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DOCTORAL DISSERTATION

Essays on Sustainable and Dynamic Efficiency

Doctoral dissertation is submitted to obtain the degrees of Doctor of Applied Economic Science, to be defended by

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Voorwoord – Preface

Gutta cavat lapidem, non vi, sed saepe cadendo.

Een druppel holt een steen uit, niet met kracht, maar door vaak te vallen.

Dit gezegde is een van de weinige nuttige dingen die ik heb geleerd in de lessen Latijn in het middelbare onderwijs. Geduld en persistentie zijn inderdaad de sleutel tot het succesvol afronden van dit doctoraat. Desalniettemin ben ik mij ervan bewust dat heel veel mensen mij geholpen hebben tijdens (en voor) dit proces.

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Summary

The first objective of this PhD thesis is to analyze the debate on weak versus strong sustainability (WS vs. SS) for the Sustainable Value (SV) approach. The SV approach intends to allow for substitutability of resources between economic entities, while simultaneously constraining this possibility in a way such that the overall level of resource use does not damage the natural capital stock. As such, this measure has been introduced by Figge and Hahn (2004a) as in line with the WS paradigm at the individual level of the economic entity, but in line with the SS paradigm at the aggregate level. Figge and Hahn (2004a) argue that the aggregate level is more relevant than the individual level, so that the SV approach is in essence an SS measure. We analyze the SV approach for the EU-15 countries covering the period of 1995-2008 in chapter 2. Chapter 3 contributes to the methodological and conceptual debate about this measure.

Second, we use the dynamic approach to analyze profit inefficiency, technical inefficiency and allocative inefficiency. Chapter 4 provides a theoretical background of the dynamic approach. In chapter 5, we use Data Envelopment Analysis (DEA) techniques to assess the dynamic profit inefficiency for a sample of Belgian dairy farms. We decompose profit inefficiency into the contributions of input and output specific technical and allocative inefficiency. Chapter 6 analyze the impact of activity in the quota market on the DEA-inferred technical and scale inefficiency for a sample of Belgian dairy farms.

Chapter 7 discusses the connections between the SV approach used in Chapters 2-3 and a production economics approach used in Chapters 4-6. We argue that the weak conceptual connection between the WS-SS link introduced by Figge and Hahn (2004a) and the SV approach can be strengthened substantially by employing a production economics approach. We also turn to the broader discussion how sustainability indicators can be implemented rigorously in a production economics framework. We draw policy conclusions in the final section.

Samenvatting

De eerste doelstelling van deze doctoraatsthesis is het analyseren van het debat omtrent zwakke versus sterke duurzaamheid (ZD vs. SD) voor de "Duurzame Waarde" (DW)-benadering. De DW-benadering poogt om de substitueerbaarheid van inputs tussen economische entiteiten toe te laten, terwijl deze mogelijkheid tegelijk op zo'n manier gelimiteerd is dat het totale inputgebruik het natuurljke kapitaalniveau niet vermindert. De DW-benadering is geïntroduceerd door Figge en Hahn (2004a) als een method die in de lijn ligt van ZD op het niveau van de economische entiteit, maar in de lijn ligt van SD op het geaggregeerde niveau. Aangezien Figge en Hahn (2004a) beargumenteren dat het groepsniveau belangrijker is dan het individuele niveau, is de DW-benadering volgens hen in wezen een SD-methode. We analyseren de DW-beandering voor de EU-15 landen voor de periode van 1995 tot 2008 in Hoofdstuk 2. Hoofdstuk 3 draagt bij tot het methodologische en conceptuele debat over deze methode.

Ten tweede gebruiken wij een dynamische benadering om de winst-, technische en allocatieve inefficiëntie te analyseren. Hoofdstuk 4 beschrijft de theoretische achtergrond van de dynamische benadering. In Hoofdstuk 5 gebruiken wij "Data Envelopment Analysis" (DEA)-technieken om de dynamische winstinefficiëntie te berekenen van een sample van Belgische melkveehouderijen. We delen de winstinefficiëntie op in de input- en outputspecifieke technische en allocatieve componenten. Hoofdstuk 6 analyseert de impact van activiteit in de melkquotamarkt op de met DEA berekende technische en schaalinefficiëntie van een sample van Belgische melkveehouderijen.

