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Sustainability and firm performance: evidence from corporate and farm level

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Doctoral Thesis:

Sustainability and Firm Performance: Evidence from corporate and farm level

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Abstract

This thesis approaches the question of sustainability and firm performance. In the contemporary business model, firm performance measurement must take into account not only economic profits, but also environmental and social issues, in order to ensure the sustainable development of the firm. By using advanced methodological approaches and exploring sustainability through a holistic view, this thesis contributes significantly to sustainability performance literature.

Three specific objectives have been fulfilled through three papers that constitute the main body of the present thesis. The first article aims to answer whether profitable business is compatible with balanced sustainability by investigating the relationship between the economic, social, environmental and governance performance for a sample of global firms. A canonical vine (C-vine) copula is used for this purpose. Results show the existence of a fairly strong positive relationship between economic, social and environmental performance. The corporate governance dimension is shown to have a weak relationship with the rest of the corporate social responsibility (CSR) dimensions. Important policy implications are derived from these results.

The second paper investigates the relationships among performance dimensions associated with corporate social responsibility focusing on the U.S. electric utility sector. Results of a statistical copula approach suggest that economic performance of utilities is compatible with environmental, social, and governance performance. The CSR model has the potential to help U.S. electric utilities become better corporate citizens while also obtaining higher economic profits.

The third paper investigates farms' stochastic production technology as the interaction of three-main types of sub-technologies that govern, respectively, the production of agricultural commodities, environmental pollution, and social outputs of agricultural activities. The model is empirically implemented through a Data Envelopment Analysis (DEA) model. The empirical application is based on a survey of Catalan arable crop farms. On average, we find our sample farms to display high technical and social performance, while they show relatively poor environmental performance.

Resumen

Esta tesis aborda la cuestión de la sostenibilidad y el rendimiento de la empresa. En el modelo de negocio contemporáneo, la medición del rendimiento de la empresa debe tener en cuenta no solo las ganancias económicas, sino también las cuestiones ambientales y sociales, para garantizar el desarrollo sostenible de la empresa. Mediante el uso de enfoques metodológicos avanzados y la exploración de la sostenibilidad a través de una visión holística, esta tesis contribuye significativamente a la literatura sobre la sostenibilidad.

Tres objetivos específicos se han cumplido a través de tres documentos que constituyen el cuerpo principal de la presente tesis. El primer artículo tiene como objetivo responder si el negocio rentable es compatible con la sostenibilidad equilibrada, mediante la investigación de la relación entre el desempeño económico, social, medio-ambiental y de gobernanza de una muestra de empresas globales. Un modelo canónico de viña de copulas (C-vine) se usa para este propósito. Los resultados muestran la existencia de una relación positiva bastante fuerte entre el desempeño económico, social y ambiental. Se muestra que la dimensión de gobernanza corporativa tiene una relación débil con el resto de las dimensiones de la responsabilidad social corporativa (RSC). Importantes implicaciones de política se derivan de estos resultados.

El segundo articulo investiga las relaciones entre las dimensiones de desempeño asociadas con la responsabilidad social corporativa que se centran en el sector de servicios eléctricos de los EE. UU. Los resultados obtenidos del análisis de las cópulas sugieren que el desempeño económico de las empresas eléctricas es compatible con el desempeño ambiental, social y de gobernanza. El modelo de la RSC tiene el potencial de ayudar a que los servicios eléctricos de los EE. UU. Se conviertan en mejores ciudadanos corporativos mientras se logran mayores beneficios económicos.

El tercer trabajo investiga la tecnología de producción estocástica de las explotaciones agrícolas como una interacción de tres sub-tecnologías que gobiernan, respectivamente, la producción de productos agrícolas, la contaminación ambiental y los productos sociales de las actividades agrícolas. El modelo se implementa empíricamente a través de un modelo de Análisis Envolvente de Datos (DEA). La aplicación empírica se basa en una encuesta de explotaciones de cultivos en la región de Cataluña. En promedio, encontramos que nuestras explotaciones muestran un alto desempeño técnico y social, mientras que muestran un desempeño ambiental relativamente pobre.

Chapter 1: Introduction

The Brundtland report, published in 1987, characterizes sustainable development as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development., 1987, p.37). The concept of sustainable development received much attention during the 1992 Rio de Janeiro Earth Summit, which called on governments to implement sustainable development strategies that ensure economic growth with environmental protection and social equality. Since the 1992 Summit, the concept of sustainability has gained increasing relevance within the business model, with many businesses adopting the Corporate Sustainable Development model. The latter has the aim to meet the needs of a company's stakeholders (such as shareholders, managers, employees, customers, governments, communities, etc.), without compromising its ability to meet the needs of future stakeholders (Dyllick & Hockerts, 2002). Corporate sustainability is often communicated through the concept of Corporate Social Responsibility (CSR) by which a company aims at achieving a balance between economic, environmental and social performance (Elkington, 1998).

While businesses engage to implement CSR strategies, tools and measures are needed in order to assess performance of the new business model, which involves expansion of firms' commitments beyond their financial objectives to embrace both environmental and social objectives. Since the 1960s, firm-level social responsibility measures started to gain interest in the US and in Europe. However, until the 1980s, attention mainly focused on pollution control as a means of managing environmental issues. Several authors have suggested that there is no single best way to measure socially responsible activities (Carroll, 2000; Wolfe & Aupperle, 1991). Nonetheless, considerable attempts have been made in this direction (Aupperle et al., 1985; Carroll, 1979; Quazi & O'Brien, 2000; Singhapakdi et al., 1996). In response for rising demand for quality CSR data, the past decade has seen the appearance of environmental, social and governance (ESG) rating agencies, which provide ratings that compare companies on CSR-related dimensions of performance (Avetisyan & Ferrary, 2013).

Nowadays, CSR has emerged as “an inescapable priority for business leaders in every country” (Porter and Kramer, 2006, p. 78). In this context, firms are increasingly shifting their focus from traditional financial orientation strategy to a broader “triple bottom line” approach. However, previous research argued that without financial profits for companies, adoption of CSR may be limited as CSR initiatives are costly and time consuming (Wang et al., 2008).

In order to shed light on whether CSR is profitable or not, previous empirical studies have analyzed the relationship between corporate social responsibility and corporate financial performance. However, despite the large number of studies examining this relationship, the literature fails to provide conclusive evidence (Hull & Rothenberg, 2008; Lu et al., 2014; McWilliams & Siegel, 2000). The main objective of this thesis is to investigate whether financial performance is compatible with the sustainable business model by means of using advanced methods not previously used for such purpose. We investigate this research question by first focusing on a sample of big corporations from different economic sectors; then on a specific economically relevant economic sector, characterized by relevant concentration; finally, we study the same question on an economically small and atomized sector.

The first article uses data from the 2012 ASSET4 ESG dataset from Thomson Reuters to investigate the relationship between economic, social, environmental and governance performance for a sample of global firms. The debates on the relationship between CSR performances are not new. However, previous studies have been mainly based on linear regressions and correlations. In this study, we propose a more sophisticated and flexible method based on copula functions. The analysis is conducted on sample of global corporations and is based upon a canonical vine (C-vine) copula.

The second article implements the statistical copulas approach to study the relationship between the four CSR dimensions for a sample of the major U.S. electric utilities from 2005 to 2012. In addition to the strategic role of the U.S. electric utility sector, the heterogeneous construct that characterizes CSR dimensions across different industries justifies the decision to focus on a single sector. To our knowledge, no study has previously assessed mutual links among the economic, environmental, social, and corporate governance dimensions of CSR within the U.S. electric utility sector. Lack of appropriate data that allows comparing across companies is one of the main reasons. Our research uses data from Thomson Reuters that includes 19 U.S. investor-owned electric utilities.

The last article investigates sustainability and performance of agricultural holdings. We build on the proposals by Chambers and Serra (2018) and Serra et al. (2014) and expand them to estimate combined measures of economic, environmental and social efficiency by allowing for the stochastic nature of agricultural production for a sample of Catalan arable crop farms. We use a completely different approach relative to the previous two studies, based on production theory. We model farms' stochastic production technology as the interaction of five different sub-technologies that shed light on firm's economic, environmental and social outputs. The first sub-technology models the production of agricultural crops. The second and third sub-technologies govern unintended pollution caused by nitrate and pesticide, herbicide and insecticide. The fourth and fifth sub-technologies concern farm social outputs and focus on the generation of farmers' satisfaction and the prevention of worker injuries. Our model is estimated using Data Envelopment Analysis (DEA) techniques.

In addition to this general introduction and the concluding remarks section, this present thesis is organized into three chapters containing the three research articles summarized above. The first article (chapter 2), entitled "Corporate Sustainable Development. Revisiting the Relationship between Corporate Social Responsibility Dimensions" has been published in *Sustainable Development*. The second paper (chapter 3), entitled "Corporate social responsibility and dimensions of performance: An application to U.S. electric utilities" has been published in *Utilities Policy*. The third article (chapter 4), entitled "Measuring Sustainability Efficiency At Farm Level : A Data Envelopment Analysis Approach" is in the second round of review in the *European Review of Agricultural Economics.*

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Chapter 2: Corporate sustainable development. Revisiting the relationship between corporate social responsibility dimensions[1]

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2.1 Introduction

With rising stakeholder concerns over sustainable development, firms have been increasingly called upon to take responsibility for their impacts on societies and the environment. As a result, many businesses have implemented sustainable practices that include environmental and social concerns into business operations (D'amato et al., 2009). Firms have also changed the way they interact with stakeholders, by devoting higher efforts to defining rules and practices to better balance their different interests. The new business paradigm involves expansion of firms' commitments beyond their financial obligations to deliver both private and public goods. Changes in the business model have also involved a fundamental change in business performance measurement, that has moved beyond financial indicators to embrace environmental, social and governance barometers. New performance measurements reflect the fact that a corporation's economic prosperity in isolation from social and environmental issues is no longer acceptable.

The term Corporate Social Responsibility (CSR) was coined to describe corporate self-regulation integrated into a business model comprising the many dimensions of corporate activities (Perrini & Tencati, 2006). The literature has proposed different definitions of CSR. These range from very limited views of the concept, to more comprehensive conceptualizations. In any case, the concept remains imprecise at best and fuzzy at worst. From the perspective of Matten & Crane (2005), CSR embraces the responsibility to be profitable, to obey the law, a philanthropic responsibility and an ethical responsibility to society to do what it is right. According to the United Nations Industrial Development Organization (UNIDO, 2015), CSR "is a management concept whereby companies integrate social and environmental concerns in their business operations and interactions with their stakeholders. CSR is generally understood as being the way through which a company achieves a balance of economic, environmental and social imperatives ("Triple-Bottom-Line- Approach"), while at the same time addressing the expectations of shareholders and stakeholders." CSR can bring an array of competitive advantages to the firm such as increased profits, better access to capital and markets, enhanced firm reputation and brand image, higher customer loyalty, etc. Skeptics argue that a significant redefinition of the role of businesses can be dangerous to the firm's financial well-being (Walley & Whitehead, 1994).

The relationship between financial performance and CSR is not well established. While several studies have tried to shed light on this question, results have been inconclusive (Margolis & Walsh, 2003; Vogel, 2005). Some authors conclude that a positive relationship exists between firm social responsibility and firm economic performance (Oeyono et al., 2011; Van Beurden & Gössling, 2008; Veronica Siregar & Bachtiar, 2010), while others find a negative or null correlation (Lima Crisóstomo et al., 2011; Smith et al., 2007; S. H. Teoh et al., 1999; Wright & Ferris, 1997) Some researchers (Alafi & Hasoneh, 2012; Galbreath & Shum, 2012; Griffin & Mahon, 1997; Margolis & Walsh, 2003; H. Y. Teoh et al., 1998) question the common approach of assessing the direct link between social responsibility and financial performance, while ignoring the role of other intervening factors, which may lead to misleading results.

Our article aims at shedding light on this debate by answering whether profitable business is compatible with balanced sustainability by investigating the relationship between the four CSR dimensions for a sample of global firms. A Canonical Vine (C-Vine) copula is used for this purpose, which represents a novel approach to model dependencies. Conventional analyses of dependency between multiple random variables are constrained by the availability of statistical tools and mainly rely on multivariate normal or student's *t* distributions. These distributions have been shown to usually misrepresent the data studied due to the presence of kurtosis, skewness and non-normality. Further, dependency between variables may be stronger in the tails of the distribution than in the center, and be characterized by asymmetries. For example, a firm may invest more intensively in environmentally friendly processes when its financial results are in the upper quartile of the distribution than when they are in the lower quartile. This reinforces the call for flexible statistical instruments (Barnett & Salomon, 2006, 2012). We use statistical copulas for such purpose. More specifically, dependence between four CSR dimensions (economic, environmental, social and corporate governance) is assessed through a Canonical Vine copula model (C-Vine). An obstacle to the analysis is the lack of comparable firm-level data on the different dimensions of CSR. We base our research on a dataset that provides firm financial metrics for a sample of global firms, as well as comparable and auditable information on environmental, social and corporate governance performance, that allows application of quantitative methods.

2.2 Literature review

CSR activities aim at promoting business practices that are compatible with sustainable development (Moon, 2007; Baumgartner, 2014; Gelbmann, 2010; Shah et al., 2016; Stewart & Gapp, 2014)(Johnson & Schaltegger, 2016). Through CSR a business commits to four main responsibilities in decreasing order of priority: the economic, the legal, the ethical, and the philanthropic. The rationale behind this prioritization is that if a firm goes out of business, it will be unable to sustain the other obligations, including the philanthropic ones (Brusseau, 2011; Chang & Kuo, 2008). Consistently, Vogel (2005) emphasizes the need to better understand the relationship between CSR and firm financial performance.

The debate on this relationship is still relevant (Esteban-Sanchez et al., 2017; Q. Wang et al., 2016) and the nature of the relationship still ambiguous. In what follows, we provide an overview of the literature that, using firm-level data, studies the links between economic, environmental, social and governance dimensions of CSR. Margolis et al. (2009) perform a meta-analysis by using 251 studies from 1972 to 2007 and conclude there is an overall positive (though small) relationship between CSR and firm financial performance. By using data of Japanese manufacturing firms from 2004 to 2008, Iwata & Okada (2011) consider the link between firm financial outcomes and two different environmental issues: waste and greenhouse gas emissions. The methodological approach is based on linear regression analysis. While waste is not found to have significant effects on financial outcomes, a reduction in greenhouse gas emissions improves them.

Molina-Azorín et al. (2009) examine 32 articles that analyze the influence of environmental management on financial performance. They find a predominance of the studies reporting a positive impact. By using structural-equation modeling, López-Gamero et al. (2009) show that the effect of environmental protection on firm performance is positive. Muhammad et al. (2015) use a linear regression analysis to study the link between environmental and financial outcomes of publicly listed companies in Australia, in periods of growth and contraction. They find a strong positive association between the two variables during the pre-financial crisis period (2001–2007) and no relationship during the financial crisis (2008–2010).

Several studies have not arrived to such optimistic conclusions regarding the impacts of environmentally friendly processes on economic results. Horváthová (2010) examines dependency between environmental and financial outcomes through a meta-regression analysis of 64 outcomes from 37 empirical studies. Results show a negative link between environmental and financial results that significantly increases when using simple correlation coefficients, relative to more advanced methodologies. Wagner et al. (2002) examine the relationship between the environmental and economic performance of firms in the European paper manufacturing industry. Findings predict the relationship to be uniformly negative. The methodological approach is based on a simultaneous equations system that allows for the mutual dependence of the two CSR dimensions considered.

Galema et al. (2008) use regressions to assess the impact of different dimensions of socially responsible performance on firm values. Soana (2011) uses Pearson correlation coefficients, in order to investigate the connection between social and financial performance in the Italian banking sector. None of these studies finds a statistically significant relationship between social performance and financial outcomes. Statman & Glushkov (2009) analyze a sample of firms that conduct CSR activities and, using descriptive statistics, find that their stocks yield higher returns than conventional companies' stocks.

Some studies indicate that firms that invest in stakeholder engagement and management have a positive image within the community, enabling them to recruit and retain high quality employees(Cerin & Reynisson, 2010; Humphrey et al., 2012; Lado & Wilson, 1994; Waddock & Graves, 1997). Proponents further argue that better-governed firms are relatively more profitable, more valuable, and pay out more cash to their shareholders (Andreou et al., 2014; Brown & Caylor, 2004). The literature suggests that good corporate reputation is important, not only because it is a precursor of value creation, but also because it is intangible, which makes imitation very difficult for the concurrent companies (S. J. Brammer & Pavelin, 2006; Eberl & Schwaiger, 2005; Roberts & Dowling, 2002). A strong and positive correlation has been observed between having been listed in one or more popular business magazines and corporate financial performance (Filbeck et al., 2009a, 2013). Nollet et al. (2016) studied the relationship between corporate social and governance performance and financial outcomes, using Bloomberg's Environmental Social Governance (ESG) Disclosure scores, covering the S&P500 firms in the period 2007–2011. Their analysis allows for linear and nonlinear relationships. Results show that a nonlinear relationship characterizes the link between corporate governance and financial results. Gupta & Sharma (2014) conduct a descriptive analysis of Indian and South Korean firms with the aim of assessing the effects of corporate governance on their economic performance. They find corporate governance practices to have limited impact on firms' financial performance and firm share prices.

As shown by the literature review presented above, previous research has usually considered the links between an incomplete set of the different dimensions of CSR. Further, lack of comparable data across firms and dimensions, has limited the type of study that can be conducted. Our analysis uses a dataset that comprises a wide range of global firms and covers the four main pillars of CSR (economic, environmental, social and governance). We thus make a comprehensive assessment of the interactions of the different CSR dimensions. The methodological approach represents a contribution to a literature that has mainly relied on linear regression and correlations to infer the relationship between CSR components.[2] Previous regression studies often involve endogeneity issues that are not always acknowledged and addressed. This may lead to imprecise and distorted parameter estimation (Hamilton & Nickerson, 2003; Crane et al., 2017). Garcia-Castro, Ariño, & Canela (2010) have shown how some results may change or even may be reversed when endogeneity is appropriately modeled. Further, both linear regression and linear correlation methods may be misleading if dependencies are characterized by nonlinearities (Manasakis et al., 2014; Nollet et al., 2016). The copula approach adopted in our article does not rely on endogeneity-exogeneity assumptions and allows for nonlinear relationships.

