-food production promise to play more influential roles in EU and OECD countries in both domestic and foreign trade (OECD, 1998; Bellesi et al., 2005).[1]

In this context, there are two main reasons for choosing the food industry as the subject of this analysis. On the one hand, unlike other sectors, the improvement in productivity and competitive trade in this sector are major drivers to environmental performance (Carpentier and Ervin, 2002; Managi and Karemera, 2005). On the other hand, investment in new technologies and the employment of skilled workers needed to implement environmental management systems and meet demand requirements in export markets can lead to opportunities for new products and also cost reductions and/or efficiency improvement (Esty and Porter, 1998; Reinhardt, 2000; Carpentier and Ervin, 2002). In particular, this paper bears in mind the implications of environmental performance on the firm's performance improvement (or worsening), leading us to consider an environmental index associated with productivity measures, also called environmental productivity, as mentioned above. This approach has been adopted in recent studies of productivity environmental analysis (e.g. Ball et al., 2004; Managi et al., 2004; Kumar and Khanna, 2009). In this case, the amount of waste and residues is used as environmental or undesirable output, determining its implications on the input–output relationship of firms' production processes. This environmental index is considered useful to determine productivity heterogeneity and to analyse differences in resource specialisation between export-oriented and non-export-oriented firms.

The rest of the paper is organised as follows. Section 2 offers a detailed discussion of the relevant literature. Section 3 describes the characteristics of and the basic evidence for the productivity differences within the empirical setting. Section 4 discusses the methods and econometric estimations. The conclusions are drawn in Section 5.

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[1] For example, recent food safety issues, including transgenic produce and the accumulation of pesticides and wastes, have alarmed consumers and shifted attention towards other production systems which are less aggressive to the environment. Also, recent analyses within the EU show greater diversification of demand due to a larger number of products for consumption. These products differ not so much in terms of nutritional composition, but due to the introduction of components related to health and other values added to the product, which are increasingly linked to environmental quality factors (Swinton et al., 1999; European Environment Agency, 2005).

2. EXPORTS, HETEROGENEITY OF FIRMS' PRODUCTIVITY AND ENVIRONMENTAL PERFORMANCE

The most widely accepted argument is that international trade favours growth and productivity, leading to a scenario in which export-oriented industries and firms are more productive than domestic-oriented ones (Greenaway and Kneller, 2007). The pressure of international competition will force exporters to cut costs and improve efficiency by eliminating managerial and organisational inefficiencies. Although almost all empirical studies find the productivity of exporters to be higher than that of non-exporters (e.g. Clerides et al., 1998; Bernard and Jensen, 1999; Aw et al., 2000; Bernard et al., 2003), much remains unexplained. For example, in a recent review of the literature, Bernard et al. (2007b) express the need for deeper analysis of the role of specialisation and reallocation within the firm in enhancing productivity and procuring welfare gains from trade.

Incorporating heterogeneous firms to explain patterns of trade and productivity growth has often led researchers to consider additional factors when estimating productivity and export premia. As pointed out by Melitz (2003) and others, the export decision is determined by a combination of sunk costs and firm productivity. As a result, the set of firm characteristics has been extended to include factors such as size, age, human capital, capital intensity, ownership and so on, supported in general by the evidence. Although environmental issues are of growing interest in international trade (for example, due to differences in environmental regulations and in firms' response to them),[2] the firms' productivity and heterogeneity related to environmental performance have received scant attention.

In the context of studies on the trade–environment relationship, in theory, relatively high environmental standards can lead to the loss of competitiveness in pollution-intensive export industries, providing factor endowments are similar (Baumol and Oates, 1988).[3] If factor endowments are different, environmental policy in addition to standard factors, such as differences in factor endowments and/or technology, can jointly determine competitiveness and trade. There exist numerous empirical

[2] This regulation can be disparate among countries. For example, in recent decades we observe a steady increase in regulation in the developed world (Cole and Elliot, 2003a), but more recently developing countries are increasing regulation at a faster rate (but from a lower base) than the developed ones (Levinson and Taylor, 2008). However, amongst countries in the same group, even, for example, within the EU, there are differences in regulation, sometimes due to different internal adaptation to the community norm (Galdeano-Gómez, 2008). More importantly, there are differences in the motivations for environmental practices and in the response of firms to such regulation (Cole et al., 2006) as discussed below.

[3] In this context, the debate related to the 'pollution haven hypothesis' has received considerable attention. This hypothesis suggests that environmental regulatory stringency in developed countries shifts polluting industries to the developing world, which has a comparative advantage in pollution-intense production (Cole and Elliot, 2003a; Levinson and Taylor, 2008).

studies which have tested whether environmental regulations affect trade patterns; see Tobey (1990) for a seminal work, as well as Jaffe et al. (1995), Antweiler et al. (2001), Copeland and Taylor (2003), Cole and Elliot (2003b), among the most referenced studies. Nevertheless, several reviews of empirical studies in this context show that the findings are mixed. Jaffe et al. (1995) conclude that there is little evidence of significant effects of environmental regulations on industrial competitiveness in developed countries. Also, reviews by Ferrantino and Linkins (1999) and Brunnermeier and Levinson (2004) show the inconclusive results on this issue.

As indicated above, the interest in factor endowment, however, has been renewed in recently developed new trade models based on firms' productivity differences (e.g. López, 2004; Yeaple, 2005). The basic argument is that firms can produce different varieties of goods, which require different technologies; consequently, domestic-oriented firms produce goods of lower quality (using inferior technology) and are less productive than export-oriented firms. The approach of Bernard et al. (2007a) combines heterogeneous firms with HO differences in factor endowments. In aggregate level studies, Harrigan (1997) and Redding and Vera-Martin (2001), and also Davis and Weinstein (2003) at firm level, follow a model in which exports are a function of TFP, prices and factor endowments. Managi and Karemera (2005) follow this approach while also considering environmental factors. In general, these models can explain how firms and industries that are more capital and skill intensive, and which also have better environmental performance (Cole and Elliot, 2003b; Managi and Karemera, 2005), are producing goods that are more consistent with comparative advantage (Bernard et al., 2007a).

At firm level, the empirical studies on environmental effects are still rather limited. Nevertheless, there are several recent research works that analyse firms' specific determinants of environmental management and performance differences. Arora and Cason (1995, 1996) show that firm size and industry effects are important determinants of a firm's participation in environmental programmes in the US. Also for the US, Khanna and Damon (1999) relate the reduction of toxic releases in chemical plants with long-term profits. Cole et al. (2006) examine the differences in environmental performance across Japanese firms and its relationship with firm-level characteristics, including exports. More recently, Albornoz et al. (2009) analyse the influence of foreign ownership (spillover effects) on encouraging environmental management practices in Argentinean firms.[4]

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[4] In a related line of study, several works examine firms' environmental decision related to different external pressures. For example, Pargal and Wheeler (1996) examine the consideration of formal factors (e.g. regulations) and informal ones (e.g. education) in Indonesian firms. In this line, several studies examine the influence of external factors (by customers, shareholders, local communities, etc.) on firms' environmental performance, such as Levy (1995), Henriques and Sadorsky (1996), Dasgupta et al. (1997), DeCanio and Watkins (1998), among others, showing in general (in developed and developing countries) how external pressures can significantly affect the firm's adoption of environmental practices.