Hoofdstuk 7 bediscussieert de connecties tussen de DW-benadering (Hoofstuk 2-3) en een productie-economieaanpak (Hoofdstuk 4-6). Wij beargumenteren dat er slechts een zwakke conceptuele connectie is tussen de DW-benadering en de ZD-SD-link geïntroduceerd door Figge en Hahn (2004a), en tonen aan dat dit substantieel versterkt kan worden met een productie-economieaanpak. Wij focussen ook op de bredere discussie hoe duurzaamheidsindicatoren rigoreus in een productieeconomiekader geïmplementeerd kunnen worden. Wij trekken besluiten omtrent beleid in het laatste deel.

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1. General Introduction

This chapter is partly taken from "Beyond the Environmentalist's Paradox and the Debate on Weak versus Strong Sustainability" (Frederic Ang and Steven Van Passel, 2012. BioScience 62: 251-259)

1.1. Integrated Performance Assessment: An Efficiency Approach

This PhD is concerned with integrated performance assessment at the country and firm level from the efficiency perspective. To this end, we use two methodologies that integrate various types of indicators into one efficiency measure: (1) the Sustainable Value (SV) approach and (2) profit, technical and allocative inefficiency. The SV approach intends to measure the contributions to sustainability by aggregating environmental, social and economic indicators. Quite some academic literature has been devoted to whether the SV approach is in line with the "Weak Sustainability" (WS) paradigm (which treats man-made capital as a substitute for natural capital) or the "Strong Sustainability" paradigm (which argues that natural capital cannot be substituted for man-made capital). This PhD will also pay attention to the link of the WS versus SS debate and both efficiency measures.

The remainder of this introduction is structured as follows. Section 1.2 describes the methodology of the SV approach. Section 1.3 elaborates on the theoretical background of profit, technical and allocative inefficiency in the production economics literature and briefly describes the empirical methodology. Section 1.4 expands on the WS versus SS debate. We link sections 1.2-1.4 in section 1.5. Finally, we sketch out the structure of the remainder of this PhD in section 1.6.

1.2. The SV Approach

The SV approach is developed by Figge and Hahn (FH, 2004a), with a conceptual explanation in FH (2005). They put forward that the SV approach is rooted in financial economics, as its rationale is that the "return on capital" should cover its "opportunity costs". The claimed novelty of the SV approach is that the opportunity costs do not only cover economic capital costs, but also environmental and social costs. Moreover, they argue that the SV approach shifts a "burden-oriented" perspective (which would presumably the case in monetary valuation of environmental and social damage) to a "value-oriented" perspective.

The SV is calculated in the following way:

(1) $$SV_i = \frac{1}{R}\sum_{r=1}^{R}\left(\frac{y_i}{x_{ir}} - \frac{y^*}{x_r^*}\right)x_{ir}$$

where SV_i is the SV of economic entity i, R is the number of considered resources, y_i is the economic output of economic entity i, y^* is the economic output of the benchmark, x_{ir} is the resource use of resource type r of economic entity i, and x_r^* is the resource use of the benchmark.

FH (2005) define y_i as the return and its opportunity cost as $\frac{y^*}{x_r^*}x_{ir}$. Since the considered resource can be economic, environmental or social, they claim that SV_i indicates the contribution to sustainability. If $SV_i > 0$, the economic entity contributes to sustainability, and *vice versa*.

The ratios clarify that this measure is efficiency-based. This is even more explicit in their definition of sustainable efficiency.[1] Sustainable efficiency is defined as follows (FH, 2005):

(2) $$SE_i = \frac{y_i}{y_i - SV_i}$$

where SE_i is the sustainable efficiency of economic entity i. The rationale is that SE_i, unlike SV_i, controls for size. In analogy to SV_i, if $SE_i > 1$, the economic entity contributes to sustainability, and *vice versa*.

[1] The terms "sustainability efficiency", "sustainable efficiency" and "return-to-cost ratio" are used by respectively FH (2005), Van Passel et al. (2007, 2009), and Hahn et al. (2010) and Ang et al. (2011). We will use these terms interchangeably throughout this PhD.

1.3. Production Economics

Production economics analyzes the transformation of inputs to outputs. First, we provide a theoretical background. Second, we describe our empirical approach to assess efficiency (*i.e.*, DEA).

1.3.1. Theoretical Background

This section discusses the theoretical background of a production economics approach. We consider (1) the set representation of the technology, (2) its representation in a directional distance function framework, and (3) its dual relationship with profit maximization, yielding a decomposition of profit inefficiency into technical and allocative components.

1.3.1.1. Technology Sets

Consider a firm that produces a vector of $n = 1 \dots N$ outputs, $y \in \mathbb{R}_{+}^{N}$, using a vector of $m = 1 \dots M$ variable inputs, $x \in \mathbb{R}_{+}^{M}$. It is convenient to represent the variable inputs and outputs as a technology set in terms of (1) the primitive characterization (the "graph"), (2) variable inputs for a given level of outputs (the "variable input requirement set"), and (3) outputs for a given level of variable inputs (the "output set").