2.3 Methodology

Given the contradicting conclusions that previous literature has reached about the links between the different CSR dimensions, our objective is to contribute to this debate. By using a sample of global firms, we identify the dependence between firm economic, environmental, social and corporate governance performance. Since we are interested in using methodological approaches

[2] Some late articles on the topic propose a nonlinear framework (Flammer, 2015; Garcia-Gallego & Georgantzis, 2009; Manasakis et al., 2013).

that impose little restrictions on the dependency structure, we base our analysis on statistical copulas (Joe, 1996 and Nelsen, 2006).

Copulas can be seen as a more sophisticated tool than linear correlation to explain dependence between variables. Copulas offer two main advantages relative to correlation analysis. First, unlike correlation analysis, copula functions do not require assuming multivariate normality, which does not usually hold in empirical data. Second, copulas are more flexible than correlation analysis, as they allow for nonlinearities such as dependence measures that changes across the distribution.

More formally, copulas are defined as a flexible tool that allows for the characterization of the dependence structure between random variables and are especially useful if no obvious choice for the multivariate density function exists. The use of copulas in the economics literature is rather recent and most empirical applications are found within the financial economics literature (Patton, 2004; Patton, 2006). Copula models are based upon the Sklar's theorem (1959) that establishes that a multivariate dependence structure can be separated from the univariate margins. Let F_1 and F_2 be two univariate continuous distribution functions of two random variables (x_1, x_2). The copula of (x_1, x_2) is the joint distribution function of $u_1 = F_1(x_1)$ and $u_2 = F_2(x_2)$, where u_1 and u_2 are the probability integral transforms of x_1 and x_2 that are distributed as *Uniform* (0,1). According to the Sklar theorem, there exists a unique copula C that can be expressed as:

$$H(x_1, x_2) = C\big(F_1(x_1), F_2(x_2)\big) = C(u_1, u_2), \tag{1}$$

where $C(u_1, u_2)$ is a bivariate distribution function with marginal distributions F_1 and F_2. The joint bivariate density function can be expressed as:

$$h(x_1, x_2) = c\big(F_1(x_1), F_2(x_2)\big) f_1(x_1) f_2(x_2), \tag{2}$$

where c is the copula density and $f_1(x_1)$ and $f_2(x_2)$ are univariate density functions.

While copulas allow the researcher to focus on modeling univariate distribution functions and this usually leads to better models (Patton, 2006), care has to be taken when modeling the dependence between more than two variables. For the bivariate case, a wealthy range of well studied copulas exists (Joe, 1997; Nelsen, 2006). In contrast, despite the wide array of bivariate copulas, there is a very limited number of higher dimensional models.

Vine copulas are specially recommended in multivariate settings. They consist of multivariate graphical models based on bivariate copulas, also called pair-copulas, where each pair-copula can be chosen independently from the other pairs, which confers the vine models great flexibility in modeling dependencies. They were introduced by Joe (1997) and further developed by Bedford & Cooke (2001, 2002) and Kurowicka & Cooke (2006). As bivariate copulas, vine models also allow separating marginals in dependence modeling.

Vines are integrated by trees (known as regular vines) that are built based on pair copulas. Regular vines are however too general and embrace a high number of possible copula decompositions. Aas et al. (2009) popularized two subclasses of regular vines: canonical vines (C-vines) and drawable vines (D-vines) (Kurowicka, D. and Cooke, 2004). D-vines are useful for variables that have a temporal order known a priori (Zimmer, 2015), whereas canonical vines are appropriate when there is a natural order of importance, i.e., when a particular variable is known to be a key variable that governs interactions in the data set. In such a situation, one may decide to locate this variable at the root of the canonical vine (Aas et al., 2009). We select a C-vine copula, under the assumption that economic performance is the most relevant CSR dimension for our sample of global firms. For example, firms may go greener to either increase their margins by reducing their costs, or to increase their market share by offering more attractive products that respond to increasing consumer awareness on environmental issues. More generally, firms investing in CSR usually pursue brand, trust and reputation, as well as consumer loyalty that may reduce demand elasticity and allow charging higher prices (Bhattacharya & Sen, 2003; Elfenbein & McManus, 2010; Starks, 2009). In the same way, improving corporate governance structures may increase market and investor confidence (Azam et al., 2011). All this may eventually lead to improved financial performance.

Figure 2.1 shows a C-vine measuring dependence between the four CSR pillars: economic (ECN), environmental (ENV), social (SOC) and governance (GOV). The C-vine consists of three trees $T_j, j = 1, \dots 3$ with a unique node that is connected to $n - j$ edges, where " n " is the number of variables in the model. The first C-vine tree measures dependence with respect to the first root node, using bivariate copulas for each pair. Conditional on this variable, pairwise dependencies with respect to a second root node are modeled. A root node is chosen for each tree and all pairwise dependencies with respect to this node are modeled, conditioned on all previous root nodes (Brechmann et al., 2013).

C-vines entail a variable ordering with a sequentially decreasing driving force as we move from the first to the last tree. The n-dimensional density corresponding to a C-vine is given by:

$$f(\boldsymbol{x}) = \prod_{k=1}^{n} f_k(x_k) \prod_{j=1}^{n-1} \prod_{i=1}^{n-j} c_{j,j+i|1,\dots,j-1}(F(x_j|x_1, \dots, x_{j-1}), F(x_{j+i}|x_1, \dots, x_{j-1})), \quad (3)$$

where $f_k, k = 1, \dots, n$ denote the marginal densities and $c_{j,j+1|1,\dots,j-1}$ bivariate copula densities. In the following lines, a description of the specification and estimation process of C-vines is offered. In order to measure bivariate dependence, we consider the most popular and most widely used copulas: the Gaussian and the Student's t, that belong to the class of Elliptical copulas. Archimedean copulas are another no less important class of copulas that we consider. Within this group, we consider single-parameter copulas such as Clayton, Gumbel and Frank copulas, as well as the two-parameter families introduced by Joe (1997) named BB1 (Clayton, Gumbel) and BB7 (Joe-Clayton), which allow for lower and upper tail dependence simultaneously. Table 2.1 below shows the properties usually considered to characterize the different types of copulas, i.e., whether they can measure positive and negative dependence, asymmetric tail dependence or upper or lower tail dependence. From the copula classes mentioned above, we choose the most appropriate copula for each pair of CSR indicators.

The use of information criteria such as the Akaike Information Criterion (AIC) or the Bayesian Information Criterion (BIC) (Joe, 1997) allows automation of the bivariate copula selection process by chosing the model with the smallest information criteria. Clarke (2007) and Vuong (1989) tests constitute alternative likelihood ratio specification tests that compare across copulas. Based on Vuong (1989) and Clarke (2007), Belgorodski (2010) provides a selection test for bivariate copulas. The test compares a bivariate copula C_0 to all other possible bivariate copula models taken into account, in order to determine which family fits the data best. If a copula C_0 is favored over another copula, it gets a score of $+1$. A score of -1 is assigned if the other copula is identified to be better. The total score is the sum of the scores from all pairwise comparisons and the model with the highest score should be chosen.

Each stage of the estimation process not only entails selection of the copula family, but the root variable as well. While our C-vine copula is based on the assumption that the economic performance constitutes the root of the first vine tree, the ordering of the remaining variables is less clear. As a result, the following six possible orderings are considered and comparison among them is based on the Vuong (1989) and Clarke (2007) tests: ECN-ENV-SOC-GOV (M1 model), ECN-SOC-ENV-GVN (M2); ECN-ENV-GVN-SOC (M3); ECN-SOC-GVN-ENV (M4); ECN-GVN-ENV-SOC (M5); ECN-GVN-SOC-ENV (M6). Once the ordering is established, the C-vine is estimated by ML techniques (Aas et al., 2009; Czado et al., 2012) . The log-likelihood is given by (4).

$$\sum_{t=1}^{T}\sum_{i=1}^{n-j}\sum_{i=1}^{n-j}\log\left(c_{j,j+i|1,\ldots,j-1}\left(F\left(x_{j,t}\middle|x_{1,t},\ldots,x_{j-1,t}\right),F\left(x_{j+i,t},\ldots,x_{j-1,t}\right)\right)\right). \tag{4}$$

In the following section we present details on the data used and the research results.

2.4 Research results

Socially responsible activities are an important part of the overall corporate performance in the modern world. While the impacts of CSR are not well known, several articles have attributed many advantages to CSR including, but not limited to, managerial benefits (Brammer & Millington, 2008) better product marketing (Fombrun, 1996), improved financial performance (Kansal et al., 2014; Lin et al., 2009), or employee retention (Greening & Turban, 2000).

Over the past two decades, investors have become increasingly interested in CSR data, as they realize the influence of CSR on firms' long-term performance. This has increased firm disclosure of environmental, social and corporate governance data. Disclosure, however, is not standardized as companies usually report in different formats, units, scope, etc. As a result, datasets offering comparable firm-level extra-financial information are limited. Our research uses data from the 2012 ASSET4 ESGhttp://financial.thomsonreuters.com/en/products/data-analytics/company-data/esg-research-data.html dataset from Thomson Reuters, which is considered a leader in providing structured and standardized ESG research data (Collison, Cobb, Power, & Stevenson, 2008; Filbeck, Gorman, & Zhao, 2009) . The ASSET4 dataset, which has already been used in the literature (Ferrero-Ferrero, Fernández-Izquierdo, & Muñoz-Torres, 2015; Rivera, Muñoz, & Moneva, 2017), provides extra-financial information that is transparent, objective and comparable across companies and that is auditable (Schäfer et al., 2006) . Based on the definition and collection of over 250 key performance indicators, ASSET4 measures firm performance in the four main CSR pillars: economic, environmental, social and governance. We choose ASSET4 ESG dataset for several reasons. In the first place, ASSET4 is a global firm dataset that includes more than 4000 firms in more than 50 global markets, and thus offers a substantial amount of data. Along with ASSET4, MSCI's Kinder, Lydenberg, Domini Research & Analytics (KLD) is one of the larger providers of CSR information (Eding & Scholtens, 2017). However, Chatterji, Levine, & Toffel (2009) found evidence that KLD's ratings are not optimally using publicly available data. Along the same lines, Ziegler, Busch, & Hoffmann (2009) claim that data from Innovest Strategic Value Advisors and KLD include highly subjective elements. Another ASSET4 advantage is that it also contains economic data, which makes the dataset suitable for studies examining the relationship between CSR and economic performance (Ioannou & Serafeim, 2012).

ASSET4 environmental (ENV) performance score is built based on the firm reduction of resource use; emission reduction; and product innovation. The social (SOC) score is based on indicators of employment quality; health and safety; training and development; diversity; human rights; community; and product responsibility. The corporate governance (GOV) indicator is developed based on information on board structure; compensation policy; board functions; shareholder's rights; vision and strategy. Finally, the economic (ECN) performance score is founded on client loyalty; financial performance; and shareholders' loyalty. The performance indicators are equally weighted computations of the relative performance of the firm, being the benchmark the ASSET4 universe. Ratings are then z-scored and normalized so that the score lies between 0 and 100%. ASSET4 is strictly built on publicly available information, including firm sustainability reports, company websites, annual reports, proxy filings, news of major providers, as well as NGOs, and the Carbon Disclosure Project (Thomson Reuters, 2013). We analyze the relationship that exists between the four CSR performance scores of 2,728 corporate firms in 2012. While the dataset comprises around 4,000 firms, we exclude those with missing values in any of the performance indicators considered.

Table 2.2 shows the descriptive statistics for the economic, environmental, social and corporate governance scores. Our dataset is heterogeneous, containing firms from different economic sectors. A distribution of firms across sectors is presented in Table 2.3 below. The table shows that more than half of sample firms belong to the financial, industrial and consumer cyclicals sectors. As a result, each of the ESG pillars is built based on rather heterogeneous data. While some firms strongly pollute the air, other production activities have a stronger impact on water streams. As noted above, the methodology used by ASSET4 allows comparison of the ratings across different firms. In spite of the heterogeneity embedded in the sample, standard deviations in Table 2.2 do not indicate a very high variability in performance scores. All four scores fluctuate around 50%, with the environmental and social scores being on the order of 57%, followed by the governance score of 55%, and the economic score of almost 50% (Table 2.2). The skewness and kurtosis values suggest that our data have flatter distributions relative to the normal. Distributions are further asymmetric with a long tail to the left. The Jarque-Bera and Kolmogrov-Smirnov tests confirm the non-normality of the four scores used (at the 5% significance level).

In Figure 2.2, we present contour plots with standard normal margins below the diagonal and scatter plots above. Visual analysis suggests significant dependence between economic, environmental and social performance indicators. The environmental-social pair appears to display the strongest correlation, with tail dependencies especially on the lower (left) part. Conversely, governance scores are clearly less correlated with the other performance scores.

Table 2.4 shows the results of the C-vine copula M1 model estimation. Table 2.5 presents the Vuong (1989) and Clarke (2007) goodness of fit tests of our selected C-vine model (M1) against the other five alternatives (M2 to M6). The p-values corresponding to the Vuong test indicate that M1 is preferred to M2 and M4, and equally valid against the alternatives M3, M5 and M6. Clarke test results support selection of model M1 against all possible alternatives. The information criteria and goodness-of-fit test scores for the bivariate copulas are presented in Table 2.6. For each bivariate copula, we first present the scores assigned to copulas according to Belgorodski (2010), i.e., the bigger the value, the better the copula fit. The, we present AIC and SBC criteria that decline with the increase in the goodness of fit. We mark in bold the best copula according to these criteria. Since different copula families have different parameters that are not directly comparable, we measure the strength of dependence involved by each copula through the corresponding Kendall's τ value, which focuses on the central area of the bivariate distribution, as well as the lower and upper tail dependencies (λ_L, λ_U) that measure dependency at the extremes of the distribution (Table 2.4). Hence, while columns four and five in Table 2.4 contain the values of the bivariate copula parameters, columns six to eight contain comparable dependence measures that increase with the strength of dependence.

Results from table 2.4 show that, according to the Frank copula, which is found to best represent dependency between economic and environmental and social outcomes, firms with better economic results, usually stand out as firms with better social (with a Kendall's τ of 0.5) and environmental performance (τ = 0.42). The BB1 copula, that quantifies the links between economic and governance performance, shows a Kendall's τ on the order of 0.24, suggesting a substantially lower degree of dependence between these two CSR dimensions. While small, the relationship is positive, implying the possibility to improve financial performance by improving the relationship between the firm and its stakeholders. Further, the link between these two scores is found to be characterized by a lower tail dependency of 0.26. This suggests that those firms characterized by lower economic performance, relative to best economic performers, usually put higher efforts into defining rules and practices to balance the interests of the different firm stakeholders, such as shareholders, managers, employees, customers, suppliers, creditors, as well as the government and the community. The BB1 Copula also shows an upper tail dependency, but with a negligible magnitude.

The second tree of our C-vine relates environmental with social and governance performance, conditional on the economic outcome. The BB1 copula is found to offer the best fit to describe dependence between environmental and social scores. Consistently with the first tree, firms with better environmental performance are also seen to have remarkable social performance, being the Kendall's τ for this dependence on the order of 0.41. The BB1 copula allows for different nonzero lower and upper tail dependence coefficients. Tail dependence estimates refine research findings by suggesting that it is in the lower tail of the distribution when higher efforts to excel in both dimensions are put by corporations. In the upper tail of the distribution, reflecting firms that are already outperforming in both dimensions, the correlation drops to 0.25. The relationship between governance and environmental dimensions, conditional upon the first tree, is found to be very close to zero. The last tree also shows that social and governance ratings have hardly any link. The next section presents policy conclusions from our research results and concludes.

2.5 Policy conclusions and concluding remarks

While the market-based economy has emerged as an efficient mechanism to allocate scarce economic resources, it has also led to unprecedented social tensions and environmental pressures that need to be considered for business sustainability. More recently, given the effect of poor corporate governance on shareholder value, issues such as business ethics have also become part of the investor agenda. The new business paradigm recognizes that long-term sustainable returns depend on well governed social, environmental and economic systems. Changes in the business model have led to changes in firm performance measurement: firm disclosure of environmental, social and corporate governance data has become increasingly common. The relationship between financial performance and other dimensions of CSR has not been well established by the literature. Our article sheds light on this debate by conducting a firm-level study based on a sample of global corporations.

Our analysis is based on ASSET4 ESG dataset in 2012. We identify the empirical regularities characterizing dependence between firm economic, environmental, social and corporate governance using a C-Vine copula model. To our knowledge, this is the first work assessing dependence between all four dimensions of CSR. It is also the first work that adopts a flexible statistical copula approach for such purpose.

Results from copula analysis suggest that our sample firms are integrating sustainability into their business practices, with a rather strong positive relationship between three CSR dimensions: economic, social and environmental. The positive link between economic and environmental dimensions suggests that a reduction in resource use and emissions is likely to lead to a decline in production costs and/or a less price-elastic demand. A policy implication of this result is that the business community has been able to make the two performance dimensions complementary rather than substitute. As a result, adoption of environmentally friendly technologies is likely to lead to improved firm financial health. Results are also suggestive that improvements in employment quality, human rights, community, and product responsibility will also bring higher economic profits. These could come through higher employee satisfaction and retention, enhanced firm reputation, less elastic demand, among others. This demands for setting aside much of the old-school labor management practices to embrace new work attitudes and philosophies in order to increase work quality.

In our sample of global firms, and in contrast to environmental and social performance, corporate governance actions don't hold a strong positive relationship with higher economic results. A policy implication is that while governance may help to create a better image for the firm, what really reduces costs and increases consumers' demand and their willingness to pay for the firm's products is effective reduction of pollution and promotion of social welfare.

To summarize, the four main pillars of CSR are positively interconnected, thus showing how improvements in one pillar will lead to improvements in the rest of the pillars. As a result, shareholders should encourage firm managers to pursue a multidimensional CSR objective, which should eventually lead to better financial outcomes. The degree of interdependence is, however, not homogeneous, being high for the cluster comprising economic, social and environmental dimensions.