Some analyses show how the motivation to implement environmental practices may be associated with organisational changes, saving costs and the effects on efficiency and productivity of the firm. For example, Diller (1997) suggests that there are organisational benefits from the introduction of environmental management systems where the organisational changes required to integrate them have a beneficial effect on the management of all systems within the company. Christmann (2000) argues that the implementation of environmental management practices may be directly related to cost advantage and may also be a significant factor in determining firm performance. In this line, Sheldon (1997) states how direct cost savings may be derived through the more efficient use of raw materials and energy, leading to less need for expensive waste management. Boyd and McClelland (1999) also show that improvement in environmental performance can be associated with firm productivity improvement.

Turning to the specific case of the food industry, Carpentier and Ervin (2002) show the improvement of productivity and competitive trade as important drivers to environmental performance. Among the few empirical studies in this sector, Alpay et al. (2004) state that environmental performance has a positive impact on the firms' export performance in the Turkish food industry. Galdeano-Gómez et al. (2006) show that environmental performance may have a positive relationship with productivity and efficiency in Spanish food firms.

This paper focuses on the effect of environmental performance in production process changes and the differences between export-oriented and non-export-oriented firms. Thus, the first aim is to analyse productivity differences by measuring the components of total factor productivity (TFP) and including an environmental performance index. This approach involves an adjustment of productivity indices (Malmquist–Luenberger) incorporating quantifiable environmental or undesirable outputs (waste and residues of production) and an estimation of the implications in the input–output relationship (environmental productivity). The second aim of the analysis is to estimate the effects of exports (export premia) on the heterogeneity of these firm productivity indicators. The third aim is to analyse the effects of productivity changes and other factors of firm specialisation on exporting by using an export performance (intensity) model and generalised method of moments (GMM) estimates.

3. EMPIRICAL SETTING FEATURES AND PRODUCTIVITY DIFFERENCES

a. Data and Export Classification

The set of analysis is a balanced panel containing 876 observations over the period 1994–2005, obtained from 73 firms in the Spanish food industry. These firms are located mainly in Andalusia and the Mediterranean area and the sample represents 41 per cent of the value of total national agri-food production. The main activities of these firms are the handling, manufacture and commercialisation of food products (fruit, vegetables, olive oil and citrus products are among the most important). In this sector, the intensive production and successful marketing of the produce have generated considerable exports to the EU, the destination for over 90 per cent of total exports, over the last few decades. The exports of these products from this area represent about 43 per cent of the national total (Instituto Español de Comercio Exterior, ICEX, 2006). In recent years, the concentration of the food industry in some regions, particularly in Mediterranean areas, and the increasing export activity in this sector, which requires intensive use of factors, have generated high levels of waste, representing one of the most important environmental issues (Downward and Taylor, 2007).

The application of environmental management systems has also constituted one of the major challenges for these business activities in recent years, due to increasing environmental quality requirements in European markets.[5] Moreover, environmental practices may represent a major driver to invest in new technologies and the incorporation of skilled workers, such as engineers and technicians (Céspedes-Lorente and Galdeano-Gómez, 2004).

As these changes in the production process can have implications for costs and productivity factors, the firms' environmental performance associated with total factor productivity (TFP), i.e. environmental productivity, is measured in order to test these implications (for further details, see the following subsection). The productivity estimates are adjusted by including environmental outputs or undesirable outputs, in this case taking the amount of waste and residues, mainly from chemicals, waste produce, packaging and other raw materials[6] (measured in kilograms per tonne of firm's market output).[7] See also Appendix B for details of variables.

[5] The main importers are Germany, France, Holland, Great Britain and Scandinavian countries. Consumers in these countries are typically concerned about environmental issues and demand strict regulations on food products compared to consumers in Spain.

[6] Similar measures for undesirable outputs are used in studies by Ball et al. (2001) and Graham (2004) for the agri-food sector in the US and Australia, respectively. In the present work we have considered non-recycled waste, and hence a more adequate measure of pollutant output. It can be considered a general measure of undesirable output since less waste and residues typically imply less environmental contamination and also better environmental management (Galdeano-Gómez et al., 2006).

[7] The data were collected from individual annual surveys and they are contrasted with the reports from Regional Environmental Councils of Andalusia and Murcia. This database was initiated in 1994 in the framework of the Project SEC-1578 of the Spanish Ministry for Education and Science (see e.g. Galdeano-Gómez et al., 2006, as a recent work on productivity analysis, using part of these data). Financial data were obtained from the firm's annual financial reports and from the database *Sistema de Análisis de Balances Ibéricos* (SABI) of the Spanish Mercantile Registry.

TABLE 1
Distribution of the Export Percentage and the General Classification (1994–2005)

Export Sales Ratio (%)	*Percentage of Firms*
0 to 10	5.4
10 to 20	6.2
20 to 30	19.1
30 to 40	10.4
40 to 50	12.5
50 to 60	21.3
60 to 70	14.2
70 to 80	5.0
80 to 90	4.3
90 to 100	1.6
Export General Classification	*Percentage of Firms*
Non-export-oriented	44.7
Export-oriented	55.3

Regarding export activity, the sample allows a classification of firms according to their trajectories with respect to the export market over the period of analysis. Most of the firms are considered continuing exporters (72.8 per cent), some of them are entering exporters (17.6 per cent), and a few firms are classified as non-exporters (5.4 per cent), switching (2.8 per cent) and exiting exporters (1.4 per cent). Nevertheless, the export sales ratio varies considerably throughout the sample and over the analysed period, from 14 per cent to 92 per cent of total sales. In this case, we opt to consider the highest and lowest specialisation in domestic and export markets (see e.g. Fu, 2005, for a similar classification). The panel dataset is divided into two main groups: export-oriented and non-export-oriented firms (domestic-oriented, including non-exporters), according to whether the firm's export sales ratio is above or below the average export sales ratio of the sample over the analysed period.[8] Nevertheless, other groups of export ratio distribution have been used in the analysis in order to check the sensitivity of model estimations. Table 1 shows this classification and the distribution of export sales ratios.

[8] Some preliminary statistical tests have been made to check the suitability of the split considered in the sample (Shesking, 2007). Using the export sales ratio, and under the assumption of normal distribution, the *Z*-test of Kolmogorov–Smirnov is used to test the differences between the two subsamples, rejecting the null hypothesis of equality at the 5 per cent level of significance (p-value $= 0.018$). Also, the t-Student (Welch test) and F-Snedecor statistics are used to test the equality of means and variances, respectively, between the two groups. These tests also confirm the rejection of the null hypothesis of equality of means and variances.

b. Productivity Differences

We estimate the TFP by using an output-oriented Malmquist–Luenberger productivity index (see Appendix A). This approach allows us to obtain an environmental productivity indicator.