Graph

The graph GR, *i.e.*, the set of feasible variable input-output vectors, can be defined as follows (Coelli et al., 2005; Fried et al., 2008; Kumbhakar and Lovell, 2000):

(3) $GR = \{(y, x) : x \; can \; produce \; y\}$

This is the most general representation of the technology set. We assume that the following properties hold:

G.1. GR is closed.

G.2. GR is bounded from above.

G.3. Inactivity is possible: $(0, x) \in GR$.

G.4. There is no free lunch: $(y, 0) \in GR \Rightarrow y = 0$.

G.5. Outputs are strongly disposable: $(y, x) \in GR \wedge y' \leq y \Rightarrow (y', x) \in GR$.

G.6. Inputs are strongly disposable: $(y, x) \in GR \wedge x' \geq x \Rightarrow (y, x') \in GR$.

G.7. GR is convex.

The directional distance function $\vec{D}_T(.)$ is defined as follows (Chambers et al., 1996, 1998):

(4) $$\vec{D}_T(y, x; g_y, g_x) = \max_{\beta} \{\beta : (y + \beta g_y, x - \beta g_x) \in GR\}$$

where $g = (g_y, g_x)$ with $g_y \in \mathbb{R}_+^N$ and $g_x \in \mathbb{R}_+^M$. $\vec{D}_T(.)$ measures the distance to the technological frontier in the direction of $(g_y, -g_x)$, simultaneously contracting inputs and expanding outputs. Although this measure is additive, it is thus a generalization of the more familiar ratio-based output- or input-oriented distance measures. Chambers et al. (1998) prove that $\vec{D}_T(.)$ and GR are equivalent representations.

Figure 1 shows an example of one input and one output following the properties of GR and illustrates the mechanism of the directional distance function. We choose $g_x = x$ and $g_y = y$ for this example. In this case, $\vec{D}_T(.)$ is the simultaneous maximum proportional expansion of outputs and contraction of inputs. If $\vec{D}_T(.) = 0.3$ for firm A, this means that simultaneously increasing output and decreasing input by 30% would result in $B(y^*, x^*)$, which is the corresponding efficient performance on the technological frontier.

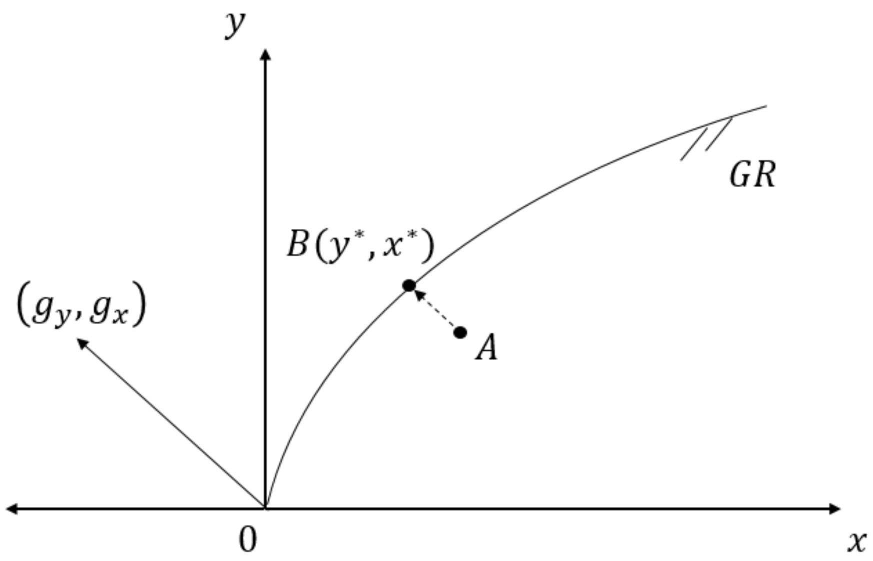

Fig.1. The directional distance function in the variable input-output space.

Variable input requirement set

The second characterization of the production possibilities describes the feasible input vectors for a given output vector as $L(y)$ (Coelli et al., 2005; Fried et al., 2008; Kumbhakar and Lovell, 2000):

(5) $L(y) = \{x: (y, x): x\ can\ produce\ y\}$

Assuming that G.1-G.7 hold and given that $L(y)$ is defined in terms of GR, the following properties hold:

L.1. $L(y)$ is closed.