Our empirical approach is limited by data availability, which did not allow us to characterize the causes underlying the relationship between the four CSR dimensions. Future research may seek to understand these causes that may be related to legislation, sector, location, etc. Sectorwise or regionwise analyses will allow a better understanding the concept of CSR. Our analysis is based on global companies that usually show high reputation indices and tend to be socially responsible (Epstein & Buhovac, 2014). Future research should also consider Small and

Medium Sized Enterprises (SMEs), whose performance may significantly differ from the global companies in our sample.

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Table 2.1 Bivariate copula families considered and their properties.

	Gaussian	T-copula	Clayton	Gumbel	Frank	BB1	BB7
Positive dependence	X	X	X	X	X	X	X
Negative dependence	X	X	·	·	X	·	·
Tail Asymmetry	·	·	X	X	·	X	X
Lower tail dependence	·	X	X	·	·	X	X
Upper tail dependence	·	X	·	X	·	X	X

Table 2.2 Descriptive Statistics of ESG data

	GOV Score	ECN Score	ENV Score	SOC Score
Mean	55.30	49.86	57.75	57.01
Std. Dev.	29.95	30.57	31.39	31.05
Min	1.39	1.09	8.59	3.66
Max	96.86	98.85	94.21	97.39
Skewness	-0.46	0.001	-0.33	-0.33
Kurtosis	-1.18	-1.37	-1.49	-1.37
Jarque Bera test	256.18*	213.47*	304.42*	265.50*
Kolmogorov Smirnov test	0.11*	0.08*	0.14*	0.12*

* Indicates statistically significant at 5% level.
Number of firms = 2728

Table 2.3 A distribution of firms across sectors (by numbers & percentages)

		All Sectors	Financial	Industrial	Consumer Cyclicals	Basic Materials	Consumer Non Cyclicals	Technology	Energy	Healthcare	Utilities	Telecom.
Firms By sectors	Nº	2728	514	484	423	369	219	206	200	126	110	77
	%	100%	19%	18%	16%	14%	8%	8%	7%	5%	4%	3%

Table 2.4 ML estimate for C-Vine copula & corresponding Kendall's τ value for each pair-copula.

Tree	Pair-copula	copula	par1	par2	λ_U	λ_L	Kendall's τ
1	ECN, ENV	Frank	4.54	-	0	0	0.42
1	ECN, SOC	Frank	5.86	-	0	0	0.50
1	ECN, GOV	BB1	0.48	1.06	0.08	0.26	0.24
2	ENV, SOC |ECN	BB1	0.65	1.25	0.25	0.41	0.41
2	ENV, GOV | ECN	Gumbel	1.06	-	0.07	0	0.06
3	SOC, GOV | ECN, ENV	BB1	0.2	1	0	0.03	0.09

Table 2.5 Vine copula ordering tests

Model		M2 ECN-SOC-ENV-GOV	M3 ECN-ENV-GOV-SOC	M4 ECN-SOC-GOV-ENV	M5 ECN-GOV-ENV-SOC	M6 ECN-GOV-SOC-ENV
M1 ECN-ENV-SOC-GOV-	Vuong Statistic	2.09	0	2.09	1.83	1.83
	P-value	0.0	1.00	0.03	0.06	0.06
	Decision	M1>M2	M1=M3	M1>M4	M1=M5	M1=M6
	Clarke Statistic	1472	411	1472	1531	1531
	P-value	0,00	0,00	0,00	0,00	0,00
	Decision	M1>M2	M3>M1	M1>M4	M1>M5	M1>M6

Table 2.6 Goodness-of-fit test scores for the bivariates Copula

Pairs modeled	Test	Gaussian	T-copula	Clayton	Gumbel	Frank	BB1	BB7
ECN, ENV	Vuong/Belgorodski	3	3	-5	-5	**6**	0	-2
	Clarke/Belgorodski	0	4	-6	-2	**6**	2	-4
	AIC	-1092.62	-1084.42	-878	-866.01	**-1186.07**	-995.54	-935.25
	BIC	-1086.71	-1072.6	-872.09	-860.10	**-1180.16**	-983.72	-923.43
ECN, SOC	Vuong/Belgorodski	4	2	-5	-5	**6**	0	-2
	Clarke/Belgorodski	1	4	-6	-2	**6**	1	-4
	AIC	-1680.06	-1668.09	-1437.16	-1315.54	**-1765.05**	-1574.01	-1494.17
	BIC	-1674.15	-1656.27	-1431.25	-1309.63	**-1759.14**	-1562.19	-1482.34
ECN, GOV	Vuong/Belgorodski	2	2	2	-6	-4	**3**	1
	Clarke/Belgorodski	-5	2	-4	-3	6	**3**	1
	AIC	-481.14	-474.90	-490.95	-323.83	-424.40	**-502.36**	-498.30
	BIC	-475.23	-463.08	-485.03	-317.91	-418.49	**-490.53**	-486.47
ENV, SOC|ECN	Vuong/Belgorodski	3	3	-3	-6	-1	**3**	1
	Clarke/Belgorodski	-1	2	-6	-4	6	**4**	-1
	AIC	-1287.34	-1280.21	-1008.66	-908.25	-1226.81	**-1273.32**	-1137.24
	BIC	-1281.43	-1268.39	-1002.75	-317.91	-1220.90	**-1261.49**	-1125.41
ENV, GOV|ECN	Vuong/Belgorodski	1	1	-6	**1**	1	1	1
	Clarke/Belgorodski	-5	0	-4	**3**	-3	3	6
	AIC	-29.01	-22.79	-11.65	**-38.91**	-21.09	-22.43	-21.15
	BIC	-23.10	-10.97	-5.73	**-33**	-15.17	-10.61	-9.32
SOC, GOV|ENC, ENV	Vuong/Belgorodski	-1	-1	4	-5	-5	**4**	4
	Clarke/Belgorodski	-6	3	1	-3	-3	**3**	5
	AIC	-82.88	-80.04	-91.95	-40.68	-68.80	**-107.98**	-101.49
	BIC	-76.97	-68.22	-86.01	-34.77	-62.89	**-96.15**	-89.67

Figure 2.1 C-vine copula with four firm performance indicators

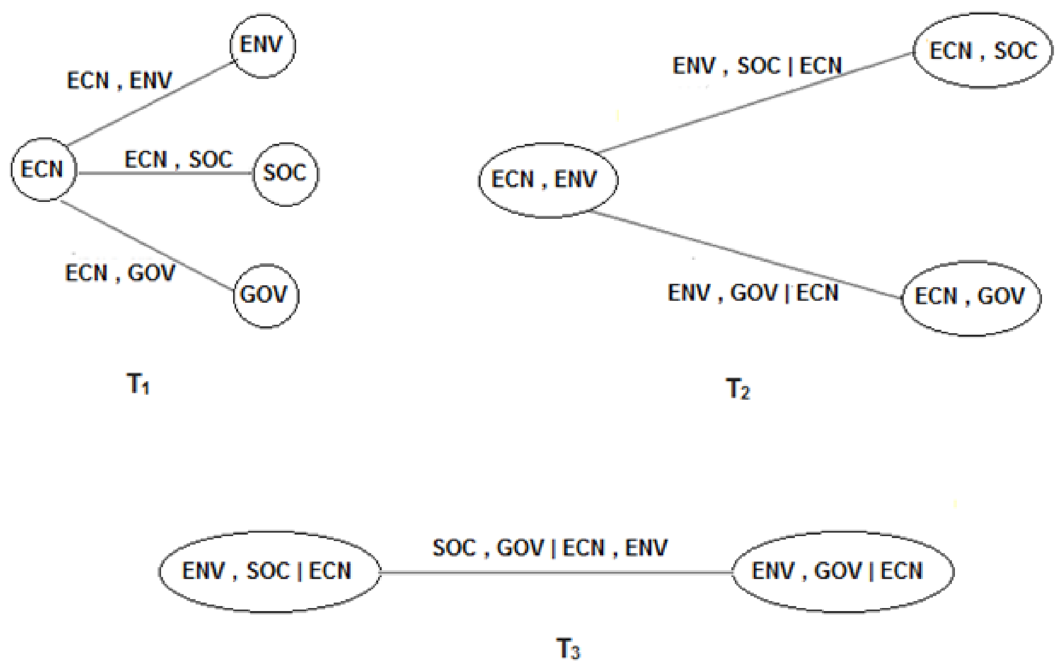
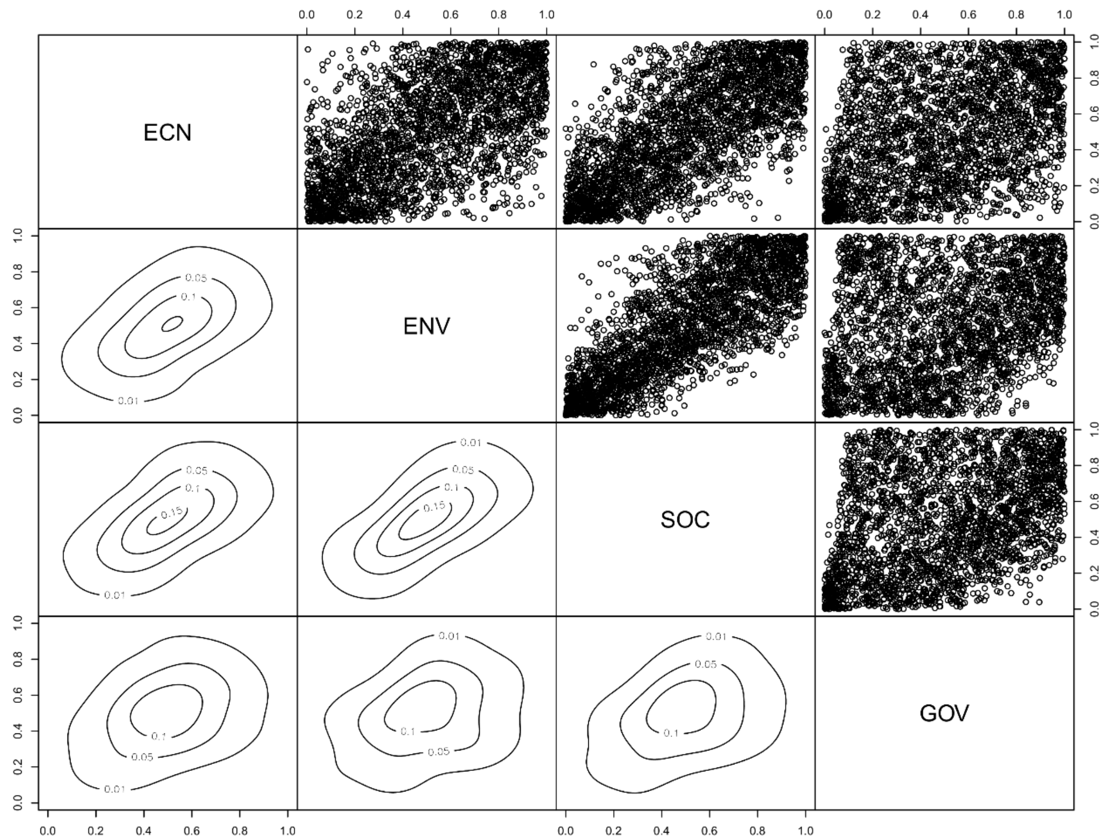


Figure 2.2 Pairs plot of the ESG data set with scatter plots above and contour plots with standard normal margins below the diagonal.



Chapter 3: Corporate Social Responsibility and Dimensions of Performance: An Application to U.S. Electric Utilities[3]

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3.1 Introduction

The ways in which businesses interact with society has evolved over time. This evolution is reflected in alternative normative theories of the firm. According to the Ownership Theory, shareholder interests should be prioritized by using corporate resources to increase profits (Jensen, 2001). According to the Stakeholder Theory, a firm's objective is to create value for society (Donaldson & Preston, 1995), reflected by the integration of social demands into business plans. Relative to the Ownership Theory, the Stakeholder Theory frames firm management within a wider context and requires a reformulation of the corporate objectives (Evans & Freeman, 1988). Specifically, it identifies the stakeholders, who are the individuals and groups that have an interest or concern in the firm (employees, customers, suppliers, creditors, the community, investors, regulators, policymakers, etc.), and considers them to have both the right and obligation to participate in the firm management. The main objective of the company should be the flourishing of all stakeholders (Werhane & Freeman, 1999). Some authors, such as Jensen (2001), disagree with firms having this multidimensional objective, as it may create confusion and disorder and preclude effective decision-making.

Corporate Social Responsibility (CSR) Theory is a hybrid "*whereby companies integrate social and environmental concerns in their business operations and in their interaction with their stakeholders on a voluntary basis*" (European Commission 2001, p. 6). The goal of CSR is to align the financial activities of the company with social objectives. While there is no universal characterization of the CSR, it is usually regarded as a four-dimensional concept. The economic dimension relates to the direct and indirect financial performance of the firm. The environmental dimension concerns the impact of business activity on natural ecosystems. The social dimension includes issues related to the quality of life for employees, customers, and future generations (Ioannou & Serafeim, 2012b) (Ioannou & Serafeim, 2012b). Finally, the corporate governance dimension deals with relationships among directors, managers, and other stakeholders.

According to CSR Theory, a firm has four main responsibilities in decreasing order of priority: the economic, the legal, the ethical, and the philanthropic. After meeting the top obligation, attention is turned progressively to the remaining obligations as long as they do not compromise the financial viability of the firm. The logic behind this prioritization is that if a firm goes out of business, it will be unable to meet its other obligations, including the philanthropic ones (Brusseau, 2011).

Interest in CSR has gained ground with increasing societal demands for firms to take responsibility for their social impacts and serve the general interest and not just the one of the shareholders minority (Blair, 1996; Wagner-Tsukamoto, 2006). An increasing number of firms have changed their business models to reflect CSR concepts. While these changes were initially aimed mainly at including environmental and social targets (Du et al., 2011), more recently, firms have also become interested in the way they interact with stakeholders. Further, CSR has evolved from being considered detrimental to a firm's profitability, to be regarded as a potential competitive advantage, at least in the long-run (Castelo Branco & Lima Rodriques, 2007; Porter & Kramer, 2002).

These trends in the business world have brought about fundamental changes in the way that firm performance is measured. To the extent that viewing a corporation's financial prosperity in isolation from social, environmental, and governance practices is no longer acceptable, financial indicators have become insufficient for assessing firm performance (Hansen & Wernerfelt, 1989; Porter & der Linde, 1995). The 1990s saw an expansion in corporate reporting of social information. In 1997, the U.S.-based Coalition for Environmentally Responsible Economies (CERES) and the United Nations Environmental Program (UNEP) launched the Global Reporting Initiative (GRI) to develop economic, environmental, and social reporting guidelines (Ioannou & Serafeim, 2012a). The objective was to place sustainability reporting at the same level as financial reporting.

Given the central role that CSR can play in new business models, a considerable body of literature has been devoted to examining the "why" question, that is, why do firms change their business model to become better corporate citizens (Garay & Font, 2012; Matten, 2006), and the "what" question, that is, what is CSR (Matten & Crane, 2005). The question of "how" CSR affects business performance remains the most elusive one despite a relevant number of studies in this area. While some studies conclude that a positive relationship exists between CSR and financial performance (Berman et al. 1999; Roshayani et al. 2009; Brammer and Pavelin 2006; Carmeli et al. 2007; Saeidi et al. 2015; Waddock and Graves 1997), other findings suggest that social commitments can lead to relatively high costs and eventually erode financial results performance (Cornell & Shapiro, 1987; Friedman, 1970; Lima Crisóstomo et al., 2011; Teoh et al., 1999).

Our analysis sheds light on this debate by studying a sample of the major U.S. electric utilities from 2005 to 2016. Although several studies have assessed the relationship between financial performance and CSR, few have examined this relationship in the context of a single industry (Peloza, 2009). Given the heterogeneity in the economic, environmental, social, and governance dimensions across different industries, aggregate studies may lead to misleading results. To our knowledge, this article is the first focusing on the role of CSR in the U.S. electric utility industry, a $377 billion industry that employs more than 500,000 workers.[4] The strategic relevance of this industry is undisputable, as electricity makes all other economic activities possible, from agriculture, to manufacturing, to telecommunications. The electric industry's economic relevance is matched by its environmental impacts, as the sector is responsible for 29% of greenhouse gas emissions in the United States (US EPA, 2017). As a result, it is relevant to assess the financial implications of electric utilities becoming better corporate citizens along the environmental dimension.

[4] http://www.eei.org/resourcesandmedia/industrydataanalysis/industrydata/Pages/default.aspx. accessed April 15, 2016.

3.2 Literature review

According to Arrowsmith and Maund (2009), CSR is one of the major developments affecting businesses over the last decade. The influence of CSR on firm financial performance has been found to be contingent as opposed to universal (Ullmann, 1985; Wang et al., 2016) and to vary across different operational environments. Consequently, the relationship between corporate social performance (CSP) and corporate financial performance (CFP) is likely to depend on different institutional factors such as public and private regulations or the degree of market development (Campbell, 2007; Q. Wang et al., 2016). While regulations are likely to promote adoption of CSR practices, more loosely regulated environments will encourage firms to behave more irresponsibly. Wang et al. (2016) conduct a meta-analysis that considers the influence of the operational environment on the relationship between CSP and CFP and conclude that, overall, CSR enhances financial results, being the link stronger in developed economies relative to less developed ones.

In his meta-analysis comprising 159 studies during a period of 36 years (1972-2008), Peloza (2009) investigated the relationship between CSP and CFP, concluding that 77% of the examined articles do not identify the economic sectors studied. To the extent that the institutional context influences CSP and CFP, the relationship between the two shall vary across different economic sectors (Reed, 1999). Our analysis focuses on the U.S. electric utility sector. As concern about the environmental impact of economic activities has gained momentum and given that the electric utility industry is one of the most polluting, the environmental performance of electric utilities has become a highly relevant research area (Masters, 2013). In contrast, other CSR dimensions have received almost no attention.

Sueyoshi and Goto (2009) investigated the impact of environmental expenditures and investments on the CFP of the U.S. electric utility industry. Environmental expenditure is measured by the environmental protection cost, environmental investment is measured by the total amount of investment for environmental protection facilities, and CFP is measured by return on assets. Using firm-level data and regression analysis for a sample of 167 utilities observed from 1989 to 2001 the authors find that environmental expenditures under the U.S. Clean Air Act have had a negative impact on CFP. In contrast, environmental investments have had no significant impact.