In productivity analyses, the measurement of environmental performance of firms has received increasing attention in recent years. As indicated above, the adjustment of productivity indices has involved incorporating quantifiable environmental effects (pollution, waste, residues, etc.), usually as undesirable output, into the output or input vector (for a review of the different approaches, see e.g. Tyteca, 1997). One novel work in this field is that by Färe et al. (1989), who developed a vector measure of environmental performance, evaluating producer performance in terms of the ability to obtain an equi-proportionate increase in desirable or market output and reduction in undesirable output. Among others, Chung et al. (1997), Reinhard et al. (1999) and Ball et al. (2004) claim that an environmental performance indicator can be derived as the ratio between the overall productivity measure (using both desirable and undesirable output), and the gross productivity index where undesirable output is ignored. Along these lines, Kaneko and Managi (2004) and Managi et al. (2004) derive environmental indices as the ratio of a total productivity index (TFP_{total}) and a market productivity index (TFP_{market}).

In the present study we follow this approach and three measures are obtained: technological change (*TEC*), efficiency (*EFC*) and environmental productivity (*EP*). Regarding *EP*, by using a vector of directions in the distance function approach, which is positive for desirable or market output and negative for undesirable output, and given the same level of productivity: (1) a reduction of undesirable output implies a higher index of environmental performance (*EP*); (2) otherwise, an increase in undesirable output implies a lower *EP*.[9]

Figure 1 shows the estimates for the whole sample. Figures 2, 3 and 4 show the comparison between export-oriented and non-export-oriented firms of the three productivity components estimated.

The productivity results of the total sample indicate that the productivity improvement is due mainly to technological change, *TEC*, which shows an average annual growth of 1.4 per cent over the period studied. Efficiency change, *EFC*, and environmental productivity, *EP*, show an average annual growth of 0.5 per cent and 0.9 per cent, respectively. Nevertheless, the increase in the latter

[9] In other words, since *EP* is obtained as the ratio of TFP indices ($TFP_{\mathrm{total}}/TFP_{\mathrm{market}}$), if a given firm from our empirical setting reduces the amount of waste, this implies a positive effect on total productivity – *EP* increases. In contrast, an increase in the amount of waste implies a negative effect on total productivity – *EP* decreases (Kaneko and Managi, 2004).

FIGURE 1
Total Sample Estimates of Productivity Components

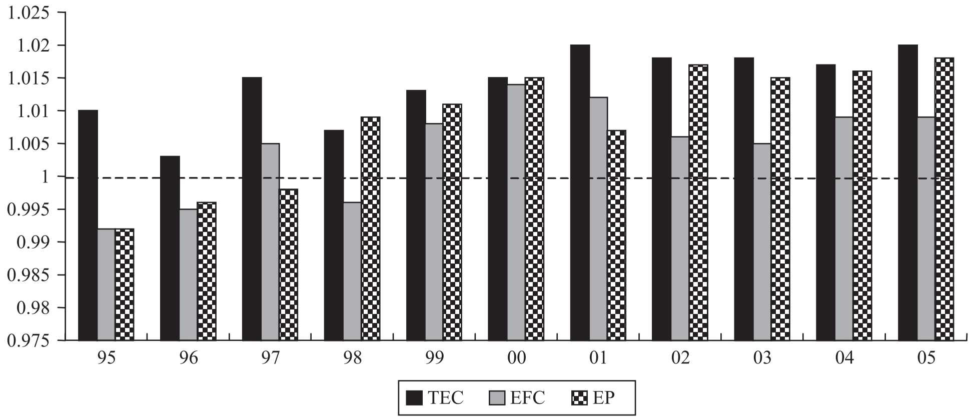
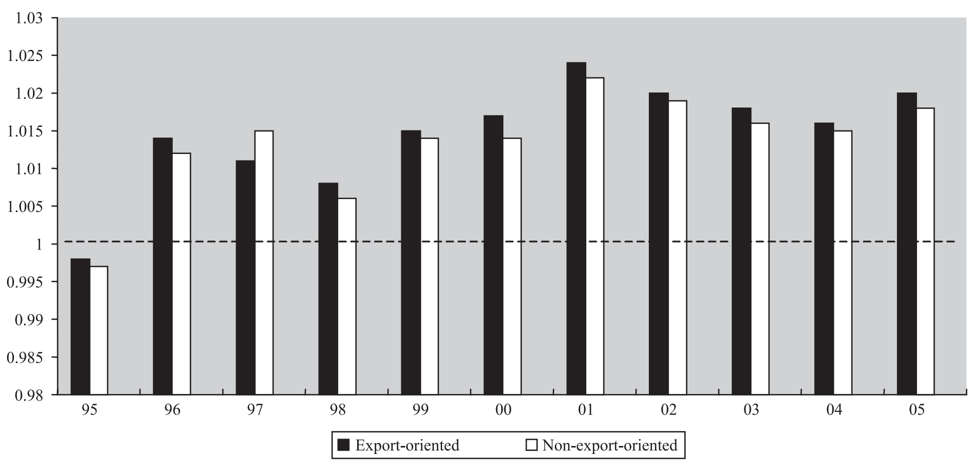


FIGURE 2
Technological Change (TEC) Estimates



is particularly noteworthy. For example, taking unity as reference, inefficiencies in environmental performance ($EP < 1$) are observed for the three first years; however, from 1998 these are turned into efficiency ($EP > 1$).

Comparing export-oriented and non-export-oriented firms, we observe that there is little difference in the technological change of both groups in terms of average annual growth over the period. On average the greatest differences between the two groups are for efficiency change and particularly for environmental