L.2. $L(y)$ is bounded from below.

L.3. Inactivity is possible: $.L(0)\ \in \mathbb{R}_{+}^{M}$.

L.4. There is no free lunch: $0 \notin L(y)$.

L.5. Inputs are strongly disposable: $(y, x) \in L(y) \wedge x' \geq x \Longrightarrow (y, x') \in L(y)$.

L.6. Outputs are strongly disposable: $(y, x) \in L(y) \wedge y' \geq y \Longrightarrow L(y') \subseteq L(y)$.

L.7. $L(y)$ is convex.

Figure 2 shows a one variable input – one variable input example obeying these properties. The marginal product of each variable input is non-negative, and there are no upward sloping isoquants. Analogous to the primitive characterization in GR, it is possible to represent $L(y)$ by a directional distance function. Since the vector of outputs is held fixed, the directional vector is defined in terms of variable inputs. In our example, $g_x = (g_{x_1}, g_{x_2})$. If firm C would maximally reduce its technical inefficiency along g_x, then it would use a level of variable inputs at $E(x_1^*, x_2^*)$.

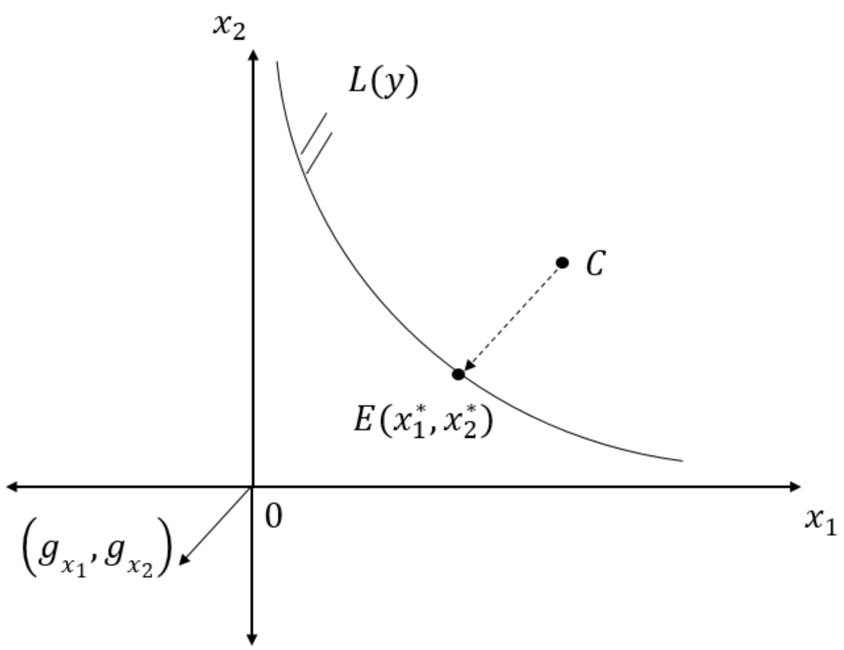

Fig.2. The directional distance function in the variable input-variable input space.

Output set

The third characterization of the production possibilities describes the feasible output vectors for a given input vector (Coelli et al., 2005; Fried et al., 2008; Kumbhakar and Lovell, 2000):

(6) $P(x) = \{y: (y, x): x\ can\ produce\ y\}$

Assuming that G.1-G.7 hold and given that $P(x)$ is defined in terms of GR, the following properties hold:

P.1. $P(x)$ is closed.

P.2. $P(x)$ is bounded.

P.3. Inactivity is possible: $P(0) \in \{0\}$.

P.4. There is no free lunch: $0 \notin L(y)$.

P.5. Inputs are strongly disposable: $(y, x) \in P(x) \wedge x' \geq x \Longrightarrow P(x') \supseteq P(x)$.

P.6. Outputs are strongly disposable: $(y, x) \in P(x) \wedge y \leq y' \Longrightarrow (y', x) \in P(x)$.

P.7. $P(x)$ is convex.

Figure 3 shows a one output – one output example complying with these properties. Again, we can represent $P(x)$ by a directional distance function. Since the vector of variable inputs is held fixed, the directional vector is defined in terms of variable inputs. In our example, $g_y = (g_{y_2}, g_{y_1})$. If firm G would maximally reduce its technical inefficiency along g_y, then it would use a level produce at $H(y_2^*, y_1^*)$.