Gollop and Roberts (1983) investigated the effect of sulfur dioxide emission restrictions on the rate of productivity growth of the U.S. electric power industry during the period 1973 to 1979. Based on a cost function, their results suggest a negative relationship, as regulations generate higher costs and reduce the rate of productivity growth. Filbeck and Gorman (2004) analyzed the link between environmental and financial performance of 24 firms from the IRRC/S&P 500 electric company industry from 1996 to 1998. Environmental performance is based on five indices prepared from a raw dataset: hazardous waste clean-up, permit restriction, toxic chemicals, reported spills, and a compliance index. Using regression models, their results suggest a negative relationship.

Moving beyond the environmental dimension of CSR, Zhou and Wei (2016) assess the influence of the Chinese Renewable Energy Law on the relationship between the different CSP dimensions and CFP in the Chinese energy sector. Using a panel data of 26 renewable energy companies observed during 13 years (2001 to 2013), they conclude that the Renewable Energy Law has promoted a positive link between CSP and CFP. Outside the boundaries of the electric utilities sector, several studies have considered how the different dimensions of CSR influence CFP. Mayer (1997, p. 8) notes that "Despite the intense debate, evidence on the effects of different governance systems is still sparse." Some research findings support that promoting stakeholder engagement generates a positive image within the community, allowing firms to attract high quality employees(Cerin & Reynisson, 2010; Humphrey et al., 2012; Maditinos et al., 2011) . Good corporate reputation is important (Eberl & Schwaiger, 2005; Fernández-Gámez et al., 2016) and positive portrayals in popular business magazines can positively impact CFP (Filbeck et al., 2013).

From a statistical perspective, linear regressions and correlations have been widely used to assess relationships. However, these methods involve endogeneity issues that are not always acknowledged and addressed and that can lead to inconsistently estimated regression coefficients (Hamilton & Nickerson, 2003). Research that studies the link between CSR and financial performance is plagued with endogeneity issues because the decision to engage in CSR is correlated with the error term (Bénabou & Tirole, 2010). Garcia-Castro et al. (2010) show how results on the relationship between CSP and CFP may be reversed when endogeneity is properly taken into account. Further, both linear regression and linear correlation methods may be misleading if dependencies are characterized by nonlinearities and/or non-normality (Manasakis et al., 2014; Manescu & Staricad, 2010; Nollet et al., 2016). Endogeneity issues can be addressed by estimating a simultaneous equation system (Al-Tuwaijri et al., 2004), which requires adopting a multivariate statistical distribution. The most commonly used multivariate statistical distributions are the normal and the Student's t. However, these have been shown to usually misrepresent real data. Our methodological approach seeks to improve on these shortcomings.

3.3 Methodology

To our knowledge, no one has assessed mutual relationships among the economic, environmental, social, and corporate governance dimensions of CSR within the U.S. electric utility sector. Lack of standardized data that allows comparing across firms is one of the main reasons. Our analysis uses a dataset that comprises 19 U.S. investor-owned electric utility holding companies observed from 2005 to 2012 and covers the four main pillars of CSR.

Statistical copulas are used in this study to assess the relational structure between the different CSR dimensions in the U.S. electric utility sector. A copula is a multivariate probability distribution function whose one-dimensional marginals are uniform and that is used to characterize dependence between random variables (Nelsen, 1999, p. 5). The copula approach adopted in our article does not rely on endogeneity-exogeneity assumptions, allows for nonlinear and non-normal dependencies, and does not require us to adopt any multivariate distribution function. The methodological approach adopted in this research thus represents a significant contribution to a literature that has mainly relied on linear regression models to assess the links between CSP and CFP.

Copulas are based on the Sklar's theorem (Sklar, 1959), that shows that any multivariate distribution function can be decomposed into the marginal cumulative distribution functions and a copula function which captures the relational structure between the components. Let F_1 and F_2 be two univariate continuous distribution functions of two random variables (x_1, x_2). The copula of (x_1, x_2) is the joint distribution function of $u_1 = F_1(x_1)$ and $u_2 = F_2(x_2)$, where u_1 and u_2 are the probability integral transforms of x_1 and x_2 and are distributed as Uniform (0,1). According to the Sklar theorem, there exists a unique copula C that can be expressed as:

$$H(x_1, x_2) = C\big(F_1(x_1), F_2(x_2)\big) = C(u_1, u_2) \tag{1}$$

where $C(u_1, u_2)$ is a bivariate distribution function with marginal distributions F_1 and F_2. The multivariate probability density function can be expressed as follows:

$$f(x_1, x_2) = c(u_1, u_2) f_1(x_1) f_2(x_2) \tag{2}$$

where *c* is the copula density and $f_1(x_1)$ and $f_2(x_2)$ are univariate density functions.

Copulas are used to investigate the relationships between the different dimensions of CSR. More specifically, this research aims at assessing the relationship between economic performance $(x_{1,t})$ and the environmental $(x_{2,t})$, social $(x_{3,t})$, and corporate governance $(x_{4,t})$ dimensions of performance. As a result, we focus on the following three joint probability distributions:

$$H(x_1, x_2) = C(F_1(x_1), F_2(x_2)) \tag{3}$$

$$H(x_1, x_3) = C(F_1(x_1), F_3(x_3)) \tag{4}$$

$$H(x_1, x_4) = C(F_1(x_1), F_4(x_4)) \tag{5}$$

A variety of copulas are considered. Different copulas include the Gaussian, T-student, Clayton, Gumbel, Frank, BB1, and BB7. These copulas allow for a wide variety of relational structures, including both positive and negative relationships and a wide range of upper and lower tail dependence, including asymmetric or symmetric tail dependence. While the Gaussian and the Student's t, belong to the class of Elliptical copulas, the rest of the copulas considered belong to the Archimedean copula group. Due to space limitations, we do not offer the density functions of the different copulas. Interested readers are directed to Joe (1997) and Nelsen (2006).

Tables 3.1 and 3.2 below show the most relevant properties of the elliptical and Archimedean copulas considered in this study, respectively. More specifically, the parameters of each copula and their value range are presented. Since different copulas imply different parameters that are not directly comparable, tables 3.1 and 3.2 also present the equivalent Kendall's τ, which measures dependency in the central area of the bivariate distribution, as well as the corresponding lower and upper tail dependency measures in order to compare across copulas. For each pair of CSR dimensions, the optimal copula is chosen based on the Goodness of Fit (GoF) tests described below.

Copula parameters are estimated using maximum likelihood techniques. Let β denote the vector of marginal parameters and α be the vector of the copula parameters. Let $\theta = (\beta, \alpha)$ be the parameter vector to be estimated. The log-likelihood function is given by (6).

$$l(\theta) = \sum_{i=1}^{n} \log\ c\,\{F_1(x_{i1};\beta), F_2(x_{i2};\beta);\alpha\} + \sum_{i=1}^{n}\ \sum_{j=1}^{2} \log f_j\big(x_{ij};\beta\big) \tag{6}$$

The ML estimator of θ is $\hat{\theta}_{ML} = \underset{\theta\in\Theta}{\operatorname{argmax}}\ l(\theta)$.

GoF tests assess the discrepancy between an estimated copula model and the unknown true copula and are used to select the best copula for each pair of variables. In this article we use the Crámer-Von Mises (CvMc) and Kolmogorov-Smirnov (KSc) test statistics and their p-values derived from bootstrapping. The latter are copula GoF tests based on Kendall's process for bivariate data, as investigated by Genest and Rivest (1993) and Wang and Wells (2000). These tests can be expressed as follows: $CvMc = \sum_{i=1}^{T}\big\{C\big(u_1, u_2\hat{\theta}_T\big) - \hat{C}_T(u_1, u_2)\big\}^2$ and $KSc = \max_t \big|C\big(u_1, u_2\hat{\theta}_T\big) - \hat{C}_T(u_1, u_2)\big|$.

Finally, we also rely on the Vuong (1989) and Clarke (2007) tests, which compare nonnested models and constitute an alternative to likelihood ratio specification tests. Based on

Vuong (1989) and Clarke (2007), Belgorodski (2010) provides a selection test for bivariate copulas. The test compares a bivariate copula C_0 to all other possible bivariate copula models taken into account, in order to determine which fits the data best. If a copula C_0 is favored over another copula, it gets a score of $+1$. A score of -1 is assigned if the other alternative copula is identified to be better. The total score is the sum of the scores from all pairwise comparisons. Further details on the selection tests can be found in the cited literature.

3.4 Empirical approach

Our research uses data from Thomson Reuters (ASSET4 dataset).[5] The dataset provides objective, auditable, and comparable financial and extra-financial information for a sample of global firms. Based on the definition and collection of over 250 key performance indicators (KPIs), ASSET4 measures firm performance by distinguishing among the four CSR main pillars: economic, environmental, social, and corporate governance. The economic performance score is based on client loyalty; financial performance; and shareholders' loyalty. The environmental performance score is based on the reduction of resource use by the firm; emission reduction; and product innovation. The social score is based on indicators of employment quality; health and safety; training and development; diversity; human rights; community; and product responsibility. Finally, the corporate governance indicator is based on information on board structure; compensation policy; board functions; shareholder's rights; vision and strategy.

Performance scores are equally weighted computations of the relative performance of the firm, being the benchmark the ASSET4 universe. Performance scores are then z-scored and normalized so that they lie between 0 and 100%. ASSET4 is strictly built on publicly available

[5] Founded in 2003, ASSET4 is a private Switzerland-based firm (Goldman Sachs and Bank of America Merrill Lynch), and was acquired by Thomson Reuters in 2009.

information, including firm sustainability reports, company websites, annual reports, proxy filings, news of major providers, as well as NGOs, and the Carbon Disclosure Project (Thomson Reuters, 2013). In this study, we focus on 19 U.S. investor-owned electric utility holding companies (see table 3.3) observed from 2005 to 2012.[6] Collectively, these 19 firms account for more than 57 million customers in the United States, represent more than 40% of the total electric utility industry revenue, and account for more than 16% of sales from renewable energy resources in the United States.

Table 3.4 shows the summary statistics for the economic, environmental, social, and corporate governance scores for our sample of U.S. electric utilities from 2005 to 2012. While there is slight evidence of skewness and kurtosis, the Jarque-Bera test suggests a normal distribution for most of the scores at the 5% significance level.

Figure 3.1 shows the evolution of sample average scores over time. The economic score is the lowest and is characterized by an increasing trend and the highest volatility. Economic performance volatility over time can be explained by the fact that electricity production costs and prices are variable, as electricity is a non-storable product and companies may need a few years to adapt their operations to supply and demand shifts (Graves et al., 2007). The smaller volatility of the non-economic CSR dimensions is indicative of more stable and long-term practices in these areas. The social score follows closely the economic score at a slightly higher level. With a much flatter trend, environmental performance starts at a higher level, but shows less improvement over time. There seems to be a convergence in the economic, environmental. and social performance dimensions over time, at around 70-75%. The corporate governance scores, notably above the rest, show a mild improvement over time as well as little variability.

[6] The 2012 series presents only 12 firms. This is not the choice of the authors but rather the data were not available through DataStream in 2013.

Table 3.5 shows the results of the relational assessment between the economic and the non-economic CSR dimensions by year (table 3.6 reports the copula selection tests). All Kendall's τ dependencies are positive and show a stronger link of economic performance with environmental and social performance than with corporate governance. The relationship between economic and environmental scores has an average of τ =0.594 and a range of 0.541 – 0.644 over the period studied. The relationship between economic and social scores fluctuates around an average of τ =0.611 and has a range of 0.506 – 0.684. Hence, on average, the U.S. electric utilities with better (worse) economic performance, usually stand out as companies with better (worse) environmental and social performance too. The degree with which economic and governance scores are correlated is, on average, much smaller, with an average of τ =0.423 and a range of 0.307 – 0.561.

Figure 3.2 shows the evolution over time of the Kendall's τ for each pair of performance scores considered. The figure indicates an improvement in the compatibility between the economic and all the non-economic CSR dimensions over time. Increasing trends in Kendall's τ are especially strong for the economic and corporate governance pair. In a time span of 8 years, the relational measure increases from τ = 0.323 to τ = 0.561, bringing economic-governance relationship closer to the economic-social and economic-environmental relationship levels. The bottom line of our results is that the U.S. electric utilities have not only improved their economic performance over time, but have also been capable to make this economic performance compatible with the adoption of further responsibilities embedded in the CSR. In short, the U.S. electric utility holding companies in our sample have become better corporate citizens. There does not seem to be a trade-off between economic and non-economic dimensions of performance for our sample of firms.

Tail dependencies, i.e., the lower tail (λ_L) and upper tail (λ_U) coefficients for the economic and non-economic CSR performance measures for each year are summarized in Figure 3.3. Tail dependence takes either positive or zero values. Zero tail dependence is associated to the Archimedean Clayton and Gumbel copulas that only allow for either lower or upper tail dependence. In contrast, the two-parameter BB7 allows for both lower and upper tail dependence. The left panel in figure 3.3 reports the lower tail dependence. The average lower tail dependence between economic and social performance is 0.809,[7] with a range of 0.735 – 0.852. This suggests that those firms with poorest economic performance levels are also characterized by lowest social performance ratings. The economic and corporate governance also shows lower positive tail dependence, with an average magnitude of 0.653, and a range of 0.537 – 0.725. Hence, poor economic performance also seems to go hand in hand with poor governance performance. The relationship between the economic and environmental performance has half of the lower tail dependencies equal to zero. This may indicate that firms that have lower environmental scores, are not necessarily the ones with lower economic scores.

The right panel of figure 3.3 reports the upper tail dependence over the period studied: the predominance of zero upper tail dependence suggests that firms exceling in economic performance do not necessarily excel in the non-economic dimensions. In short, while poor and average economic results seem to bring, respectively, poor and average social, environmental and governance results, economic results in the upper quartiles do not seem to go hand to hand with the other dimensions of CSR. This may suggest that while firms may be able to become average corporate citizens, exemplar corporate citizens are less apparent in the U.S. electric utilities sector.

[7] Copulas that do not allow for lower tail are not considered in the computation of this average.

3.5 Conclusion

The manner in which businesses interact with society has changed over time. As the concept of CSR has gained reputation, companies have taken responsibility for their impacts on societies and the environment. The relationship between the different CSR dimensions is likely to be different in different industries (Reed, 1999). This article studies relationships among the four main CSR dimensions: economic, environmental, social, and corporate governance in the U.S. electric utility sector. For this purpose, we use a sample of U.S. investor-owned electric utility holding companies observed from 2005 to 2012.

The empirical regularities characterizing relationships are identified using statistical copulas. Results from copula analysis show a relatively strong positive link between economic and environmental performance (the Kendall's τ being on the order of 0.6), suggesting that adoption of environmentally friendly technologies may improve firm efficiency and financial health. Evidence of a strong positive relationship between economic and social performance is also found (the Kendall's τ being on the order of 0.6), which may indicate that providing better working environments leads to better economic outcomes. With a positive, albeit weaker relationship (the Kendall's τ being on the order of 0.42), results also suggest that economic performance improves when the interests of various stakeholders (including shareholders, customers, managers, suppliers, and the community) are better balanced.

The relationships among CSR dimensions follow an upward trend over time, a trend that is especially strong for the economic and corporate governance pair. Firms appear to have learned how to improve compatibility between financial goals and corporate citizenship. This compatibility, however, is not seen for the higher ends of the bivariate distributions. As a result, while poor and average economic results seem to be associated, respectively, to poor and average environmental, social, and governance results, economic performance in the upper quartiles do not seem to go hand to hand with the other dimensions of CSR. This may suggest that exemplar corporate citizens are less apparent in the U.S. electric utilities sector.

A major limitation of our research is that we do not identify the causes underlying the relationship between CSP and economic performance. The U.S. electric utility industry is a highly regulated industry and regulation is likely to influence our results. The impacts of regulations on the relationship between CSP and CFP can be identified by assessing dependency before and after regulation changes (Zhou and Wei, 2016) and offers scope for future research. Results from our research are useful for corporate accountability reports and should motivate shareholders to be active owners and encourage the company to improve environmental, social, and governance performance, which should eventually lead to better financial performance. Further, our results can be relevant for policy design, as they suggest that an institutional framework encouraging CSR could lead to better financial results for electric utilities.