FIGURE 3
Efficiency Change (EFC) Estimates

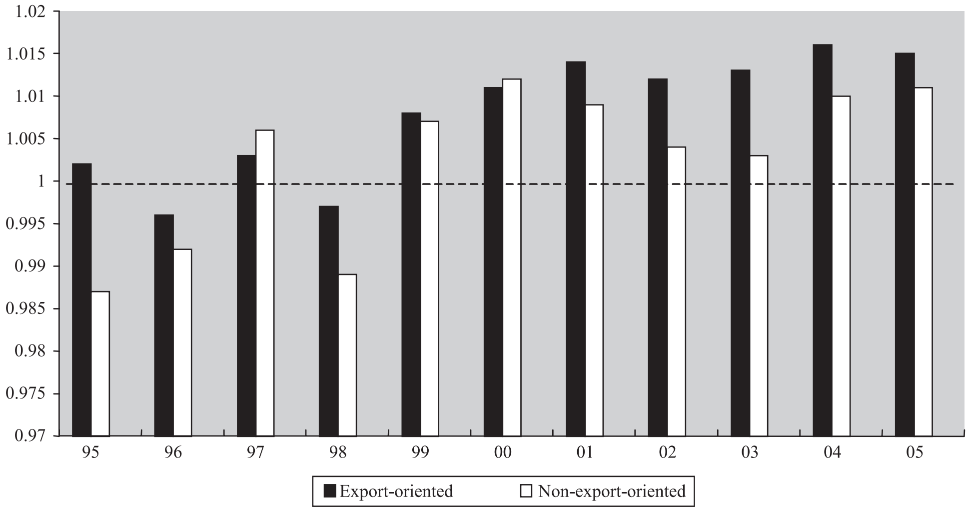
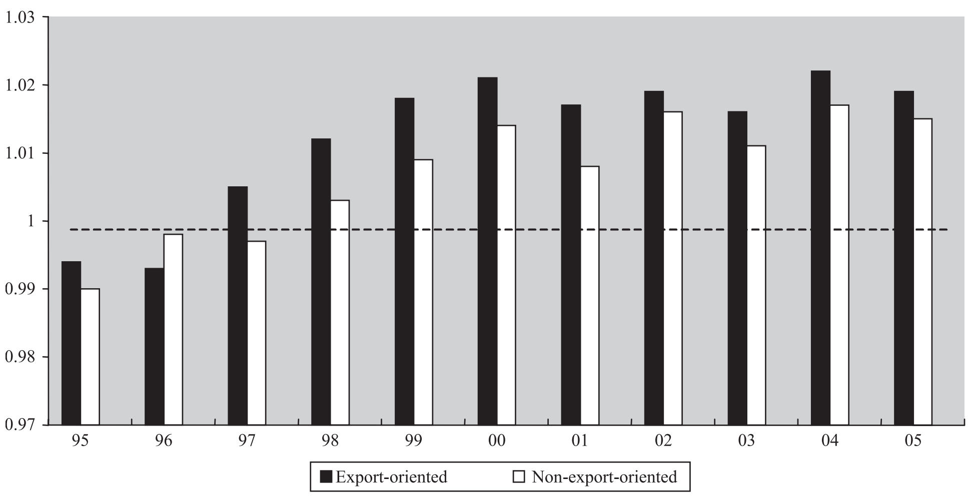


FIGURE 4
Environmental Productivity (EP) Estimates



productivity, showing average growth per annum of 1.2 per cent and 0.7 per cent for export-oriented and non-export-oriented firms, respectively. Thus, we can expect *a priori* a positive relationship between exports and environmental performance.

4. METHODS AND ESTIMATIONS

a. Export Premia and TFP Components Heterogeneity

To estimate the differences between export-oriented and non-export-oriented firms more precisely, we use a similar specification to that used by Bernard and Jensen (1995, 1999), which is widely used in empirical analysis (Aw et al., 2000; Greenaway et al., 2003; Fariñas and Martín-Marcos, 2007, among others). The export premia are estimated from a regression of the form:

$$\ln X_{Pit} = \alpha + \beta Export_{it} + \sum_{s} \gamma_s Size_{it} + \sum_{b} \phi_b Subsector_i + \sum_{T} \delta_T Time_t + \eta Young_i + \varepsilon_{it}, \quad (1)$$

where X_{Pit} are the productivity estimates of firm i at time t; $Export_{it}$ is a dummy variable indicating the export status of firm i at time t (i.e. export-oriented or non-export-oriented);[10] $Size_{it}$ is a set of three size dummies that assign a size category to each firm i at time t defined in terms of workers: small (fewer than 50 employees), medium (between 50 and 250 employees) and large (more than 250 employees); $Subsector_i$ is a set of five dummies that assign produce specialisation (fruit, vegetables, olive oil, citrus products and others); $Time_t$ is a collection of time dummies; $Young_i$ is a dummy variable identifying firms of five years old or less at the beginning of the period; and ε_{it} is a random error.[11] The omitted categories for subsector, time and size are other produce, 1995 and medium-sized firms, respectively.

Table 2 shows the results from equation (1) considering the two export groups, i.e. export-oriented and non-export-oriented firms. We carry out three estimations according to the productivity components considered, i.e. technological change, *TEC*(i), efficiency, *EFC*(i), and environmental productivity, *EP*(i). The parameter of interest is β, which measures the percentage difference in productivity between the two groups of firms. The Wald test of joint significance is used for size, subsector, young and time effects.

[10] Whether the firm's export sales ratio is above or below the average export sales ratio of the sample at time t, respectively.

[11] Other firm characteristics, such as foreign ownership, are not considered due to relatively low equity owned in the sample firms (only 19 present foreign ownership, and most of them with less than 50 per cent of equity). See e.g. Cole et al. (2008) and Albornoz et al. (2009) as recent works on the implications of foreign ownership on firms' environmental performance.

TABLE 2
The Premium to Export for Firm Productivity Differences (Status at time *t*)

	TEC(*i*)	*EFC*(*i*)	*EP*(*i*)	*TEC*(*ii*)	*EFC*(*ii*)	*EP*(*ii*)
$Export_{it}$	0.37	0.46	0.41	0.39	0.49	0.45
	(7.96)**	(9.03)**	(8.97)**	(7.34)**	(6.95)**	(7.83)**
Control variables						
Size-small	−0.17	−0.24	−0.11	−0.24	−0.31	−0.18
	(−2.05)*	(−2.63)**	(−2.18)*	(−1.98)*	(−2.86)**	(−2.23)*
Size-large	0.39	0.32	0.22	0.45	0.29	0.20
	(4.87)**	(4.27)**	(2.19)*	(4.83)**	(3.71)**	(2.07)*
Time	Included	Included	Included	Included	Included	Included
Subsector	Included	Included	Included	Included	Included	Included
Young	−0.05	−0.11	−0.03	−0.09	−0.17	−0.04
	(−1.57)	(−1.99)**	(−1.04)	(−1.92)*	−(3.04)**	(−1.35)
Observations[a]	803	803	803	454	454	454
R^2	0.53	0.63	0.51	0.52	0.66	0.52

Notes:
The values of *t*-statistics are reported in parentheses: * Significant at 5 per cent; ** significant at 1 per cent.
The parameters of intercept, subsector and time dummies are not reported.
[a] The export status for 1994 is not considered, taking into account the nature of incremental values of productivity indicators.

The results show important differences in productivity indicators as a function of exports. The difference in technological change is 37 per cent more for export-oriented than for non-exported-oriented firms. The major differential is observed in efficiency, with 46 per cent of differential between the two groups.[12] The differences in environmental productivity as a measure of environmental performance are also relevant: average performance is 41 per cent higher for export-oriented firms than for non-export-oriented ones. The parameters related to product specialisation show no significant differences.

With regard to the control variables, we observe major differences in technological change and efficiency, whose parameters are positive for large firms and negative for small ones. Nevertheless, these differences are small in relation to environmental productivity. Also, the age factor is less important in relation to environmental indicators than technological and efficiency changes. This is probably the consequence of a general adaptation to environmental quality requirements in export markets on the part of food industry firms regardless of their age. Nevertheless, there is a relative negative effect related to young

[12] Other studies on Spanish firms (e.g. Fariñas and Martín-Marcos, 2007) show similar results for productivity differences.

firms on efficiency, which can be associated with the characteristics of labour management in the sector and the importance of experience in international markets.[13]

In order to check the robustness of these findings, and also to test the split considered in the sample between export-oriented and non-export-oriented firms, the estimations have been carried out considering the export groups according to Table 1: the three groups classified at the top, i.e. the lowest exporters, and the four groups at the bottom of the table, i.e. the highest exporters.[14] Table 2 also reports the estimations carried out considering the same productivity indices, now termed *TEC*(*ii*), *EFC*(*ii*) and *EP*(*ii*). The estimated parameters confirm the differences between the lowest and highest exporters established in the first estimations, showing that these differences appear greater for efficiency and environmental productivity for both groups. Also, the differences between large and small firms are greater than those estimated previously, with the exception of *EP*. Parameters of young firms are still negative and particularly significant for efficiency index.