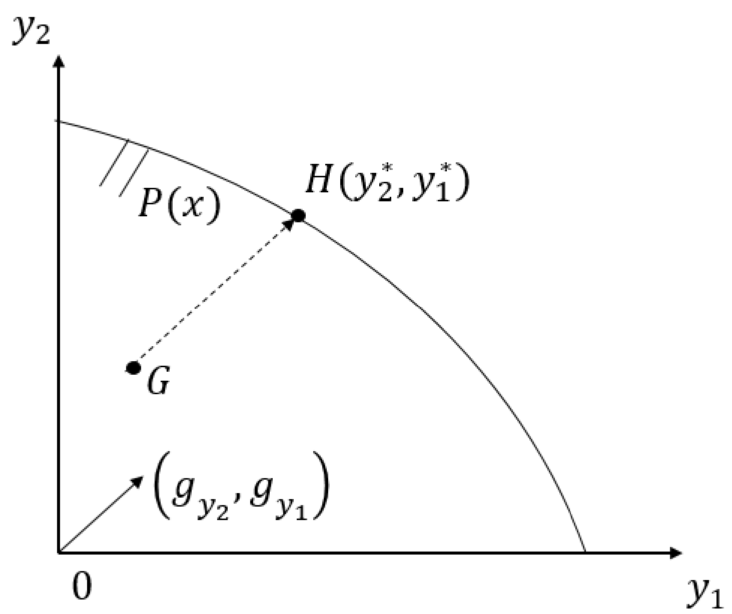

Fig. 3. The directional distance function in output-output space.

1.3.1.2. Profit Inefficiency, Technical Inefficiency and Allocative Inefficiency

Let $p \in \mathbb{R}_+^N$ be a vector of output prices and $w \in \mathbb{R}_+^M$ be a vector of variable input prices. We can define the profit maximization problem as follows:

(7) $\pi(p,w) = \max_{y,x} \{p'y - w'x: (y,x) \in GR\}$

Chambers et al. (1998) show that the profit function in (5) is dual to the directional distance function in (4). This duality allows for a decomposition of profit inefficiency PI into technical inefficiency TI and allocative inefficiency AI:

(8) $PI = TI + AI$

where $PI = \frac{\pi(p,w)-(p'y-w'x)}{p'g_y+w'g_x}$ and $TI = \vec{D}_T(.)$.

Most contributions focus on ratio-based efficiency measures. The advantage of the ratio-based approach is that the efficiency scores can be interpreted easily. If an output-oriented efficiency measure (the reciprocal of the output-distance function) yields for example a score of 0.70, the firm operates at 70% of its output capacity given its vector of inputs. Likewise, an input-distance function (the reciprocal of input-oriented efficiency) of 0.30 indicates that the firm can reduce its inputs by 30% without changing the output level. The seminal contribution of Farrell (1957) introduces the idea of decomposing overall "economic" efficiency into technical and allocative components. Shephard (1970) shows that the revenue function is dual to the output distance function, and that the cost function is dual to the input distance function. As a result, both revenue efficiency and cost efficiency can be decomposed into technical and allocative components.

However, ratio-based efficiency measures are constrained to *either* the output direction *or* the input direction. Hence these do not provide a full dual representation in the profit-maximization framework. As the directional distance framework allows for the consideration of output as well as input directions, we are able to dually link it with the profit function. The flexibility and additive nature of this family of inefficiency measures may come at the expense of a straightforward interpretation of the inefficiency scores. The researcher should therefore choose a directional vector that is suitable for the application. Nonetheless, given the importance of the behavioral assumption of profit maximization in many applications, the decomposition of *profit* inefficiency into technical and allocative components is a worthwhile endeavor.

The vast majority of studies in the production economics literature use a static approach as presented in this section, in which firms are assumed to instantaneously adjust inputs and outputs to their long-run optimal levels. However, firms often incur costs when adjusting the quantity of quasi-fixed inputs. Such adjustments may negatively affect production in the short run, but are necessary to enhance productivity in the long run.

1.3.2. Data Envelopment Analysis[2]

The frontier that determines the best performance benchmark is largely assessed in two ways in the literature. Parametric approaches determine the frontier through statistical estimation by imposing a functional form (e.g., Cobb-Douglas and translog). Recent applications of "Stochastic Frontier Analysis" (SFA) to the agricultural sector can be found in Barnes (2008) and Areal et al. (2012). Non-parametric approaches use linear programming techniques to determine the frontier. Recent applications of "Data Envelopment Analysis" (DEA) to agriculture can be found in Atici (2012) and Barnes et al. (2011).

Both approaches are well-represented in the literature. Since SFA relies on assumptions about the functional form, its misspecification will lead to biased estimates. Moreover, implementation of SFA can be practically difficult if more complex functional forms are assumed.