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Table 3.1 Properties of bivariate elliptical copulas considered in this study

Elliptical Copulas	Parameter range	Kendall's τ	Tail dependence (Lower, Upper)
Normal	$\rho \in [-1,1].$	$\frac{2}{\pi}\arcsin(\rho)$	(0,0)
Student-t	$\rho \in [-1,1],\ \nu > 2$	$\frac{2}{\pi}\arcsin(\rho)$	$(2T_{\nu+1}(-\sqrt{\nu+1}\sqrt{\frac{1-\rho}{1+\rho}}, 2T_{\nu+1}(-\sqrt{\nu+1}\sqrt{\frac{1-\rho}{1+\rho}})$*

****** Where $T_{\nu+1}$ is the cumulative distribution function of the univariate Student-t distribution with $\nu + 1$ degrees of freedom

Table 3.2 Properties of bivariate Archimedean copulas considered in this study

Archimedean copula	Parameter range	Kendall's τ	Tail dependence (Lower, Upper)
Frank	$\theta \in \mathbb{R} \setminus \{0\}$	$1 - \frac{4}{\theta} + 4\frac{D_1(\theta)}{\theta}$	$(0, 0)$
Gumbel	$\theta \geq 1$	$1 - \frac{1}{\theta}$	$(0, 2 - 2^{\frac{1}{\theta}})$
Clayton	$\theta > 0$	$\frac{\theta}{\theta + 2}$	$(2^{-\frac{1}{\theta}}, 0)$
BB1	$\theta > 0, \delta \geq 1$	$1 - \frac{2}{\delta(\theta + 2)}$	$(2^{-\frac{1}{\delta\theta}}, 2 - 2^{\frac{1}{\delta}})$
BB7	$\theta \geq 1, \delta > 0$	$1 + \frac{4}{\delta\theta}\int_0^1 (-(1-(1-t)^{\theta})^{\delta+1} \times \frac{(1-(1-t)^{\theta})^{-\delta} - 1}{(1-t)^{\theta-1}}\Big) dt$	$(2^{-\frac{1}{\delta}}, 2 - 2^{\frac{1}{\theta}})$

Table 3.3 Revenues, Sales and Customers of sample Electric Utilities compared to the whole U.S. Electricity Market in 2012

	Revenues (Thousands Dollars)	Sales (Megawatt/hours)	Customers (Count)	Renewable Electricity Sales (Megawatt/hours)
Duke Energy	17.697.71	205.843.04	7.130.32	6.775.40
Exelon	9.182.60	158.350.80	6.648.89	4.700.00
Southern	14.187.01	156.054.01	4.432.19	71.32
First Energy	8.392.16	146.655.78	5.982.08	3.318.80
American Electric Power	14.945.00	137.865.32	4.233.24	3.649.65
Entergy	7.293.83	107.006.91	2.778.02	682.57
NextEra Energy, Inc.	9.745.55	102.127.93	4.576.42	1.318.43
Xcel	7.419.14	89.197.69	3.417.33	16.157.01
Edison International	11.121.83	86.480.01	4.941.08	14.415.20
PPL Corporation	3.899.78	66.922.74	2.338.93	1.130.46
Pepco holdings	3.636.44	48.145.83	1.840.48	1.623.97
DTE Energy	5.187.92	47.990.73	2.129.92	1.989.41
Public Service Enterprise Group	3.972.20	41.641.44	2.164.59	2.051.41
Pinnacle West Capital	3.055.49	28.154.14	1.132.30	1.507.02
AES	2.105.49	28.014.22	984.04	148.75
Wisconsin Energy Corporation	2.944.99	27.043.20	1.123.78	1.532.20
Alliant Energy	2.348.75	25.732.53	986.76	1.391.00
TECO Energy, Inc.	1.953.72	18.408.58	684.24	NA
Dynegy	1.230.00	36.000.00	NA	NA
Total for the 19 sample utilities	130.319.61	1.521.634.91	57.524.58	62.462.58
U.S. Electric Market	363.687.00	3.694.650.00	145.293.84	368.712.45*

Note : NA = not available

* : in 2012, renewable energy sources accounted for about 9,3% of total U.S. energy consumption (NREL, 2013)

Source: CERES (2014) (http://www.ceres.org/resources/reports/benchmarking-utility-clean-energy-deployment-2014)

Table 3.4 Descriptive statistics for the four CSR indicators 2005-2012

	2005				2006				2007				2008			
	GOV	ECN	ENV	SOC	GOV	ECN	ENV	SOC	GOV	ECN	ENV	SOC	GOV	ECN	ENV	SOC
Mean	82,29	65,43	71,11	64,14	82,25	57,26	69,51	65,50	84,68	65,81	71,45	68,25	88,72	63,39	74,07	68,44
Std.Dev.	14,64	25,25	23,81	24,78	13,12	26,48	20,88	23,96	7,58	22,33	18,73	19,16	7,50	24,42	18,12	20,07
Min	41,9	13,82	18,65	15,26	41,32	11,75	29,88	19,52	70,50	25,20	25,88	15,92	70,55	20,05	23,77	29,94
Max	95,73	98,74	96,38	97,44	96,11	94,73	94,68	94,67	95,57	96,54	91,37	91,43	96,04	96,83	92,41	95,15
Skewness	-1,25	- 0,49	- 0,88	- 0,38	- 1,57	- 0,02	- 0,60	- 0,56	- 0,21	-0,40	-0,96	-1,23	-0,93	-0,26	-1,12	- 0,58
Kurtosis	0,77	- 1,13	- 0,39	- 1,21	2,43	- 1,45	- 0,92	- 1,18	- 1,01	-1,28	-0,24	0,74	-0,42	-1,37	0,61	- 1,11
Jarque - Bera Normality Test	7,02*	1,55	2,92	1,35	16,49*	1,29	1,70	1,91	0,65	1,53	3,47	6,68*	3,26	1,36	5,47	1,87
pvalue	0,02	0,46	0,23	0,51	0,00	0,52	0,43	0,39	0,72	0,47	0,18	0,04	0,20	0,51	0,06	0,39

	2009				2010				2011				2012			
	GOV	ECN	ENV	SOC	GOV	ECN	ENV	SOC	GOV	ECN	ENV	SOC	GOV	ECN	ENV	SOC
Mean	86,31	69,87	74,21	75,02	87,16	65,49	70,61	73,32	85,01	68,77	73,58	70,38	85,59	70,19	73,28	75,07
Std.Dev.	10,24	21,75	18,12	19,22	8,04	21,14	19,11	15,91	9,42	28,28	19,87	19,29	8,39	23,30	16,47	19,69
Min	55,13	34,88	30,37	40,57	69,58	29,54	20,63	37,50	68,51	13,67	30,25	32,32	71,69	24,84	40,82	36,27
Max	96,05	98,31	93,31	95,30	96,14	98,11	90,85	95,91	96,35	98,07	92,92	97,13	94,43	98,61	92,12	92,49
Skewness	-1,48	-0,06	- 0,88	- 0,52	-0,75	- 0,14	-1,16	-0,57	- 0,28	- 0,74	-1,00	-0,30	- 0,45	- 0,62	-0,57	-0,88
Kurtosis	2,02	- 1,67	- 0,32	-1,51	- 0,66	-1,23	0,37	-0,87	-1,51	-1,05	-0,47	-1,23	-1,55	-1,11	-1,08	-0,87
Jarque - Bera Normalality Test	13,51*	1,84	2,87	2,44	2,23	0,91	5,46	1,51	1,71	2,59	3,78	1,18	1,34	1,29	1,08	2,14
pvalue	0,00	0,40	0,24	0,29	0,33	0,63	0,07	0,47	0,43	0,27	0,15	0,55	0,51	0,52	0,58	0,34

Note: GOV denotes the Corporate Governance, ECN the Economic, ENV the Environmental and SOC the Social performance scores.

* Indicates statistically significant at 5% level.

Table 3.5 Bivariate Copula Analysis Results

				2005									2006			
Pairs	Copula	θ_1	θ_2	SE_1	SE_2	Kendall's τ	λ_L	λ_U	Copula	θ_1	θ_2	SE_1	SE_2	Kendall's τ	λ_L	λ_U
ECN-ENV	Clayton	2,36	-	0,86	-	0,54	0,75	0,00	BB7	3.32	0.82	0,79	1,19	0,61	0,43	0,77
ECN-SOC	BB7	1.53	2.26	0,45	1,04	0,57	0,74	0,43	Gumbel	2,03	-	0,38	-	0,51	0,00	0,59
ECN-GOV	Normal	0,49	-	0,13	-	0,32	0,00	0,00	Normal	0,46	-	0,15	-	0,31	0,00	0,00
				2007									2008			
	Copula	θ_1	θ_2	SE_1	SE_2	Kendall's τ	λ_L	λ_U	Copula	θ_1	θ_2	SE_1	SE_2	Kendall's τ	λ_L	λ_U
ECN-ENV	Normal	0,76	-	0,08	-	0,55	0,00	0,00	Normal	0,76	-	0,08	-	0,55	0,00	0,00
ECN-SOC	Normal	0,81	-	0.06	-	0,60	0,00	0,00	Clayton	3,04	-	0,96	-	0,60	0,80	0,00
ECN-GOV	Clayton	1,52	-	0,67	-	0,43	0,63	0,00	BB7	1,00	1,12	0,17	0,63	0,36	0,54	0,00
				2009									2010			
	Copula	θ_1	θ_2	SE_1	SE_2	Kendall's τ	λ_L	λ_U	Copula	θ_1	θ_2	SE_1	SE_2	Kendall's τ	λ_L	λ_U
ECN-ENV	Clayton	3,54	-	1,14	-	0,64	0,82	0,00	Frank	9,26	-	2,29	-	0,64	0,00	0,00
ECN-SOC	Clayton	4,33	-	1,30	-	0,68	0,85	0,00	Clayton	3,33	-	1,13	-	0,63	0,81	0,00
ECN-GOV	Clayton	1,79	-	0,72	-	0,47	0,68	0,00	Clayton	1,66	-	0,70	-	0,45	0,66	0,00
				2011									2012			
	Copula	θ_1	θ_2	SE_1	SE_2	Kendall's τ	λ_L	λ_U	Copula	θ_1	θ_2	SE_1	SE_2	Kendall's τ	λ_L	λ_U
ECN-ENV	Frank	7,59	-	2,02	-	0,59	0,00	0,00	BB7	1,00	3,31	0,52	1,52	0,62	0,81	0,00
ECN-SOC	Frank	8,47	-	2,15	-	0,62	0,00	0,00	Clayton	4,29	-	1,66	-	0,68	0,85	0,00
ECN-GOV	Clayton	1.84	-	0,68	-	0,48	0,69	0,00	BB7	1,22	2,44	0,27	1,35	0,56	0,73	0,23

Note: GOV denotes the Corporate Governance, ECN the Economic, ENV the Environmental and SOC the Social performance scores.

θ_1 and θ_2 represent the copula parameters. SE_1 and SE_2 represent the standard errors corresponding to each copula parameter, respectively. λ_L and λ_U are the Lower and Upper tail dependence coefficients, respectively.

Table 3.6 Goodness-of-fit tests for bivariate copulas

	2005							
	GOF Tests	Gaussian	T-Copula	Clayton	Gumbel	Frank	BB1	BB7
ECN-ENV	Vuong	0	1	0	-1	0	0	0
	Clarke	0	0	0	0	0	0	0
	statistic.CvM	0,13	0,09	0,09	0,10	0,11	0,09	0,09
	p.value.CvM	0,40	0,50	0,50	0,30	0,10	0,70	0,50
	statistic.KS	0,84	0,66	0,77	0,74	0,70	0,74	0,75
	p.value.KS	0,40	0,70	0,40	0,40	0,20	0,40	0,40
	Selected Copula: Clayton							
ECN-SOC	Vuong	0	1	0	-1	0	0	0
	Clarke	-1	1	0	-1	0	0	1
	statistic.CvM	0,11	0,12	0,07	0,15	0,14	0,09	0,08
	p.value.CvM	0,20	0,00	0,60	0,30	0,10	0,30	0,70
	statistic.KS	0,71	0,78	0,62	0,80	0,77	0,70	0,67
	p.value.KS	0,40	0,20	0,80	0,40	0,10	0,40	0,60
	Selected Copula: BB7							
ECN-GOV	Vuong	0	0	0	0	0	0	0
	Clarke	1	0	0	-1	0	0	0
	statistic.CvM	0,10	0,11	0,15	0,00	0,11	0,13	0,14
	p.value.CvM	0,60	0,70	0,40	-	0,50	0,30	0,40
	statistic.KS	0,77	0,79	0,81	0,00	0,76	0,79	0,80
	p.value.KS	0,40	0,40	0,40	-	0,20	0,60	0,50
	Selected Copula: Gaussian							

	2006							
	GOF Tests	Gaussian	T-Copula	Clayton	Gumbel	Frank	BB1	BB7
ECN-ENV	Vuong	-3	2	-2	1	-4	1	5
	Clarke	1	0	-5	2	-2	2	2
	statistic.CvM	0,08	0,00	0,13	0,08	0,09	0,08	0,07
	p.value.CvM	0,50	-	0,40	0,50	0,40	0,40	0,60
	statistic.KS	0,78	0,00	0,90	0,75	0,69	0,75	0,75
	p.value.KS	0,00	-	0,10	0,40	0,70	0,10	0,40
	Selected Copula: BB7							
ECN-SOC	Vuong	0	1	0	0	-1	0	0
	Clarke	0	1	0	0	-1	0	0
	statistic.CvM	0,08	0,10	0,14	0,08	0,08	0,09	0,09
	p.value.CvM	0,80	0,50	0,10	0,90	0,40	0,50	0,40
	statistic.KS	0,82	0,91	1,01	0,75	0,79	0,86	0,88
	p.value.KS	0,30	0,00	0,00	0,60	0,10	0,00	0,00
	Selected Copula: Gumbel							
ECN-GOV	Vuong	0	0	0	0	0	0	0
	Clarke	0	0	0	0	0	0	0
	statistic.CvM	0,15	0,17	0,15	0,00	0,17	0,15	0,15
	p.value.CvM	0,30	0,30	0,20	-	0,10	0,30	0,20
	statistic.KS	0,90	0,96	1,00	0,00	0,94	0,98	1,00
	p.value.KS	0,30	0,20	0,10	-	0,00	0,20	0,00
	Selected Copula: Gaussian							

	2007							
	GOF Tests	Gaussian	T-Copula	Clayton	Gumbel	Frank	BB1	BB7
ECN-ENV	Vuong	0	0	0	0	-1	1	0
	Clarke	0	0	-1	0	0	-1	2
	statistic.CvM	0,10	0,10	0,14	0,07	0,08	0,13	0,14
	p.value.CvM	0,40	0,40	0,10	1,00	0,50	0,10	0,00
	statistic.KS	0,76	0,75	0,94	0,64	0,74	0,92	0,94
	p.value.KS	0,30	0,60	0,00	1,00	0,30	0,00	0,00
	Selected Copula: Gaussian							
ECN-SOC	Vuong	1	1	0	-2	0	0	0
	Clarke	-1	0	0	-1	1	0	1
	statistic.CvM	0,12	0,12	0,14	0,13	0,16	0,14	0,14
	p.value.CvM	0,20	0,10	0,00	0,10	0,00	0,00	0,00
	statistic.KS	0,73	0,76	0,91	0,69	0,86	0,91	0,91
	p.value.KS	0,20	0,10	0,00	0,40	0,00	0,10	0,00
	Selected Copula : Gaussian							
ECN-GOV	Vuong	2	0	2	-6	-2	2	2
	Clarke	-2	-2	4	-5	-3	4	4
	statistic.CvM	0,09	0,09	0,08	0,00	0,06	0,08	0,08
	p.value.CvM	0,70	0,60	0,70	-	1,00	0,60	0,60
	statistic.KS	0,69	0,70	0,77	0,00	0,54	0,77	0,77
	p.value.KS	0,60	0,40	0,60	-	1,00	0,30	0,40
	Selected Copula: Clayton							

	2008							
	GOF Tests	Gaussian	T-Copula	Clayton	Gumbel	Frank	BB1	BB7
ECN-ENV	Vuong	1	1	0	-2	0	0	0
	Clarke	1	1	-1	-4	0	2	1
	statistic.CvM	0,06	0,05	0,07	0,05	0,06	0,07	0,07
	p.value.CvM	0,90	0,90	0,60	0,90	1,00	0,80	0,60
	statistic.KS	0,58	0,57	0,62	0,54	0,53	0,58	0,59
	p.value.KS	0,80	0,80	0,60	0,80	1,00	0,80	0,90
	Selected Copula:Gaussian							
ECN-SOC	Vuong	-2	1	3	-6	-2	3	3
	Clarke	-3	1	2	-4	0	2	2
	statistic.CvM	0,09	0,08	0,06	0,14	0,10	0,06	0,06
	p.value.CvM	0,50	0,80	0,80	0,20	0,30	0,50	0,70
	statistic.KS	0,74	0,79	0,70	0,81	0,79	0,70	0,70
	p.value.KS	0,50	0,40	0,50	0,30	0,10	0,20	0,20
	Selected Copula: Clayton							
ECN-GOV	Vuong	2	0	0	-2	0	0	0
	Clarke	0	0	0	0	0	0	0
	statistic.CvM	0,16	0,16	0,06	0,00	0,13	0,06	0,06
	p.value.CvM	0,30	0,30	0,90	0,00	0,30	0,80	1,00
	statistic.KS	0,76	0,77	0,69	0,00	0,68	0,69	0,69
	p.value.KS	0,60	0,60	0,60	0,00	0,50	0,60	0,70
	Selected Copula: BB7							

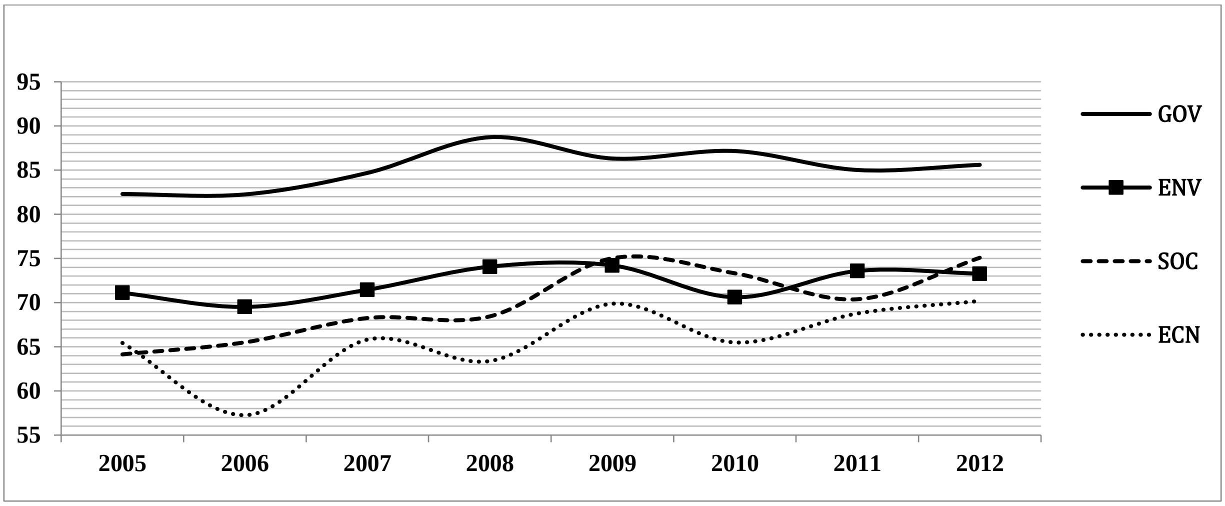
2009								
	GOF Tests	Gaussian	T-Copula	Clayton	Gumbel	Frank	BB1	BB7
ECN-ENV	Vuong	-3	1	3	-4	-3	3	3
	Clarke	-4	1	1	-4	1	2	3
	statistic.CvM	0,07	0,06	0,18	0,05	0,09	0,18	0,18
	p.value.CvM	0,90	0,80	0,10	0,90	0,50	0,00	0,10
	statistic.KS	0,51	0,79	1,12	0,49	0,81	1,12	1,12
	p.value.KS	1,00	0,30	0,00	0,90	0,10	0,00	0,00
	Selected Copula: Clayton							
ECN-SOC	Vuong	0	0	1	0	-3	1	1
	Clarke	1	1	0	-2	-3	1	2
	statistic.CvM	0,06	0,06	0,08	0,13	0,08	0,08	0,08
	p.value.CvM	0,60	0,90	0,30	0,20	0,50	0,30	0,20
	statistic.KS	0,64	0,62	0,65	0,82	0,66	0,65	0,65
	p.value.KS	0,60	0,90	0,40	0,30	0,50	0,30	0,30
	Selected Copula: Clayton							
ECN-GOV	Vuong	1	1	2	-5	-3	2	2
	Clarke	1	1	1	-2	-3	1	1
	statistic.CvM	0,10	0,11	0,21	0,00	0,10	0,21	0,21
	p.value.CvM	0,63	0,60	0,07	0,00	0,90	0,00	0,00
	statistic.KS	0,96	0,99	1,25	0,00	0,93	1,25	1,25
	p.value.KS	0,09	0,10	0,00	0,00	0,30	0,00	0,00
	Selected Copula: Clayton							