Table 3 reports results from specification (1) when the dummy variable $Export_i$ identifies exporting firms according to their general status over the whole period. The differences in productivity indicators between export-oriented and non-export-oriented firms are very similar to those shown in Table 2, with the exception of technological index, for which the difference is greater, and which can be related to a long-term effect when considering the average status of the whole period. This difference is also detected by the second estimation, considering the lowest and highest exporters.

b. Export Performance and Specialisation Factors

As stated in the previous subsection, most firms in the sample are, strictly speaking, exporters (continuing, entering and switching exporters) although with considerable differences in export sales ratios. This leads us to consider a relative

[13] For example, many workers in these firms are involved in handling and they are contracted for short periods (usually from some months to one year). Therefore, the firms' experience in labour management can affect, for example, productivity components. Experience can also be important in this sector, due to the volatility in prices and production, and also to achieve better clients and better contracts with food distribution chains, particularly in foreign markets, and this can affect the adaptation of the production process (Pérez-Mesa, 2007).

[14] The consideration of these subsamples implies a reduction of the observations, using 55.8 per cent of them approximately. Nevertheless, the observations can be different when considering the annual status and the average status of the whole period. For example, one firm classified as the lowest exporter at year *t*, can became a medium exporter group at *t* + 1 or in the following years, and vice versa. Therefore, in the estimations in Tables 2 and 3, the observations related to these subsamples vary.

TABLE 3
The Premium to Export for Firm Productivity Differences (Status at time *t*)

	TEC(i)	*EFC(i)*	*EP(i)*	*TEC(ii)*	*EFC(ii)*	*EP(ii)*
$Export_{it}$	0.41	0.47	0.39	0.43	0.48	0.42
	(8.07)**	(9.11)**	(7.65)**	(7.88)**	(7.72)**	(7.90)**
Control variables						
Size-small	−0.15	−0.19	−0.14	−0.20	−0.21	−0.16
	(−1.90)*	(−2.08)*	(−1.94)*	(−1.96)*	(−2.91)**	(−2.09)*
Size-large	0.49	0.34	0.17	0.42	0.31	0.12
	(4.98)**	(3.91)**	(2.03)*	(3.75)**	(3.42)**	(2.18)*
Time	Included	Included	Included	Included	Included	Included
Subsector	Included	Included	Included	Included	Included	Included
Young	−0.07	−0.14	−0.02	−0.08	−0.21	−0.06
	(−1.89)*	(−2.12)*	(−1.10)	(−2.05)*	(−3.16)**	(−1.32)
Observations[a]	803	803	803	448	448	448
R^2	0.54	0.62	0.52	0.57	0.61	0.49

Notes:
The values of *t*-statistics are reported in parentheses: * Significant at 5 per cent; ** significant at 1 per cent.
The parameters of intercept, subsector and time dummies are not reported.
[a] The export status for 1994 is not considered.

trade specialisation in the food industry under analysis, but also the existence of heterogeneity in firms' export performance.

As noted above, based on the factor endowment hypothesis, authors such as Harrigan (1997) and Redding and Vera-Martin (2001) developed a model in which the export propensity is determined by general technology as reflected in TFP and factor supplies differences. Managi and Karemera (2005) extended this approach with a decomposition of productivity components and environmental factors. Davis (1995) and Davis and Weinstein (2003) determine export propensity from a combination of technological proficiency (productivity indicators) with scale economies and other specialisation factors in production ('old trade' and 'new trade' theories) at firm-level analysis. We use a similar approach to Davis and Weinstein (2003) extended with environmental factors and productivity decomposition (Harrigan, 1997) to determine firms' export performance. This is specified as follows:

$$\begin{aligned} \ln\ Exp_{it} = {} & \pi_0 + \pi_1 \ln TEC_{it} + \pi_2 \ln\ EFC_{it} + \pi_3 \ln\ EP_{it} + \pi_4\ \ln\ Scale_{it} \\ & + \pi_5 \ln\ Price_{it} + \rho\ \mathbf{Z}_{it} + \rho * \boldsymbol{Env}_{it} + \kappa\ \boldsymbol{Control}_{it} + \omega_{it}, \end{aligned} \tag{2}$$

where Exp_{it} represents the export performance, measured by the export sales ratio or export intensity of firm *i* at time *t*; TEC_{it}, EFC_{it} and EP_{it} refer to the productivity components described above; $Scale_{it}$ indicates the scale economies of firm i at time t; $Price_{it}$ is the average price of output of firm i at time t; $\boldsymbol{Z}_{it}$ is a vector containing variables of firms' specialisation (capital intensity, skilled workers and wages); $\boldsymbol{Env}_{it}$ is a vector containing variables of firms' specialisation related to environmental factors (environmental investment intensity and risk of environmental audits); $\boldsymbol{Control}_{it}$ is a vector of control variables (size, age and concentration index); and ω_{it} is a random error.

The consideration of a *Scale* measure in specification (2) responds to simultaneity problems derived from the inclusion of ordinary inputs (to measure factor endowment) as indicated by Davis and Weinstein (2003). To measure this variable, a scale efficiency, *SE*, is used as the ratio of technical efficiency calculated under the assumption of constant returns to scale (TE_{CRS}) to technical efficiency calculated under the assumption of variable returns to scale (TE_{VRS}), i.e. $SE = TE_{CRS}/TE_{VRS}$.[15] The average price of marketed output, *Price*, is calculated by a weighted average price index. With regard to the variables related to firm specialisation: capital intensity is measured by the annual investment in machinery and equipment over total assets;[16] the skilled workers variable is measured as the ratio of qualified workers (engineers, technicians, etc.) over total workers; and the wage rate is calculated by the annual labour costs divided by the number of workers. The set of environmental variables comprises two elements: an environmental investment intensity, measured by the annual expenditure on environmental practices over sales; and a risk indicator of environmental audits, calculated by the number of annual audits as a consequence of irregularities in environmental controls of produce. In control variables we have included, in addition to size and age of the firm, a concentration ratio that takes into account the effects of industrial agglomeration in export orientation and regional specialisation (Davis and Weinstein, 1996; Greenaway and Kneller, 2007). This concentration in the sector is estimated by the Hirschman–Herfindahl index.