This PhD uses DEA, as it does not suffer from this problem since it essentially does not use a functional form to construct the frontier. However, it is highly sensitive to outliers (Coelli et al., 2005; Reinhard et al., 2000). Notwithstanding the conceptual critiques on both sides, most studies show a high rank correlation between the efficiencies obtained by SFA and DEA (Van Meensel et al., 2010). Moreover, a recent Monte Carlo simulation study shows that, depending on the assumptions, both methods perform adequately (Andor and Hesse, 2014).

1.4. Weak versus Strong Sustainability

Since the publication of Our Common Future by the World Commission on Environment and Development (WCED) in 1987, the notion of sustainable development has come to the fore in political discussions. The WCED advised a "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 43). This widely accepted description of sustainable development (Kates

[2] This section draws heavily from an (unpublished, internal) scoping study that I have conducted as lead author (with Simon Mortimer, Francisco Areal and Richard Tiffin) within the "Sustainable Intensification Platform" at the University of Reading.

et al., 2005) takes human well-being as a central concept. Although this definition implies a focus on both intragenerational and intergenerational equity, we will only consider the latter in this thesis. The concept of nondeclining human well-being will therefore be our main concern with regard to sustainable development.

Environmentalists generally assume that ecological deterioration will (eventually) lead to declines in human well-being. Economists have studied the relationship between nature and human well-being throughout history (Perman et al., 2003, Common and Stagl, 2005). In 1798, the classical economist Thomas Malthus doubted in his Essay on the Principle of Population that economic growth would be everlasting in the presence of natural constraints. Assuming a fixed stock of land, he argued that population would increase exponentially while food supply could only grow linearly. This might cause a long-term decrease of unit output per capita over time. The eventual number of living people would be driven down to a stationary-state subsistence level. Later, as a result of the vast improvements in living standards during the Industrial Revolution, the pessimistic Malthusian outlook was replaced by the more optimistic neoclassical economic theories. Neoclassical economists considered scarcity a relative issue rather than an absolute one. As a result, they believed that nature does not put any absolute limits on the improvement of well-being.

Only in the 1970s did the environment reclaim a prominent role in economic analysis. On one hand, natural-resource economists study the economic activity–induced flow of natural resources from the environment to the economy (Callan and Thomas, 2000). With their theories, they mainly search for the economically efficient and optimal depletion of natural resources. Moreover, they also consider amenity inputs from the natural environment and the feedback effects of pollution on well-being. On the other hand, environmental economists generally study the flow of residuals coming from the economy to the environment (Callan and Thomas, 2000). Basically, they concentrate on residuals that have undesired effects on the environment.

To put it simply, natural-resource and environmental economists consider natural resources important determinants for an economy. Nevertheless, both natural-resource economics and environmental economics are still conceptually in line with neoclassical theories, because in these fields, it is argued that the economy and the natural environment are distinct entities (Common and Stagl, 2005).

Ecological economists perceive connections between nature and economics as essential. They do not deny the importance of monetarily valuing pollution and natural resources, as did the neoclassical economists. Their starting point, however, is the acknowledgement that the economy is a subsystem within the environment (Common and Stagl, 2005). Ecological economics arises out of the understanding that since the 1970s, human economic activities appear to have had such a negative impact on nature that future generations could be made economically worse off. The main objective of this relatively new field is to tackle these problems (Perman et al., 2003), and ecological economists usually agree with environmentalists that the natural environment could put limits on the improvement of human well-being.

Because most environmentalists (and ecological economists) on one hand and neoclassical economists on the other hand ultimately share the WCED goal of the improvement of human well-being, both groups view the problem of environmental degradation from an anthropocentric perspective (Jamieson, 1998). However, this dichotomy of academic traditions yielded a fundamental disagreement about the relationship between nature and human wellbeing. Since the upswing of ecological economics in the middle of the 1990s, a serious debate on the link between environmental damage and well-being has been conducted in formalized, economic terms. The dispute essentially boils down to the belief in the ability of natural capital (natural resources such as crude oil, gas, forests, and fisheries) and human-made capital (e.g., production plants, equipment and infrastructure, but also the stock of learned and disembodied skills and knowledge) to be substituted for one another. Whereas weak sustainability (WS) supporters (primarily natural-resource and environmental economists) are more optimistic concerning the interchangeability of natural and human-made capital, strong sustainability (SS) adherents (chiefly ecological economists and environmentalists) are more pessimistic about this possibility (Perman et al., 2003; Neumayer, 2010). In spite of the differences between neoclassical economics and ecological economics, these fields seem to converge, as evidenced by recent analyses of citations and contents (Illge and Schwarze, 2009; Plumecocq, 2014).