2010								
	GOF Tests	Gaussian	T-Copula	Clayton	Gumbel	Frank	BB1	BB7
ECN-ENV	Vuong	-4	1	1	-1	1	1	1
	Clarke	-6	2	0	-4	2	3	3
	statistic.CvM	0,09	0,00	0,22	0,08	0,14	0,22	0,22
	p.value.CvM	0,50	-	0,00	0,70	0,10	0,00	0,00
	statistic.KS	0,81	0,00	0,96	0,79	0,71	0,96	0,96
	p.value.KS	0,00	-	0,00	0,50	0,20	0,00	0,00
	Selected Copula: Frank							
ECN-SOC	Vuong	-3	1	1	-1	0	1	1
	Clarke	-5	2	0	-3	0	4	2
	statistic.CvM	0,07	0,00	0,14	0,05	0,07	0,14	0,14
	p.value.CvM	0,70	-	0,10	1,00	0,90	0,20	0,10
	statistic.KS	0,54	0,00	1,01	0,52	0,71	1,01	1,01
	p.value.KS	0,80	-	0,10	1,00	0,70	0,00	0,00
	Selected Copula: Clayton							
ECN-GOV	Vuong	2	0	2	-6	-2	2	2
	Clarke	2	0	2	-6	-2	1	3
	statistic.CvM	0,13	0,12	0,06	0,00	0,09	0,06	0,06
	p.value.CvM	0,40	0,50	1,00	-	0,40	1,00	0,80
	statistic.KS	0,70	0,69	0,65	0,00	0,66	0,65	0,65
	p.value.KS	0,50	0,60	0,90	-	0,40	0,80	0,60
	Selected Copula: Clayton							

				2011				
	GOF Tests	Gaussian	T-Copula	Clayton	Gumbel	Frank	BB1	BB7
ECN-ENV	Vuong	0	0	0	0	0	0	0
	Clarke	1	1	0	-3	1	0	0
	statistic.CvM	0,09	0,09	0,08	0,17	0,09	0,08	0,08
	p.value.CvM	0,70	0,50	0,30	0,20	0,80	0,30	0,30
	statistic.KS	0,81	0,79	0,61	1,04	0,74	0,60	0,61
	p.value.KS	0,40	0,10	0,60	0,00	0,50	0,40	0,80
				Selected Copula: Frank				
ECN-SOC	Vuong	0	0	0	-3	3	0	0
	Clarke	-3	-3	3	-6	3	3	3
	statistic.CvM	0,25	0,25	0,09	0,00	0,12	0,09	0,09
	p.value.CvM	0,00	0,00	0,40	-	0,10	0,20	0,10
	statistic.KS	1,00	0,98	0,63	0,00	0,72	0,63	0,63
	p.value.KS	0,00	0,00	0,70	-	0,10	0,20	0,40
				Selected Copula: Frank				
ECN-GOV	Vuong	0	0	0	0	0	0	0
	Clarke	0	0	0	0	0	0	0
	statistic.CvM	0,19	0,20	0,08	0,41	0,14	0,12	0,11
	p.value.CvM	0,10	0,00	0,40	0,00	0,00	0,40	0,50
	statistic.KS	0,95	0,98	0,73	1,23	0,79	0,84	0,83
	p.value.KS	0,20	0,20	0,30	0,00	0,10	0,30	0,10
				Selected Copula: Clayton				
				2012				
	GOF Tests	Gaussian	T-Copula	Clayton	Gumbel	Frank	BB1	BB7
ECN-ENV	Vuong	-2	-2	4	-6	-2	3	5
	Clarke	1	1	2	-5	-3	2	2
	statistic.CvM	0,17	0,18	0,06	0,00	0,12	0,06	0,06
	p.value.CvM	0,10	0,30	0,90	0,00	0,50	0,90	1,00
	statistic.KS	0,95	0,95	0,61	0,00	0,82	0,61	0,61
	p.value.KS	0,10	0,20	0,80	0,00	0,20	0,70	1,00
				Selected Copula: BB7				
ECN-SOC	Vuong	-3	0	3	-3	-3	3	3
	Clarke	-4	-1	2	-4	3	2	2
	statistic.CvM	0,15	0,00	0,12	0,23	0,14	0,12	0,12
	p.value.CvM	0,60	-	0,20	0,10	0,10	0,10	0,30
	statistic.KS	0,91	0,00	0,83	1,06	0,71	0,83	0,83
	p.value.KS	0,30	-	0,20	0,00	0,20	0,00	0,20
				Selected Copula: Clayton				
ECN-GOV	Vuong	1	1	0	-2	0	0	0
	Clarke	1	1	0	-3	0	0	1
	statistic.CvM	0,10	0,11	0,06	0,00	0,09	0,06	0,06
	p.value.CvM	0,50	0,70	0,80	-	1,00	1,00	0,90
	statistic.KS	0,61	0,64	0,56	0,00	0,54	0,56	0,57
	p.value.KS	0,80	0,80	0,80	-	1,00	1,00	0,90
				Selected Copula: BB7				

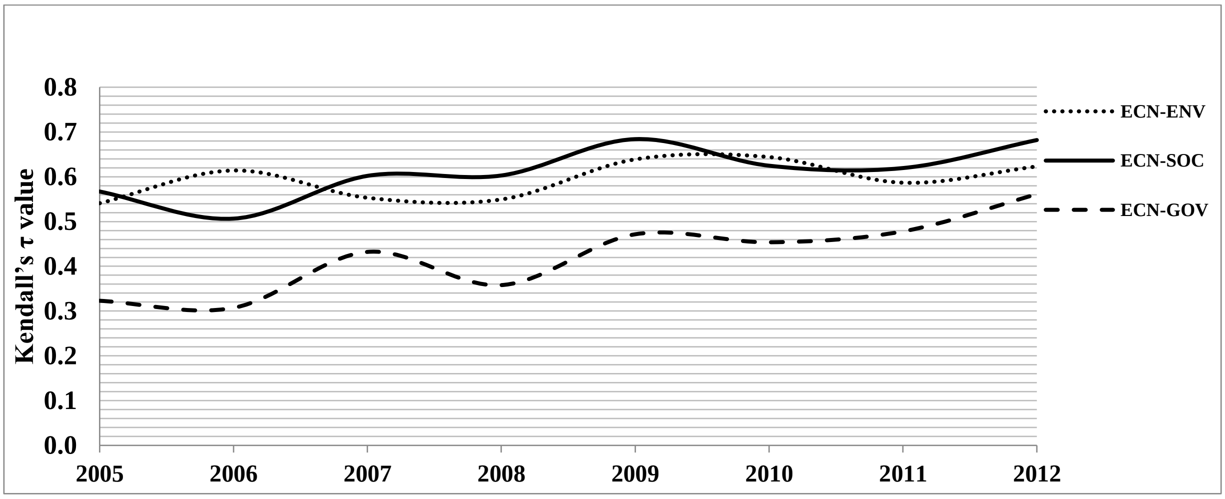
Note: GOV denotes the Corporate Governance, ECN the Economic, ENV the Environmental and SOC the Social performance scores.

Figure 3.1 Evolution of average SCR scores (2005-2012)



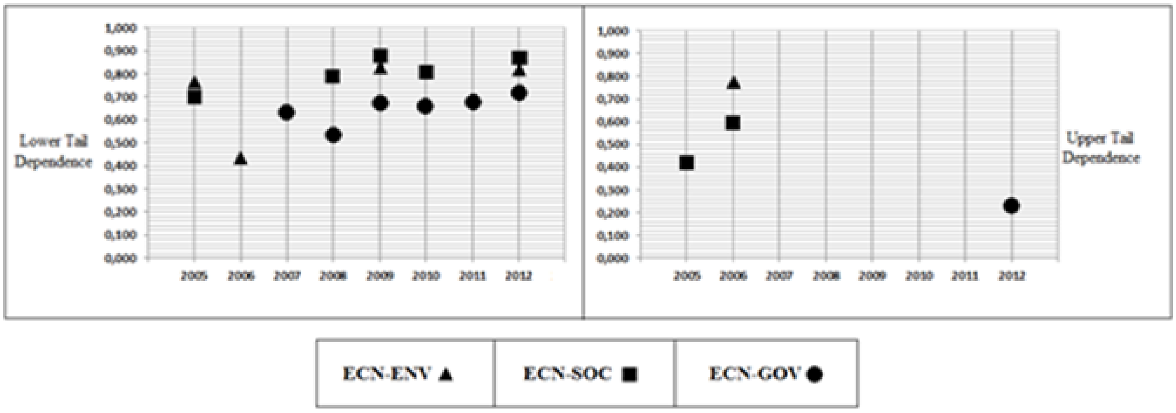
Note: GOV denotes the Corporate Governance, ECN the Economic, ENV the Environmental and SOC the Social performance scores.

Figure 3.2 Evolution of economic and non-economic CSR dimensions' dependence (2005-2012)



Note: GOV denotes the Corporate Governance, ECN the Economic, ENV the Environmental and SOC the Social performance scores.

Figure 3.3 Evolution of economic and non-economic CSR dimension' tail dependence (2005-2012)



Note: The left hand side (the right hand side) of the figure shows the distribution of the Lower tail (upper tail) dependence measures between economic and CSR performance over the studied period.

GOV denotes the Corporate Governance, ECN the Economic, ENV the Environmental and SOC the Social performance scores.

Chapter 4: Measuring Sustainability Efficiency at Farm Level: A Data Envelopment Analysis Approach[8]

[8] Publication information: Ait Sidhoum, A. and Serra, T. Measuring Sustainability Efficiency at Farm Level: A Data Envelopment Analysis Approach. *European Review of Agricultural Economics* (second-round review)

4.1 Introduction

The Committee on Twenty-First Century Systems Agriculture (NRC, 2010, p. 4) characterizes sustainable agriculture as the one satisfying human food, feed, fiber and biofuel needs; enhancing the quality of the environment and resource base; ensuring the economic viability of the agricultural sector; and improving the quality of life of farmers, farm workers and society. Sustainability can be pursued both at the aggregate (i.e. country or region) and at the individual (firm) level on which we focus. Through the concept of corporate social responsibility (CSR) the business model has embraced sustainability. Firms have progressively taken responsibility for their impact on society and on the environment, becoming better corporate citizens (CC) who adopt CSR strategies (Bowen, 1953; Carroll, 1999). Agricultural policies in developed countries have promoted adoption of such strategies among agricultural holdings. The European Union's Common Agricultural Policy (CAP) has been no exception. Since its inception, it has undergone different reforms that reflect changing political priorities over time. While initially the CAP essentially aimed at guaranteeing food security by stimulating agricultural production and protecting farmers' quality of life, a succession of changes have reformulated the CAP into a policy that embraces food safety, animal welfare, land management, rural development, environmental development and pollution control. In short, the CAP has leaned towards promoting a more sustainable agricultural sector. Consistently, farm payments have been progressively remodeled to reward those farms that meet different economic, environmental and territorial criteria. Noteworthy is the proposal to redistribute farm payments to better align the CAP with sustainability principles and objectives.

Sound implementation of farm payment schemes requires appropriate tools to measure farms' success in achieving policy goals. Since the pioneering work by Farrell (1957), the production economics literature has developed efficiency indices that can be used to assess this success. While the literature on efficiency measurement was initially focused on the desired output production technology, as sustainability of economic activities became relevant, firm-performance studies were extended to include environmental concerns (Coelli et al., 2007; Färe et al., 2005; Murty et al., 2012; O'Donnell, 2007; Oude Lansink & Van Der Vlist, 2008; Reinhard et al., 1999). Only recently, have these measures been extended to quantify the social dimension of firm performance (Chambers & Serra, 2016). By providing quantitative guidelines for benchmarking firm performance, efficiency measures can be very relevant in assisting public payment redistribution schemes. By building on the method proposed by Chambers & Serra (2016), this article is the first to derive farm-level productive, environmental and social efficiency measures by allowing for the stochastic nature of agricultural production. Assessing the environmental and social dimensions of performance requires data that are not usually available, especially at farm-level. We elicit this information through a survey conducted to a sample of Catalan farms.

Extension of production efficiency measures to allow for the environmental dimension of economic activities has not been without debate. Late articles (Førsund, 2009; Murty et al., 2012) have criticized previous approaches because they fail to address the material balance principle. Murty et al. (2012) and Coelli et al. (2007) have led the development of environmental efficiency measures based on the materials balance concept. Serra, Chambers, & Oude Lansink (2014) extend Murty's approach by incorporating the state-contingent framework to model the stochastic nature of production. We use this proposal to measure farm performance in minimizing nitrogen and pesticide pollution. We also take the literature one-step further by extending Serra, Chambers, & Oude Lansink (2014) to allow for the social output of firms.

Substantial ambiguity surrounds the operationalization of the social dimension of sustainability (Dempsey, Bramley, Power, & Brown, 2011; Vifell & Soneryd, 2012; Dixon, Colantonio, & Lane, n.d.; Murphy, 2012; Thin, 2002), which has received much less attention than the other two pillars of sustainability (Cuthill, 2010; Vavik & Keitsch, 2010). An essential question is which indicators should be used to reflect the social outputs of a business. Lebacq et al. (2013) suggest taking a set of indicators that revolve around labor, including workload, employment quality and health. Our research focuses on one particular indicator that reflects worker exposure to different health and safety issues (Ridley, 2010; Myers, Layne, & Marsh, 2009): fatal and non-fatal injuries suffered by farmers and farm workers. A second indicator that we use to represent farm social outputs is the generation of farmers' satisfaction, which we measure using a Likert scale (Bacon, Getz, Kraus, Montenegro, & Holland, 2012; Pissourios, 2013).

Ignoring the stochastic nature of an economic activity may lead to biased efficiency results (O'Donnell et al., 2010). Most empirical studies on efficiency have relied on the realized output to measure firm performance. These analyses, however, can confound poor outcomes related to the stochastic nature of production, with an inefficient use of the technology. As a result, it is relevant to model efficiency by allowing for the stochastic conditions in which production takes place. Our article follows the proposal by Chambers & Quiggin (1998, 2000) and models risk using the state-contingent approach. This approach, which has its foundations in Debreu (1959) and Arrow (1965), differentiates output according to the state of nature in which it is realized (i.e., the distribution of ex-ante outputs is used instead of the realized ex-post output). Due to its data requirements, few empirical studies in production and efficiency are based on the state-contingent approach. Our farm-level survey elicits ex-ante production data to empirically represent the state-contingent technology of sample farms.

4.2 Methods

Our theoretical framework builds on the papers by Murty et al. (2012), Chambers & Serra (2016) and Serra et al. (2014). The three articles contribute to the academic debate on how to properly model byproducts from production technologies. Along the lines of Frisch (1965) and Førsund (2009), Murty et al. (2012) model a company's production technology as the interaction of two sub-technologies; an intended output and an unintended output technology. Serra et al. (2014) extend Murty et al. (2012) by incorporating the state-contingent approach to modelling production risk. Chambers & Serra (2016) study the social dimension of firm performance by considering a third sub-technology in which social outputs are production netputs. Our work takes Chambers & Serra (2016) one-step further by modelling production risk.

Following Chambers & Quiggin (2000) uncertainty is represented through the state space Ω, which contains a number of states ($\omega = 1, \dots, \Omega$) randomly chosen by nature. Random variables are represented by vectors in R^{Ω} and are distinguished from non-random variables using tildes, e.g. $\tilde{y} = [y_e : e \in \Omega]$, where y_e represents the ex-post value of $\tilde{y}$ if nature chooses state e. Production of our sample farms is the result of the interaction of five different sub-technologies that shed light on firm's economic, environmental and social outputs. The first sub-technology models the production of intended agricultural outputs. The second and third sub-technologies reflect unintended pollution caused by nitrate and pesticide, herbicide and insecticide (PHI). The fourth and fifth sub-technologies reflect farm social outputs and focus on the generation of farmers' satisfaction and the minimization of work-related accidents.

The production technology is defined as a function of different netputs. Desired agricultural production is represented by $\tilde{y}_h$ for $h = 1, \dots, H.$, where H is the number of stochastic desired outputs, and assumed to depend on crop growing conditions. A farmer's overall satisfaction with her professional activity (s) is considered as another good output. Three types of unintended byproducts are considered: environmental impacts of PHI, fertilizer pollution and worker injuries. Nitrogen pollution is assumed to be contingent on the state of nature and denoted by $\tilde{z}_k$ for $k = 1, \dots, K$. Due to data constraints, farmer's satisfaction (s), environmental impacts of PHI pollution (p) and worker injuries (i) are treated as non-stochastic outputs. Outputs are generated using several inputs. We consider a set of N nonpolluting productive inputs, denoted by $x \in \mathbb{R}^N$ for $n = 1, \dots, N$. In our empirical application, variable x_1 represents land planted to crops and x_2 measures the capital replacement value. Variable x_3 represents paid and unpaid family work. Inputs x_4 and x_5 measure, respectively, the costs of energy and seeds. Organic and chemical fertilizers applied are denoted by $r_k \in \mathbb{R}^K$ for $k = 1, \dots, K$. PHI applications, measured in liters of active ingredients, are denoted by $c_d \in \mathbb{R}^D$ for $d = 1, \dots, D$. Working conditions are considered as an input and denoted by $w_a \in \mathbb{R}^A, a = 1, \dots, A$, with better working conditions being represented by higher values of w_a.