An alternative specification to (2) is used, particularly in order to reduce the bias associated with price estimation (Harrigan, 1997),[17] and this variable may be replaced with temporal dummies to identify time effects as follows:

$$\begin{aligned}\ln\ Exp_{it} &= \pi_0 + \pi_1 \ln\ TEC_{it} + \pi_2 \ln\ EFC_{it} + \pi_3 \ln\ EP_{it} + \pi_4 \ln Scale_{it} \\ &\quad + \delta_T \boldsymbol{Time}_t + \rho \boldsymbol{Z}_{it} + \rho * \boldsymbol{Env}_{it} + \kappa \boldsymbol{Control}_{it} + \omega_{it}.\end{aligned} \tag{3}$$

[15] In order to obtain TE_{VRS}, the distance function is also estimated (equation (A.5)) under VRS ($\Sigma_i\, \theta_i = 1$).

[16] Low investment is observed in R&D activities, probably due to the smaller size of most of the firms in the sample.

[17] This consideration is plausible if all goods are perfectly tradable and each firm in an open economy faces exogenous relative goods prices rather than endogenous ones (Managi and Karemera, 2005).

Due to the heteroscedasticity of unknown form and the potential simultaneity, the estimation is carried out using GMM (Hansen, 1982; Arellano and Bond, 1991) extended by Blundell and Bond (1998), which combines in a single system the regression in differences with the regression in levels. The vectors of instruments are constructed using the endogenous and exogenous variables, lagged levels and lagged differences. To contrast the validity of the instrumental variables in each equation, the statistical test suggested by Sargan and Bhargava (1983) is applied. The Ramsey reset test was conducted for functional form misspecification. A fixed effects model is considered and Table 4 reflects the estimates of equations (2) and (3).

The results in the two specifications are very similar. The low effect of the price variable may indicate that the analysed firms face exogenous prices in export markets. The Sargan test indicated the validity of the vector of instruments in GMM estimates (variables in levels lagged three periods and variables in differences lagged two periods). Diagnostic tests suggest the absence of residual serial correlation, and problems related to functional form, normality and heteroscedasticity for the estimated models.

Overall, the parameters estimated show significant effects of technology variables (productivity components) on firm-level exports, complementing the results obtained in the previous analysis. Although technological change presents positive coefficients, efficiency and environmental productivity show greater effects. This is probably due to the homogeneous adoption of technology among firms and the slight differences found (particularly in the first estimation above) between export-oriented and non-export-oriented ones. Specialisation and endowment variables, particularly capital intensity and skilled workers, are significant factors affecting export levels. More skill-intensive labour is associated in most cases with specialised engineers and technicians for the adoption of environmental requirements (mainly from export markets), and this fact may complement the effects of efficiency and environmental performance on export intensity.[18]

As regards the environmental factors, environmental investment intensity shows positive coefficients, though their incidence is not as high as expected (only significant at the 5 per cent level). This may indicate that not all expenditure is translated into great environmental productivity (e.g. reduction of pollutants and wastes) or that this environmental effort is not transmitted adequately to the exports markets (e.g. via certified environmental produce) (Holleran and Bredahl, 1997). Nevertheless, as expected, the risk of environmental audits has a significant negative effect on the firms' export intensity.

Scale economies, measured by scale efficiency, present positive but not significant parameters, indicating that large firms do not obtain higher returns to

[18] In this case, the available data do not lead to a distinction between workers specialised exclusively in environmental management systems and other activities of the firm.

TABLE 4
Export Performance Function Estimates

Explanatory Variables	*Equation (2)*	*Equation (3)*
Technology variables		
Technological change	0.718	0.743
	(2.11)**	(2.29)**
Efficiency change	0.924	0.907
	(4.23)***	(4.08)***
Environmental productivity	0.882	0.869
	(3.52)***	(3.30)***
Specialisation and endowment		
Capital intensity	0.087	0.093
	(2.25)**	(2.31)**
Skilled workers	0.126	0.110
	(3.81)***	(3.57)***
Wage	0.019	0.086
	(1.65)*	(1.62)*
Environmental factors		
Environmental investment intensity	0.095	0.104
	(1.92)**	(2.26)**
Risk of environmental audits	−0.137	−0.153
	(−4.92)***	(−5.08)***
Scale economies and price/time		
Scale efficiency	0.025	0.031
	(1.09)	(1.18)
Price	−0.019	–
	(−0.87)	
Time dummies	–	Included
Control variables		
Size	0.085	0.091
	(1.59)*	(1.62)*
Age	0.007	0.009
	(0.56)	(1.62)*
Concentration	0.291	0.278
	(3.76)***	(3.55)***
R^2	0.49	0.51
Observations (non-exporters excluded)	759	759
F-test (fixed effects)	74.22***	80.16***
Sargan ($t-3$)	0.064	0.071
Sargan difference ($t-3$ and $\Delta[t-2]$)	0.287	0.306
Serial correlation[a]	0.178	0.239
Functional form[b]	0.296	0.287
Normality[c]	0.531	0.584
Heteroscedasticity[d]	0.448	0.353

Notes:
The values of t-statistics are reported in parentheses: * significant at 10 per cent; ** significant at 5 per cent;*** significant at 1 per cent. The parameters of intercept and time dummies are not reported. Results of Sargan and diagnostic tests are shown as p-values.
[a] Lagrange multiplier test of residual serial correlation using 3 lags length (based on Akaike information criteria).
[b] Ramsey's reset test using the square of the fitted values.
[c] Jarque–Bera normality test.

accumulable factors of production, and more specifically they do not result in higher export levels. As indicated above, the price variable also shows non-significant parameters, which may indicate that the analysed firms face exogenous prices in export markets. Regarding the control variables, exports are slightly affected by the age and size of the firm, which also agrees with the results of the analysis carried out in the last subsection, particularly for environmental index. On the other hand, the concentration ratio shows positive and significant effects on firms' export intensity, complementing the idea of agglomeration as a determining factor of export specialisation.

Some tests have been carried out in order to check the sensitivity of these results. Although not reported for reasons of space, as a first corroboration of the estimations, both models have been re-estimated using the ordinary least squares (OLS) fixed effects method (a simplified method, frequently used to test other estimation approaches). The results obtained do not contradict the previous ones, particularly regarding the sign of coefficients of the main variables. Other robustness checks of interest are those related to the environmental factors considered. For example, environmental investment intensity has been replaced by the amount of certified environmental output over total market output.[19] Also, the environmental risk variable may have different effects depending on the time of consideration,[20] and this has been replaced by its lagged measure. Although for the latter the negative effects were softened, the results show few differences with respect to those obtained previously. In addition, some control variables have been replaced and/or omitted, particularly age and size, which showed parameters of relative significance in the previous estimations. However, there were few differences in the new estimations carried out, showing that the results broadly support those presented in the paper.

5. CONCLUSIONS

This study represents a search for connections between export activity and environmental issues at firm level. To this end, empirical models from new and traditional trade theories have been considered. From these frameworks, we have explored the effect of export orientation on firm productivity, including technological change, efficiency change and environmental productivity

[19] As Tyteca et al. (2002) indicate, a higher level of environmental investment or expenditure sometimes does not imply an improvement in environmental performance, since this depends on adequate management and other firm characteristics.