Weak versus strong sustainability

One could observe the relationship between man and nature through the lens of natural-capital stock yielding ecosystem services, which eventually affects human well-being. Capital is seen as a key concept in ensuring well-being and should therefore not decline over time. Capital is "the stock that possesses the capacity of giving rise to flows of goods and/or services" (Ekins et al., 2003, p. 166). Natural capital represents the ecosystem structures and processes that provide ecosystem functions (regulation, habitat, production, and information), which yield several natural goods and ecosystem services (de Groot et al., 2002). The WS–SS debate since the 1990s has held a focus on the substitutability of natural capital. We elaborate on the notions of WS and SS below.

Weak sustainability. Supporters of WS suggest that natural capital and human-made capital are, in general, interchangeable with respect to well-being improvement (Dietz and Neumayer, 2007). This means that depletion of one form of capital can be compensated by a surplus of the other one. The WS concept originates in the 1970s as a by-product of neoclassical economic theories used in the search for an optimal extraction path for nonrenewable natural resources. Dasgupta and Heal (1974) claimed that because of a positive utility-discount rate and the scarce nature of nonrenewable resources, consumption would fall to zero in the long run. In order to avoid this undesirable outcome and instead to achieve sustained well-being over time, Solow (1974) asserted that early generations may extract exhaustible resources in an optimal way, as long as they add optimally to the stock of reproducible capital. Hartwick (1977) refined this statement and proposed the savings investment rule (now known as the Hartwick rule). According to this rule, the rents (defined as the difference between the price at which one can sell the concerned resources and all associated costs) from exhaustible resource depletion should be saved and reinvested in produced capital in order to achieve nondeclining consumption. The Hartwick rule is in fact the statement of WS: If resources are optimally extracted, reinvestment may offset these losses so that the total capital stock will not fall over time. As a result, natural capital and human-made capital are generally substitutes for each other from the WS perspective.

For WS advocates, monetary valuation of natural resources, ecosystem services and future environmental damage is the most important objective. The WS paradigm supposes that sufficient technological progress can improve human wellbeing despite environmental damage.

The initial strong-sustainability stance: Maintaining the economic value of natural capital. The SS paradigm originates as a countermovement to the neoclassical WS paradigm. Adherents of SS argue that natural and human-made capital may be regarded as substitutes for each other in an "empty" world in which human-made capital is limiting and natural capital superabundant. However, in the current "full" world, natural and human-made capital should be regarded as complements, because natural capital is becoming the limiting factor and human-made capital the superabundant one.

Therefore, from the perspective of SS supporters, natural capital should be maintained (Daly, 1995). Contrary to the WS advocates, SS adherents are generally pessimistic with regard to the possibility of technological progress. Daly (1995) furthermore argued that SS does not mean that "no species could ever go extinct, nor any nonrenewable resource should ever be taken from the ground, no matter how many people are starving," and dismissed this idea as "absurdly strong sustainability" (p. 49). SS refers to the separate protection of the different natural capital forms. From this perspective, the value of natural capital should not decline. Unlimited replacements within natural capital are assumed possible. The rents from oil extraction could, for example, be partly invested in future energy provision (Dietz and Neumayer, 2007). As in the case of WS, natural capital should then be measured in monetary terms (Hanley, 2000).

Strong sustainability through the determination of critical natural capital. The two paradigms described above have in common that they take an economic perspective with respect to natural capital, in the sense that it could be monetarily valued. This perspective is, however, increasingly contested. According to Douai (2009), two implicit assumptions could prove troublesome. First, monetary valuation of the environment presumes commensurability of environmental values (i.e., all different kinds of human wants can be translated into monodimensional utility). Second, one supposes the commodification of natural resources (i.e., this utility can be transformed into monetary values). For these two reasons, several authors have advocated the noncompensability of the environment (e.g., Munda, 1997; Spash, 1999; Trainor, 2006). This line of reasoning constitutes another strand within ecological economics that puts a particular emphasis on discussing natural capital in *physical* instead of in *monetary* terms (Özkaynak et al., 2004). This interpretation of SS implies that an essential physical subset of natural capital must be preserved, because this critical natural capital (CNC) cannot be substituted for by any form of human-made capital (de Groot et al., 2002; Chiesura and de Groot, 2003). Consequently, neither substitutions between natural capital and human-made capital nor substitutions among different forms of CNC are permitted under this point of view. This viewpoint of SS therefore allows for environmental damage only if environmental functions irreplaceable by human-made capital are not affected.