T, the general production technology, is assumed to be composed by an intended output sub-technology T^Y, a PHI pollution sub-technology T^P, a fertilizer runoff sub-technology T^Z, a work satisfaction sub-technology T^S, and a work injuries sub-technology T^I. The general production technology, integrated by the different sub-technologies, can be expressed as follows:

$$T = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i) : (x_n, r_k, c_d, w_a) \text{ can produce } (\tilde{y}_h, \tilde{z}_k, p, s, i)\} \quad (1)$$

Following previous research (Coelli et al., 2007; Serra et al., 2014), our representation of T meets material balance conditions requirements. In this regard, the applications of the runoff inputs (organic and chemical fertilizers – r_k and PHI – c_d) equal the quantity absorbed in the production of intended outputs plus the runoff byproducts. Fertilizer runoff is state-contingent since the quantity of fertilizer absorbed by plants depends on plant growth and can be represented by $r_k =$

$\tilde{q}_k + \tilde{z}_k$, where $\tilde{q}_k$ is the quantity of fertilizer input r_k absorbed by agricultural production, and $\tilde{z}_k$ represents the runoff. Only the quantity of fertilizer that remains on the crop ($\tilde{q}_k$) has an impact on the quantity of crop produced (Serra et al., 2014). Pollution derived from the application of PHI is assumed to have environmental and health impacts (p), which can be computed as the product of c_d and an environmental impact quotient (EIQ) per unit of active ingredient ($\varepsilon_d \in \mathbb{R}^D$). Since PHI are damage abatement inputs that do not contribute to crop growth, runoff coincides with the amount applied $p = \sum_d \varepsilon_d c_d$.

The specification of the intended output technology is:

$$T^Y = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): (x_n, r_k - \tilde{z}_k, c_d, w_a) \text{ can produce } \tilde{y}_h\}. \tag{2}$$

Following Serra et al. (2014), fertilizer runoff could be affected, for example, by the quality of the fertilizer applicator. Hence, fertilizer pollution is assumed to depend on productive inputs (x_n) such as labor and capital. To the extent that working conditions (w_a) can influence labor performance, they could also influence farmers' judgement regarding the need to apply fertilizers and consequently nitrogen runoff. As a result, the fertilizer runoff byproduct technology is expressed by:

$$T^Z = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): (x_n, r_k, w_a) \text{ can produce } \tilde{z}_k\} \tag{3}$$

The PHI pollution technology models the environmental impact derived from PHI application. Since we do not observe the environmental impact, we construct an estimate (p) by weighting the amount of active ingredients applied by an EIQ. We assume that an increase in conventional inputs (x_n) such as quantity of land sprayed, will increase the environmental impact of PHI. An exception is the amount of seeds, as a larger quantity of seed implies a higher crop density, thus less space for weeds which should reduce the need for herbicides. The PHI pollution technology is thus:

$$T^P = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): (c_d, x_{n\neq5}, x_5) \text{ can produce } p\} \tag{4}$$

This research considers two outputs related to the social dimension of economic activities, the level of work satisfaction as perceived by farmers (s) and the number of work injuries (i). Satisfaction is assumed to depend on working conditions (w_a). Since the use of conventional inputs can ease the work burden of labor and affect farmers' overall satisfaction with the work, they are also considered in the definition of T^S as follows:

$$T^S = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): (x_n, r_k, c_d, w_a) \text{ can produce } s\} \tag{5}$$

The last sub-technology is related to preventing or reducing farmers' injuries and fatalities. In order to avoid zeros in the dataset, the injuries variable is transformed so that high positive values represent little or no injuries and small values represent numerous injuries (see next section for further details). Conventional agricultural inputs such as PHI, agricultural machinery, or labor hours are assumed to increase injuries. An improvement in w_a, in contrast, is likely to reduce injuries. The T^I sub-technology is thus specified as:

$$T^I = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): (x_n, r_k, c_d, w_a) \text{ can produce } i\} \tag{6}$$

The overall technology T is then defined as the intersection of these five production sets: $T = T^Y \cap T^Z \cap T^P \cap T^S \cap T^I$.

To empirically estimate the model, we use a nonparametric Data Envelopment Analysis (DEA). Constant returns to scale (CRS) and free disposability are assumed to characterize the intended output technology T^Y. The intended output technology can be expressed as follows:

$$T^Y(J) = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): \tag{7}$$

$$x_n \geq \sum_j \beta^j x_n^j, n = 1, \dots, N$$

$$r_k - \tilde{z}_k \geq \sum_j \beta^j \left(r_k^j - \tilde{z}_k^j\right), k = 1, \dots, K$$

$$c_d \geq \sum_j \beta^j c_d^j, d = 1, \dots, D$$

$$w_a \geq \sum_j \beta^j w_a^j, a = 1, \dots, A$$

$$\tilde{y}_h \leq \textstyle\sum_j \beta^j \tilde{y}_h^j, h = 1, \dots, H,$$

$$\beta^j \in R_+^N\}$$

where *j* indexes the number of observations.

T^P is approximated as follows. An increase in the quantity of PHI applied (c_d) increases the environmental impacts. We assume that PHI pollution cannot be disposed without additional cost, which implies weak disposability of the byproduct. Thus T^Pcan be approximated as follows:

$$T^P(J) = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): \tag{8}$$

$$c_d \leq \sum_j \alpha^j c_d^j, d = 1, \dots, D$$

$$x_{n\neq 5} \leq \sum_j \alpha^j x_n^j, n \neq 5$$

$$x_5 \geq \sum_j \alpha^j x_5^j$$

$$p = \sum_j \alpha^j p^j \text{ , } \alpha^j \epsilon\, R_+^N\}$$

T^Z, the nitrogen runoff technology, imposes free disposability on non-polluting inputs and costly disposability of $\tilde{z}_k$ (Serra et al., 2014)

$$T^Z(J) = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): \tag{9}$$

$$x_n \geq \sum_j \gamma^j x_n^j \text{ , } n = 1, \dots, N$$

$$r_k \leq \sum_j \gamma^j r_k^j \text{ , } k = 1, \dots, K$$

$$w_a \geq \sum_j \gamma^j\, w_a^j, a = 1, \dots, A$$

$$\tilde{z}_k \geq \sum_j \gamma^j \tilde{z}_k{}^j \text{ , } k = 1, \dots, K, \gamma^j \epsilon\, R_+^N\}$$

Usually, adults spend much of their time working, which gives the workplace a very important dimension in people's life and impacts heavily on their well-being. The fourth sub-technology reflects satisfaction from work. As a qualitative factor, s is measured on a Likert scale. Traditional DEA models are not appropriate for non-continuous data. Cook et al. (1996, 1993) proposed the first modified DEA model including ordinal data. Cooper et al. (1999)'s imprecise DEA (IDEA) allows for imprecise measurements such as bounded data, ordinal data and Likert scales, into standard DEA. This results in a non-linear and non-convex DEA model. Cook & Zhu (2006) present a unified DEA structure allowing the integration of rank order or Likert scale information. As shown by Chen et al. (2015), however, in the radial DEA approach used by Cook & Zhu (2006), the projected points on the frontier do not necessarily correspond to Likert Scale information. We therefore adopt the adjusted DEA model proposed by Chen et al. (2015). As noted, we assume the use of conventional and good working conditions to ease the work burden of labor and thus increase work satisfaction. The approximation to T^S can be expressed as:

$$T^S(J) = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): \tag{10}$$

$$c_d \geq \sum_j \delta^j c_d^j, d = 1, \ldots, D$$

$$x_n \geq \sum_j \delta^j x_n^j, n = 1, \ldots, N$$

$$w_a \geq \sum_j \delta^j w_a^j, a = 1, \ldots, A$$

$$s \leq \sum_j \delta^j s^j, \qquad \delta^j \in R_+^N,$$

The last process concerns prevention of injuries at the farm level and assumes that increased input use such as pesticide, machinery, etc. tends to increase the number of injuries, while improved working conditions helps reducing them. By assuming free disposability of worker injuries, T^I can be expressed as:

$$T^I(J) = \{(x_n, r_k, c_d, w_a, \tilde{y}_h, \tilde{z}_k, p, s, i): \tag{11}$$

$$x_n \leq \sum_j \eta^j x_n^j, n = 1, \ldots, N$$

$$c_d \leq \sum_j \eta^j c_d^j, d = 1, \ldots, D$$

$$w_a \geq \sum_j \eta^j\, w_a^j, a = 1, \dots, A$$

$$i \leq \sum_j \eta^j i^j\,, \qquad \eta^j \ \in R_+^N, \}$$

Following Murty et al., (2012), the overall efficiency index is obtained by adding the five sub-technologies as follows:

$$E(x, r, c, w, \tilde{y}, \tilde{z}, p, s, i) = \frac{1}{5} \min_{\xi_1, \xi_2, \xi_3, \xi_4, \xi_5} \frac{\sum_\omega \xi_{1\omega}}{\Omega} + \xi_2 + \frac{\sum_\omega \xi_{3\omega}}{\Omega} + \xi_4 + \xi_5 \Bigg|$$

$$\langle x, r, c, w, \tilde{y} \text{Ø} \xi_{1\omega}, p \otimes \xi_2, \tilde{z} \otimes \xi_{3\omega}, s \text{Ø} \xi_4, i \otimes \xi_5 \rangle \in T\ ) \tag{12}$$

where $\tilde{y}\text{Ø}\xi_1 = \langle y_1/\xi_{11}, \dots, y_\Omega/\xi_{1\Omega}\rangle$, $p \otimes \xi_2 = p\xi_2, \tilde{z} \otimes \xi_3 = \langle z_1\xi_{31}, \dots, z_\Omega \xi_{3\Omega}\rangle$, $s\text{Ø}\xi_4 = s/\xi_4,\ , i \otimes \xi_5 = i\xi_5$. In the following section a description of the data used is offered.

4.3 The Data

Our analysis is based on cross sectional, farm-level data collected from a sample of 173 Spanish holdings specialized in the production of cereal, oilseed and protein (COP) crops and located in the region of Catalonia. The Spanish COP production reached nearly 4 billion euros in 2015 and represents more than 13% of the total vegetable production in the country (MAPAMA, 2016). The COP sector represents more than 130,000 farm holdings, 13% of total Spanish agricultural holdings (INE, 2013) and the highest proportion of the utilized agricultural area (UAA) in Spain. The UAA in Spain totaled 23.3 million hectares in 2013 (INE, 2013) of which 32% were being devoted to COP crops.

As noted by Chambers & Quiggin (2000), the key challenge to construct empirical representations of state-contingent technologies is the lack of information on the ex-ante distribution of the random variables. We follow Chambers, Serra, & Stefanou (2015) and use survey-elicited ex-ante outputs to empirically represent the stochastic technology. For this purpose, we conducted the survey before the beginning of the agricultural season (October 2015) to collect point estimates of anticipated yields for three alternative states of the nature: bad, normal and ideal growing conditions $y = (y_1, y_2, y_3)$ (see Chambers et al., (2015) and Serra et al., (2014) for further details). Table 4.1 provides summary statistics for the variables considered in this study and shows COP output value per farm to fluctuate from less than 30 thousand to more than 63 thousand euros, depending on the state of nature, being 46 thousand euros the most common. We also collected detailed information from each farm on planned input use, which includes crop land ($x_1$in hectares), capital (x_2 in replacement value), paid and unpaid labor (x_3 in hours), energy (x_4 in euros) and crop-specific inputs (crop protection products – c in liters, seeds - x_5 in euros, fertilizers - r in kilos). On average, sample farms cultivate 72 ha, have a capital replacement value of 145 thousand euros, devote slightly less than 900 labor hours per year to the farm and spend around 4,4 thousand and 3,9 thousand euros on energy and seeds, respectively. In order to estimate the sub-technologies representing farm social outputs, farmers' degree of work satisfaction (s) and information on the accidents and work injuries (i) occurring in the farm was also collected.

On average, sample farms apply 80 liters of PHI, which corresponds to a rate of slightly more than 1 liter per hectare. PAN Germany (2003) places this value around 1.84 Kg/ha in Spain, which involves our sample farms are below the national average. We use the environmental impact quotient (EIQ) developed at Cornell University to provide an estimation of the environmental and health impacts derived from PHI (Eshenaur, B., Grant, J., Kovach, J., Petzoldt, C., Degni, J., &

Tette, 2017; Kovach, Petzoldt, & Degni, 1992)[9]. The EIQ was developed to help farmers formulate informed decisions on pesticide selection. More specifically, to estimate pesticide pollution by farm, we multiply the amount of active ingredient applied in liters by the corresponding EIQ. The resulting quantity is taken as the estimate of p, the output of the PHI pollution technology. Noteworthy is the relatively small standard deviation of p for our sample farms (Table 4.1). In order to estimate pollution from fertilizers, we follow Serra et al. (2014). More specifically, our survey gathered information on the quantities of chemical and organic fertilizers applied and converted them into nitrogen quantities. While for chemical fertilizers the quantity of nitrogen can be easily found in the product specifications, we use Mercadé, Delgado, & Gil (2012) coefficients to approximate the quantity of nitrogen contained in organic fertilizers and the Spanish Ministry of Agriculture, Fisheries (2010) coefficients to quantify the nitrogen content in seeds. The nitrogen balance constraint requires estimation of crop nitrogen removal, which depends on yields, which in turn depend on the state of nature. Based on the Spanish Ministry of Agriculture, Fisheries (2010 information, we estimated three possible nitrogen removal quantities per farm (q_1, q_2, q_3) (see Serra et al. (2014) for further details). By computing the difference between nitrogen applied and removed, three possible nitrogen balances (one for each state of nature) were generated (z_1, z_2, z_3). The nitrogen balance fluctuates from 5,9 thousand to 3,5 thousand kilos in bad and good crop growing conditions, which is compatible with higher amounts of nitrogen being absorbed by crops under good crop growing conditions.

Few existing studies have considered the social dimension of firm performance. Contributing to this literature, we use two different sub-technologies that represent farm social outputs: the farmer's satisfaction level with working conditions (s) measured on four-point Likert

[9] The coefficients have not been derived for Spanish agriculture and thus, they only represent and approximation.

scale and the number of work-related injuries (b). Since farms in our sample are mainly family-based farms employing a very small number of workers (mainly members of the manager's family), very few injuries have been reported (an average of 0.35 injuries per farm). As noted by Sueyoshi & Sekitani (2009); Thompson, Dharmapala, & Thrall (1993), DEA models need to treat zeros in the data carefully. In order to avoid zero values in our dataset, the injuries variable is built as follows: we give a score of 100 for each farm, and for each minor injury we remove 5 points, while we remove 20 for a serious injury. For example[10], a farm with 1 minor injury and 1 serious injury will have a score of $i = 100 - \big((5) + (20)\big) = 75$. Redefinition of the injuries variable requires flipping the inequality sign in the last equation in (11). Farmers' satisfaction is obtained by asking farmers to value their overall degree of satisfaction with their work on a Likert Scale (from 1 to 4, being 1 the lowest and 4 the highest degree of satisfaction). The average is 3.4, showing a relatively high satisfaction level. To derive a quantitative measure of working conditions, farmers were asked to value, based on a four-point Likert scale, 17 items reflecting different dimensions of working conditions (workload, difficulty of the work, creativity, skills development, freedom in decision making, flexibility of schedules, work motivation). To reduce the number of netputs and improve the discriminatory ability of DEA, we perform a principal component analysis (PCA)[11] on the 17 items of the working conditions. Assume the vector of working conditions $(w_1, \dots, w_A)$ has covariance matrix V with the following eigenvalues $\left(\eta_1 \geq \cdots \geq \eta_A\right)$ and normalized eigenvectors $l_{1,\dots,}l_A$. The principal components (PCs) are computed as: $w_{pc_i} = l_{1i}w_1 + \cdots + l_{Ai}w_A, i = 1, \dots, A$, and constitute uncorrelated linear combinations of $(w_1, \dots, w_A)$ ranked in

[10] It should be noted that several combinations have been tried by the authors leading to the same results.

[11] PCAs may contain negative values. Therefore all values were increased by the most negative value in the vector plus one, thus ensuring our data are strictly positive.

descending order by their variances. Table 4.2 shows the PCA results of the working conditions items. We select six components with an eigenvalue greater than 1. The last column of the table 4.2 shows that the selected components contain more than 62% of the information, a percent that can be considered satisfactory (Hair, 2010).

4.4 Results

Efficiency scores are derived using the General Algebraic Modeling system (GAMS) software. Results obtained imply heterogeneity in farm performance in the different sub-technologies considered (Table 4.3). Figure 4.1 presents histograms and nonparametric kernel density functions by sub-technology. Overall efficiency averages 77.5%, a score that results from equation (12). This overall efficiency score can be decomposed into the technical, the environmental and the social measures. The environmental efficiency, on the order of 54.9%, is the lowest and measures the farm businesses performance in minimizing pollution caused by both PHI and nitrogen. The desired output technical performance of the firm is on the order of 89.1%. As will be explained below, this efficiency is however sensitive to the state of nature that is realized. Social output technologies display an efficiency level of 88.6%, which measures the performance of the farm business in minimizing work injuries, as well as in providing satisfaction to farmers.