[20] For example, a lagged risk may have positive effects, encouraging environmental practices and obtaining a better export performance (we acknowledge this observation made by an anonymous reviewer). Nevertheless, using one and two lags of this variable, the parameters are of negative sign. This is probably because the extra environmental audits (e.g. from Regional Environmental Councils) usually give a negative image to the exporting firm (Pérez-Mesa, 2007), for several years at least.

components. Also, we have analysed the determinants of export performance at firm level, taking into account some firm-specific factors.

On the one hand, our results show that in the analysed food sector major differences exist in the different measures of productivity depending on the greater or lesser export intensity of the firm. Concern for environmental quality of the produce in international food markets makes the results obtained particularly interesting in relation to environmental productivity. Although the environmental activity is greater for large firms and for those with more years in the market, the effect of these two variables on this dimension of productivity is less intense in comparison with technological change and efficiency. This may indicate that the firms have had to adapt to conditions of environmental quality demanded by the consumers and environmental regulations in international markets (Bellesi et al., 2005), irrespective of their size or age. Consequently, these results on environmental productivity could be extrapolated to other export sectors with relatively stringent environmental regulations, such as chemical firms, the paper industry and other manufacturing sectors.

On the other hand, the analysis of the determinants of export propensity shows that certain specific characteristics of the firms, together with their resources and their environmental management, determine firms' export performance. These results are congruent with recently developed models of firms' productivity differences based on factor endowment (Bernard et al., 2007a), which can also explain geographical specialisation and agglomeration effects on export orientation (Greenaway and Kneller, 2007). In this line, future research could be addressed to analysing the effects of this agglomeration of exporters and/or the implications of contractual relationship of the food firms with multinationals on environmental performance, i.e. spillover effects (Albornoz et al., 2009).

Our findings particularly show that besides technology, proficiency and endowment factors, the environmental variables provide a significant explanation of the firms' export propensity. One relevant conclusion that can be drawn, therefore, is that policies associated with improving the environmental quality of the produce must go hand in hand with improvements in productivity and in capital and skill intensity, if companies wish to improve their export performance.

APPENDIX A

TFP and Environmental Productivity Estimation

A specific output-based measure of total factor productivity (TFP) is obtained by the well-known Malmquist indices approach. It measures the TFP change between two data points by calculating the ratio of two associated distance functions (Malmquist, 1953; Caves et al., 1982). A key advantage of the distance function approach is that it provides a convenient way to describe a multi-input, multi-output production technology without the need to specify functional form or behavioural objectives, such as cost minimisation or profit maximisation.

The usual specification of the distance function (Shephard, 1970) can be extended to the distance function for environmental productivity measurement. Chung et al. (1997) introduced a directional distance function to include improvements in environmental outputs under constant returns to scale (CRS). In contrast to the Shephard (1970) output distance function that measures efficiency by expanding all outputs simultaneously, the directional distance function measures efficiency due to increasing desirable outputs (market goods) while decreasing undesirable outputs (such as waste or pollutant output). Using the directional distance function specification, our problem can be formulated as follows. Let x, b and y be the vectors of inputs, undesirable outputs (environmental outputs) and market outputs (desirable outputs), respectively, and define the production possibilities set, $P(x)$, at time t by:

$$P^t(x) \equiv (x^t, b^t, y^t) : x^t \text{ can produce } (y^t, b^t), \tag{A.1}$$

which is the set of all feasible production vectors. We assume that $P^t(x)$ satisfies standard axioms, which suffice to define meaningful output distance functions (Shephard, 1970; Färe and Primont, 1995). Incorporation of undesirable outputs into the classic production technology requires the assumption of null-jointness, which implies that the decision makers (in this study, firms) should produce the undesirable outputs if they produce the desirable outputs. The assumption of null-jointness is expressed as follows:

$$(y^t, b^t) \;\; P^t(x); \; b^t = 0 \;\; y^t = 0. \tag{A.2}$$

Equation (A.2) says that the desirable or market outputs cannot be produced if the undesirable outputs are produced when the null-jointness assumption is imposed on the production possibilities.

The assumption of weak disposability is also introduced into the production possibilities set, which is mathematically stated as follows:

$$(y^t, b^t) \;\; P^t(x); \; 0 \leq \theta \leq 1 \;\; (\theta y^t, \theta b^t) \;\; P^t(x), \tag{A.3}$$

where θ is a vector of weights in constructing the production possibility frontier. This assumption (A.3) implies that any proportional contraction of the desirable and the undesirable outputs is also feasible if the original combination of the desirable and the undesirable outputs is in the production technology set, for a given vector of inputs x. It also implies that the undesirable outputs are costly to be disposed of and that abatement activities would typically divert resources away from the production of market or desirable outputs and thus lead to lower market output with given inputs (Färe et al., 1989).[21] The cost of abatement inevitably results in less production of market output.

The production possibilities set can easily be elaborated by employing the directional distance function. In other words, ease of computation and interpretation of the results are achieved if the production technology set is represented by the directional distance function. Maintaining the aforementioned assumptions, let β be the scalar valued index that measures efficiency at time $t = 1, \ldots, T$, and the directional output distance function is defined at t as

$$D_o^t(x^t, y^t, b^t; g_y, -g_b) = Sup\{\beta : (y^t + \beta g_y, b^t, -\beta g_b) \in P^t(x)\}, \tag{A.4}$$

where g is the vector of directions in which outputs are scaled. For this output-oriented distance function, we define $g = (y, 0, -b)$, i.e. market or desirable outputs are proportionately increased, inputs are held fixed and environmental or undesirable output is decreased proportionally.

Chung et al. (1997) define an output-oriented Malmquist–Luenberger productivity index that is comparable to the Malmquist productivity index, but which includes productivity changes with respect to both desirable and undesirable outputs. We calculate the productivity index by comparing distance functions in two different time periods (t and $t + 1$) using data envelopment analysis (DEA). This non-parametric mathematical programming technique is not conditioned on the assumption of optimising behaviour on the part of each individual observation and does not impose any particular functional form on production technology. Avoiding these hypotheses may be an advantage, particularly for firm-level analyses over a long period of time, where the assumptions of technological efficiency of every production unit in all time periods might be suspect (Managi et al., 2004). In this case a separate frontier is estimated for each year. Thus, for year t, the distance function for firm i is calculated as:

$$\begin{aligned} D_o^t(x^t, y^t, b^t; g^t) &= \max_{\beta,\theta} \beta, \\ \text{s.t. } -(1+\beta)y_i^t + Y^t\theta &\geq 0 \\ (1-\beta)b_i^t - B^t\theta &= 0 \\ (1-\beta)x_i^t - X^t\theta &\geq 0 \\ \theta &\geq 0, \end{aligned} \tag{A.5}$$

[21] Another assumption is the strong disposability of the outputs, which implies that some desirable and undesirable outputs can always be disposed of without any cost. Nevertheless, this assumption is less feasible in practice, as several empirical analyses have shown (e.g. Ball et al., 2004).

where Y, B and X are the vectors of output, environmental output and inputs (Chung et al., 1997). The constraints in equation (A.5) construct the reference (or frontier) technology from the data of year t. Every point in this technology set is a linear combination of observed output/environmental output–input vectors or a point dominated by a linear combination of observed points.