The efficiency results of the state-contingent desired output technology show a small difference across the different states of nature, from 85.5% for the bad state of nature to 91% for the normal and ideal crop growing conditions. Figure 4.1 shows strong negative skewness for the three state-contingent output scores, T^{Y_1}, T^{Y_2} and T^{Y_3}, which implies that most farms are operating at or close to the best–practice frontier (very few farms present performance below 70%). Our results are in line with previous studies (Serra et al. 2014), suggesting that technical farm performance is increasing with the improvement in crop growth conditions. Overall nitrogen pollution efficiency has an average of 71.9%, suggesting that there is significant room for efficiency improvements. Our sample farms display nitrogen application efficiency levels on the order of 0.6 in good states of nature, which contrasts with efficiency levels of 0.76-0.79 for the bad and normal crop growing conditions. These results are compatible with those obtained by Serra et al. (2014) and show that over-fertilization is specially problematic under ideal crop growing conditions. This is due to the fact that farms prepare for the worst conditions, which implies that under good conditions, fertilizer use is far from the best practice. Table 4.3 shows that while there are 24 farms with a nitrogen pollution efficiency of less than 50% in the bad state, the equivalent is 64 farms in the ideal state of nature. Consistently, figure 4.1 shows T^{Z_3} with a flatter kernel density function than T^{Z_1} and T^{Z_2}. Serra et al. (2014) report an average nitrogen pollution efficiency larger than our results (80%), which can be explained by the fact that agricultural consumption of mineral nitrogen increased in Catalonia between 2011 and 2015 by more than 28% (MAPAMA, 2017).

The average efficiency score of the PHI sub-technology is around 38%, which leads to an efficiency distribution function with strong right skewness, suggesting that farms have the possibility to reduce the current amount of PHI-related pollution by an average of 62%. We observe a weak positive association between the state-contingent nitrogen pollution efficiencies and PHI pollution efficiencies, with the Spearman Rank correlation coefficients ranging between 0.35 and 0.45. Hence, to some extent, farmers who tend to overuse PHI may also tend to overuse fertilizers. The environmental impact of PHI does not depend exclusively on the amount used, the type of PHI may also play a major role. Zhu et al. (2014) reported relatively low eco-efficiency scores for some organophosphorus PHI such as Chlorpyrifos. These findings are in line with our results, as glyphosate and chlorpyrifos represent around 44% of the total amount of PHIs used by our sample farms. These active ingredients are characterized by their high environmental impact, which results in low efficiency scores. However, heterogeneity in our sample may also be responsible for the low ratings in PHI. Heterogeneity could come from the fact that while some farms may be placing greater weights on the environmental impacts of PHI use, others confer more relevance to yield improvement and crop loss prevention.

Very few researchers have ventured into quantifying the performance of firms as providers of social outputs (Lebacq et al., 2013). Our article is among the pioneers and extends Chambers & Serra (2016) model to allow for stochastic agricultural production conditions. The average score of social efficiency is around 88.6%, which implies that most of the farms are highly efficient in providing social outputs. The social performance level includes two efficiency measures. First, the efficiency in generating farmer's satisfaction, with an average of 88.3%. Second, the efficiency in reducing work injuries, with an average of 89.9%. T^S exhibits the typical negative skeweness pattern, almost a third (27%) of farms achieving a score of one (Figure 4.1). High T^S ratings can be due to people's tendency to think that they are happier than they actually are, which may lead farmers to overestimate their satisfaction with their work and working conditions (contentment) (Veenhoven, 1996, 1997).The high T^I ratings can be explained by the small number of work accidents occurring in sample farms.

Our efficiency analysis allows to characterize farms receiving direct payments according to their efficiency levels. With the green revolution, agricultural productivity soared in developed countries. Increases in productivity brought however significant costs such as groundwater pollution, soil depletion, or decline in the number of family farms and disintegration of rural communities. The CAP has progressively taken responsibility for these problems. The CAP rural development measures pay farmers for the provision of environmental goods and services. The CAP cross-compliance sets different rules that need to be respected by farmers in order to receive the CAP direct payments. These rules concern environmental preservation, animal welfare, plant health, food safety and maintenance of agricultural land in good agricultural and environmental conditions.

A bivariate copula analysis is conducted in order to assess dependency between farm subsidies and different farms efficiency levels. The bivariate copula method is not detailed here for space limitations, but readers are referred to Patton (2012) for details. Since goodness of fit tests lead to estimate different types of copula for each different subsidy-efficiency measure pairs, table 4.4 offers information on the type of copula estimated, the Kendall's τ measure of dependency in the central area of the bivariate distribution, as well as λ_L and λ_U, representing dependency in the lower and upper extremes of the bivariate distribution, respectively.

Results suggest that CAP subsidies and efficiency measures are positively correlated. Hence, more efficient farms receive higher farm payments. The correlation is, in general, weak, being moderate for the productive efficiency – subsidy pair. Hence, results suggest that the technically efficient farms are the ones receiving higher subsidy levels. Dependence between these two variables changes in the tails of the bivariate distribution, being high in the lower end of the distribution and almost zero in the upper end. This finding suggests that farms with the lowest levels of technical efficiency, are the ones receiving lower subsidies.

The second lowest dependency level is between subsidies and work injuries. Farms receiving more subsidies are usually bigger farms that are likely to have better working conditions than small farms, which may reduce work-related accidents. The correlation between subsidies and farms' environmental performance is also weak and suggests that while cross-compliance and rural development policies may have spurred farms to reduce their pollution levels, there is still substantial scope to improve subsidy design, so that more environmentally efficient firms benefit from relatively higher subsidy levels. Finally, the low correlation between subsidies and farm efficiency in generating farmers' satisfaction suggests that farmers' satisfaction with their job is not related to the subsidies received. In short, to the extent that our efficiency measures can be a proxy of farms' sustainability levels, dependency analysis results show that subsidies benefit specially the economically sustainable farms, but have a weak connection to the environmental and social sustainability. By targeting the most efficient firms in all dimensions through a payment redistribution, the CAP may be able to promote higher sustainability levels at the least cost.

4.5 Concluding remarks

This study extends Chambers & Serra (2016) measure of firm-level sustainability to allow for the stochastic conditions under which production takes place using a state-contingent approach. The overall production technology is defined as a composite of several sub-technologies representing the economic, environmental and social dimensions of production. Our model is illustrated using a farm-level dataset from a sample of Catalan farms. Empirical findings suggest that our sample farms have overall efficiency scores on the order of 77.5%. The overall efficiency is specially penalized by the poor environmental performance. Overall nitrogen pollution efficiency is on the order of 71.9%, while PHI pollution efficiency scores are around 38%. Nitrogen pollution efficiency is found to decline as growing conditions improve, which suggests that farmers are risk-averse and prepare for the worse states of nature. At the social level, farms show high efficiency scores (on the order of 88%) when it comes to injury prevention and the generation of farmer satisfaction. Our measures of farm-level sustainability can be useful for policy purposes, such as the redistribution of CAP farm payments according to how well farms perform in the different sustainability dimensions. They also show that further efforts are required both by policy makers and farmers to find more environmentally friendly production processes. Specially worrisome is the low capacity of our sample farms to use PHI efficiently.

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Table 4.1 Descriptive Statistics

	Variable description	Measurement Unit	Symbol	Mean	Std. Deviation
Inputs	Land	Hectares	x_1	72,33	55,25
	Capital	Euros	x_2	145,250.21	153,940.09
	Labor (paid and unpaid)	Hours	x_3	887,05	3 604,95
	Energy	Euros	x_4	4 428,08	4 313,45
	Seeds	Euros	x_5	3 861,27	3 076,19
	Pesticide active ingredients applied	Liters	c_d	81,23	85,09
	Nitrogen application through fertilizers and seeds	Kilograms	r_k	8 982,42	8 865,51
	Nitrogen absorbed by crops under bad conditions	Kilograms	q_1	3 235,65	2 679,60
	Nitrogen absorbed by crops under normal conditions	Kilograms	q_2	4 725,69	3 661,22
	Nitrogen absorbed by crops under ideal conditions	Kilograms	q_3	6 399,17	5 218,33
Outputs	Crop output value under bad conditions	Euros	y_1	29 413,51	25 151,39
	Crop output value under normal conditions	Euros	y_2	46 439,19	36 078,32
	Crop output value under ideal conditions	Euros	y_3	63 120,70	50 472,89
	Nitrogen balance under bad conditions	Kilograms	z_1	5 865,66	7 038,22
	Nitrogen balance under normal conditions	Kilograms	z_2	4 559,28	6 359,11
	Nitrogen balance under ideal conditions	Kilograms	z_3	3 471,60	5 569,09
	Injuries score	Score	i	97,28	6,37
	Farmer satisfaction level	Likert Scale	s	3,38	0,59
	Ecological impact of PHI	Liters	p	1 376,32	1 548,35

Table 4.2 PCA analysis results of working conditions items

Initial Eigenvalues			
Component	Total	% of Variance	Cumulative %
1	3.197	18.804	18.804
2	2.350	13.823	32.627
3	1.740	10.237	42.864
4	1.273	7.489	50.353
5	1.060	6.236	56.590
6	1.032	6.073	62.662

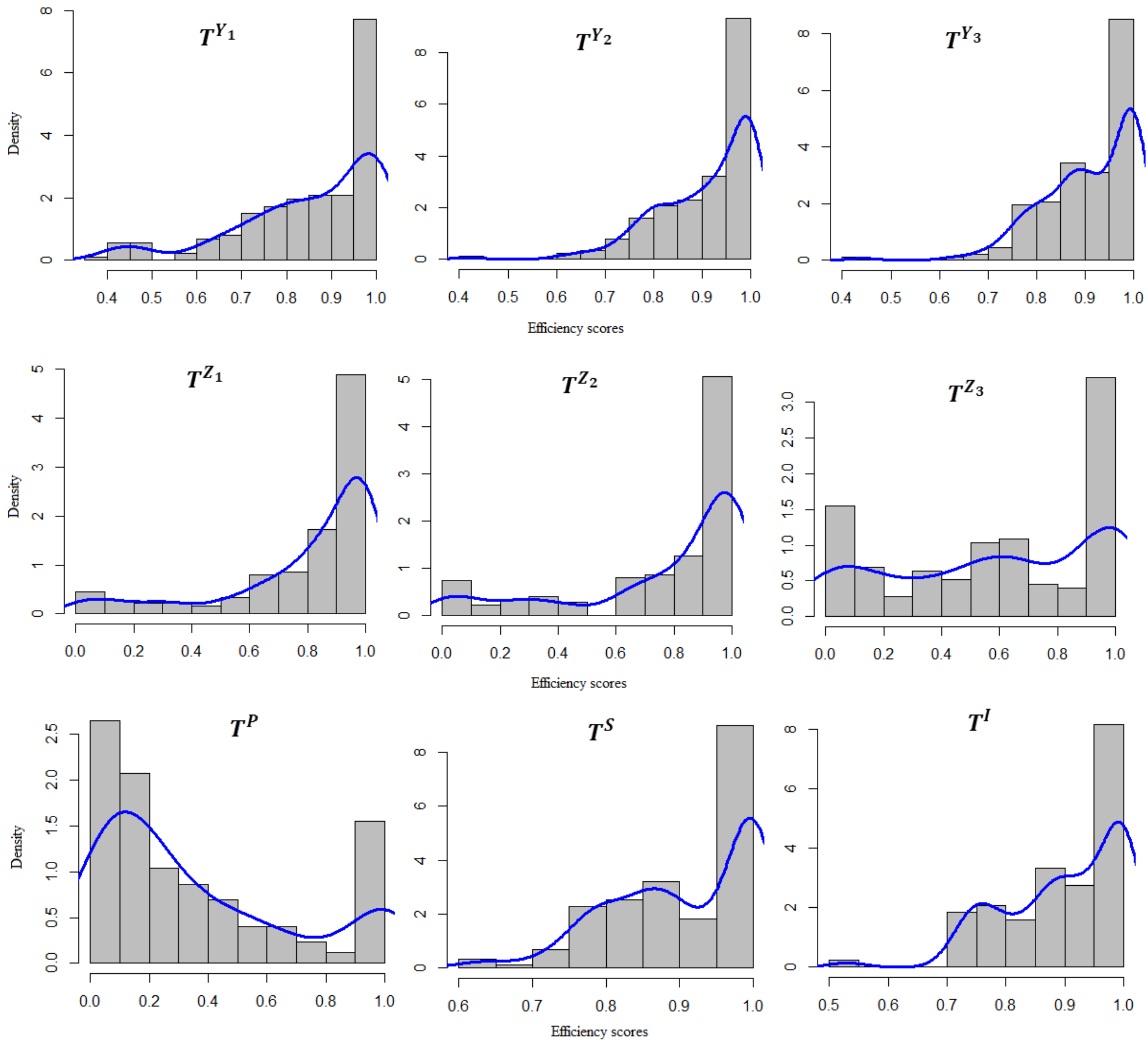
Table 4.3 Distribution of sustainability efficiency scores

Efficiency Interval	T^{Y_1}	T^{Y_2}	T^{Y_3}	T^{Z_1}	T^{Z_2}	T^{Z_3}	T^{P}	T^{S}	T^{B}
<0,1	0	0	0	8	13	27	44	0	0
0,1-0,2	0	0	0	5	4	12	26	0	0
0,2-0,3	0	0	0	4	6	5	24	0	0
0,3-0,4	1	0	0	4	7	11	14	0	0
0,4-0,5	10	1	1	3	5	9	13	0	0
0,5-0,6	2	0	0	6	0	17	8	1	2
0,6-0,7	13	5	3	14	14	19	10	5	0
0,7-0,8	28	21	21	14	14	8	5	35	34
0,8-0,9	34	38	48	30	22	7	1	51	42
0,9-1,0	85	108	100	85	88	58	28	81	95
Average	**0,855**	**0,910**	**0,908**	**0,792**	**0,765**	**0,599**	**0,380**	**0,883**	**0,899**
Average efficiency scores per sub-technology		Desirable output			Nitrogen pollution		PHI Pollution	Satisfaction	Injuries
		0,891			0,719		0,380	**0,883**	0,899
Average efficiency scores per sustainability dimension		Economic				Environmental			Social
		0,891				0,549			0,886
Overall score						**0,775**			

Table 4.4 Bivariate copula analysis results. Assessing the relationship between subsidies and efficiencies

	Copula	$Kendall's\ \tau$	λ_L	λ_U
Subsidies -T^P	BB1	0.37	0.54	0.03
Subsidies -T^S	Normal	0.05	-	-
Subsidies -T^I	Normal	0.16	-	-
Subsidies -T^Y	Frank	0.13	-	-
Subsidies -T^Z	Normal	0.13	-	-

Figure 4.1 Histogram with an overlaid kernel density estimate for the different efficiency scores



Chapter 5: Conclusions

Developing a comprehensive assessment of firm performance is a challenging task. By using advanced methodological approaches and integrating all sustainability dimensions, this thesis makes a contribution to the literature by expanding the understanding of sustainability of big corporations in different economic sectors; a relevant economic sector characterized by high degree of concentration; and finally a small and atomized sector. The thesis is integrated by three independent research articles.

In spite of the significant number of studies addressing the relationship between CSR performance dimensions, the empirical evidence is still mixed. The first research paper sheds light on this issue by using an innovative approach, the canonical vine copula model. To our knowledge, this is the first study that uses a flexible statistical copula approach for such purpose. Our empirical research is based on the ASSET4 dataset in 2012 from which we take a sample of 2,728 global firms. Our empirical findings show a strong positive relationship between three CSR dimensions: economic, social and environmental performance, suggesting that companies that integrate environmental and social concerns may improve their financial outcomes. Unlike the environmental and social performance, corporate governance performance does not appear to have a strong relationship with higher economic results. In conclusion, while integrating all CSR dimension in business practices should help the firms to become better corporate citizens, what really reduces costs and increases consumers' demand is effective adoption of environmentally friendly practices and promotion of social development.

In the second research article we focus on the U.S. electric utility industry to assess the same research question. Given the heterogeneity in the economic, environmental, social, and governance dimensions across different industries, one would expect the relationship to be different across different economic sectors (Reed, 1999), which justifies the need to approach the question within a single industry. The analysis is based on a sample of U.S. investor-owned electric utilities observed from 2005 to 2012. Results from copula analysis show that CSR activities add financial value to the firm. The relationship between non-economic CSR dimensions and financial performance appears to follow an upward trend over time, especially for the economic and corporate governance pair. Tail dependence results show that electric utilities with weak economic performance seem to be firms with poor non-economic CSR dimensions. However, electric companies that show higher financial health (upper quartiles of the distribution) do not seem to excel in the other dimensions of CSR.

In the third research paper, we study sustainability of the agricultural sector by extending the proposal by Chambers and Serra (2018) to compute technical, environmental and social efficiency measures by allowing for the stochastic nature of agricultural production. To our knowledge, no previous published work has studied agricultural production performance as an interaction of the three dimensions of sustainability. Data Envelopment Analysis is used as the technique to estimate our model. The analysis is based on farm-level data collected through a survey conducted to a sample of 173 Spanish arable crop farms in the region of Catalonia. Our empirical findings suggest that sample farms present overall efficiency scores on the order of 77.5%. The overall efficiency is specially penalized by the low pesticide, herbicide and insecticide pollution control efficiency scores of 38%. However, farms show high average social efficiency scores of 88%.

Relying on the main results of this thesis, firm management and policy implications emerge. According to these, environmental and social responsibility commitments are likely to lead to improved firm financial performance. These could be pursued through reduction of pollution, adoption of innovative environmental practices, improvements in employment quality and product responsibility. Further, our results can be relevant for policy makers, as they suggest that promotion of corporate social responsibility practices could lead to stronger economies. Our results show low levels of farm efficiency in reducing polluting inputs, which calls for action. Higher levels of sustainability may be achieved through public programs helping farmers to adequately cut down their pesticide and fertilizer use. Further, our measures of farm-level performance can be useful for redistribution of public farm payments with the objective of promoting sustainability.

Some weaknesses affecting our study as well as suggestions for future research can be pointed out. While there is scope for improved methods for further research, such as the adoption of dynamic methods in order better capture sustainability dynamics, most improvements can be achieved by improved datasets. Our analysis is mainly limited by data availability. This has prevented us from understanding more about the underlying causes and consequences of sustainability. Heterogeneity in both corporations studied in the first analysis and our sample farms in the third analysis may have influenced the results. Regarding the social sustainability, our last research paper is pioneer in that it integrates the social dimension of sustainability in performance assessment. However, for a better understanding of the social dimension, future research should clearly identify a broader range of social sustainability indicators to obtain more detailed information on this issue, which would allow for more accurate assessment of the social dimension of sustainability performance.

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