The Malmquist TFP index and its components efficiency change (*EFC*) and technological change (*TEC*) are defined in terms of the ratios of distance functions (Färe et al., 1994). In order to estimate environmental productivity, we calculate two productivity indices (Kaneko and Managi, 2004). First, a basic model is used to calculate total productivity of market output, TFP_{market}, using usual production input and output, which is decomposed into technological and efficiency changes. Second, we consider a joint model, TFP_{total}, which measures the total effect of increases in productivity due to improvements in technology and efficiency for the multi-production of marketable and undesirable outputs. In terms of the ratio of two distance functions (years t and $t + 1$) they are expressed (omitting the vector of directions, g) as follows:

$$TFP_{\text{market}}(x^t, y^t, x^{t+1}, y^{t+1}) = \left[\frac{[1 + D_o^t(x^t, y^t)]}{[1 + D_o^t(x^{t+1}, y^{t+1})]} \times \frac{[1 + D_o^{t+1}(x^t, y^t)]}{[1 + D_o^{t+1}(x^{t+1}, y^{t+1})]}\right]^{1/2}, \tag{A.6}$$

$$TFP_{\text{total}}(x^t, y^t, b^t, x^{t+1}, y^{t+1}, b^{t+1}) = \left[\frac{[1 + D_o^t(x^t, y^t, b^t)]}{[1 + D_o^t(x^{t+1}, y^{t+1}, b^{t+1})]} \times \frac{[1 + D_o^{t+1}(x^t, y^t, b^t)]}{[1 + D_o^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})]}\right]^{1/2}. \tag{A.7}$$

Increases in market output, and/or reduction in undesirable output, at a given input level, will increase TFP_{total}. Thus, the residual effects of two factors explain the changes in productivity related to the environmental factors, *EP*, given by,

$$EP = TFP_{\text{total}}/TFP_{\text{market}}, \tag{A.8}$$

where an increase in *EP* implies productivity improvements related to environmental performance. Given the same market productivity level, reduction in undesirable output increases *EP* (Managi et al., 2004) and vice versa. Thus, the growth or reduction in *EP* can be considered positive or negative effects of the firm's environmental impact.

For the estimation of TFP we have used one market output, one undesirable output and two inputs, labour and capital. Market output has been obtained from the firm's value added.[22] As indicated above, the environmental output or undesirable output is taken as the amount of waste and residues, measured in kilograms per tonne of market output, generated by the firm. The labour factor has been calculated from the total hours worked each year, and the capital factor (which includes buildings, equipment and machinery) has been obtained by the permanent inventory method.

APPENDIX B

Description of Variables and Summary Statistics

Export – A dummy variable that is 1 if the firm is export-oriented and 0 otherwise.

Size – Firm size measured as the total number of workers. This is used as a dummy variable in the estimation of equation (1) to distinguish different sizes (small, medium and large). In the estimation of equations (2) and (3) a continuous variable is used.

Subsector – Dummy variable that assigns produce specialisation (fruit, vegetables, olive oil, citrus products and others).

Time – Dummy temporal variable (first year of analysis excluded).

Young – A dummy variable equal to 1 if a firm is five years old or less at the beginning of the period.

TEC – Technological change index estimated as a component of total factor productivity (TFP_{market}) indices following the Malmquist–Luenberger approach. The distance functions include the market output (value added) and two inputs: labour (total hours worked a year) and capital (net fixed assets).

EFC – Efficiency change index estimated as a component of total factor productivity (TFP_{market}) indices following the Malmquist–Luenberger approach. The distance functions include the market output (value added) and two inputs: labour (total hours worked a year) and capital (net fixed assets).

EP – Environmental productivity index estimated as the ratio of two total factor productivity indices ($TFP_{\text{total}}/TFP_{\text{market}}$) following the Malmquist–Luenberger approach. The distance functions for TFP_{total} include an undesirable output (amount of waste and residues) together with the inputs and market output indicated above.

Exp – Export performance measured by the export sales ratio (export intensity).

Scale – Scale efficiency calculated as the ratio of technical efficiencies estimated under constant returns and variable returns to scale.

[22] As pointed out by Tyteca et al. (2002), the value added is advocated as a good candidate when environmental factors are introduced because it is assumed to reflect the contribution of corporate activity to global welfare.

Price – Price of market output (data from the Spanish Ministry of Agriculture, Fisheries and Food), calculated as weighted average price index for the case of a multi-output firm).

Capital intensity – Capital variable (to capture specialisation in capital factors) measured by the annual investment in machinery and equipment over total fixed assets.

Skilled workers – Labour variable (to capture specialisation in labour factor) calculated as the ratio of qualified workers over total workers.

Wage – Wage rate, measured by the annual labour costs divided by the number of workers.

Environmental investment intensity – Environmental variable measured by the annual expenditure on environmental practices over sales.

Risk of environmental audits – Environmental variable measured by the number of annual audits as a consequence of irregularities in environmental controls (extra audits from the Regional Environmental Councils).

Age – Firm's age.

Concentration ratio – Variable to capture the effects of agglomeration and regional specialisation calculated by the Hirschman–Herfindahl index.

TABLE A1
Descriptive Statistics of the Variables

Variables[a,b]	*Average*	*Standard Deviation*	*Maximum*	*Minimum*
Value added (market output)	241.538	279.071	407.318	49.392
Capital (input)	417.035	341.260	710.237	215.048
Labour (input)	564.698	768.523	1,291.083	192.412
Waste (undesirable output)	106.322	110.328	193.317	54.409
Technological index (*TEC*)	1.015	0.179	1.028	0.964
Efficiency index (*EFC*)	1.006	0.257	1.013	0.958
Environ. productivity (*EP*)	1.009	0.192	1.024	0.935
Export performance (*Exp*)	0.542	0.794	0.936	0.077
Scale efficiency (*Scale*)	0.994	0.489	1.004	0.824
Price output (*Price*)	0.912	1.690	1.744	0.381
Capital intensity	9.352	8.198	13.210	3.018
Skilled workers	0.153	0.241	0.292	0.078
Wage	18.547	11.413	23.255	14.927
Environmental intensity	8.021	8.911	13.427	5.620
Risk of environmental audits	4.180	9.278	11.015	1.024
Size	235.290	292.438	424.063	87.688
Age	16.290	15.227	25.360	3.035
Concentration ratio	0.091	0.049	0.112	0.053

Notes:
[a] The monetary variables (value added, capital and wage) are measured in thousands of euros, and the *Price* is measured in euros per kilogram. Waste is measured in kilograms (as the average per tonne of market output) and labour in thousands of hours. The monetary variables are deflated (base year = 1994).
[b] The descriptive statistics are calculated for the total sample, expressed as the average for the whole period.

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