1.5. The WS-SS Debate: An Efficiency Perspective

The original Sustainable Value Approach. FH (2004a) intended to bring a breath of fresh air in the polarizing WS-SS debate. One of their main arguments is that the focus of WS-SS debate has almost exclusively been on the *substitutability* of resources. In this light, they developed the "Sustainable Value (SV) approach", which concentrates on the *allocative* properties of the capital forms instead of their substitutability.

The SV approach intends to optimize the resource use of the group of considered economic entities given a predetermined (environmental) resource use level (e.g., CO_2 emission) that does not deteriorate the natural capital stock (in line with the SS paradigm), while allowing for substitutability of resources at the level of the individual economic entity (in line with the WS paradigm of efficiency measures). Because the group level is in their opinion more important than the individual level, FH (2004a, 2009) argue that the SV approach is effectively an SS measure, even though it is an efficiency-based measure. According to FH (2004a), classical efficiency measures assume that bad performance of one resource may be compensated by good performance of another resource in calculating the efficiency score. In contrast to classical efficiency measures that follow the WS paradigm, FH (2004) argue that the SV approach is conceptually in line with the SS paradigm.

Introducing a measure with WS properties at the individual level and SS properties at the group level has several advantages. First, it bridges two streams of literature with different schools of thought. This could encourage the dialogue between ecologists and economists and improve our understanding of sustainability. Second, SS is indeed arguably more important more aggregate levels than the individual level. This holds especially for pollutants that do not have a localized environmental impact. The set-up of a resource reallocation scheme with correct financial compensation while keeping the natural capital stock intact is interesting for policy makers.

A production efficiency perspective. Eq. (1) shows that the SV approach is an efficiency-based measure. Several authors have proposed to extend the SV approach with techniques from production efficiency theory. Section 1.4 clarifies that production efficiency theory is essentially concerned with measuring the performance of firms or industries. This is done by comparing the performance of the economic entity with the performance of a benchmark. The hypothetical performance of the benchmark is estimated parametrically or non-parametrically. While earlier applications focused on transformations of conventional inputs to conventional outputs, the implementation of non-conventional environmental inputs and outputs have recently gained interest. The combination of benchmarking and implementation of environmental (and social) indicators within an efficiency framework seems like a natural extension of the SV approach. The two first extensions by Van Passel et al. (2009) and Kuosmanen and Kuosmanen (KK, 2009a) included stochastic frontier techniques to parametrically estimate the benchmark technology.

Despite the appreciation of the intentions of the SV approach, KK (2009b) have thoroughly criticized the SV methodology for lacking sound statistical properties. In particular, they argue that the methodology is very likely to yield biased estimates due to a naïve assumption of a linear production function which is moreover estimated by single observations. They also put forward that the SS criterion is violated as the resources are perfectly substitutable.

FH (2009) responded that KK (2009b) wrongly specifies the underlying theory. In contrast to the production economics perspective of KK (2009b), the SV approach has been developed from the viewpoint of financial economics. They restate that the SV approach holds to the SS paradigm at the aggregate ('societal') level.

1.6. General Objective and Outline of Thesis

Although the efficiency perspective in the WS-SS debate is in our opinion an interesting development in the literature, section 1.5 clarifies that its validity seems to be contested. More specifically, both the SV approach and classical production efficiency measures are criticized at the methodological and conceptual level.

Moreover, the vast majority of studies in the production economics literature use a static approach as presented in section 1.3.1, in which firms are assumed to instantaneously adjust inputs and outputs to their long-run optimal levels. However, firms often incur costs when adjusting the quantity of quasi-fixed inputs. Such adjustments may negatively affect production in the short run, but are necessary to enhance productivity in the long run.

This PhD thesis mainly contributes to the literature in two ways:

1. We shed light on whether the SV approach is a WS or SS measure.
➔ Chapters 2-3
2. We use the dynamic approach to analyze profit inefficiency, technical inefficiency and allocative inefficiency.
➔ Chapters 4-6

The remainder of this thesis is structured as follows. Chapter 2 provides a macroeconomic application of the SV approach to the EU-15 countries and discusses the drivers of SV. In chapter 3, we methodologically discuss the limitations and possibilities of the SV approach. Chapter 5 provides a theoretical background on the dynamic approach. We analyze dynamic profit inefficiency and its decomposition in technical and allocative components for a sample of Belgian dairy farms in chapter 5. Chapter 6 assesses the impact of activity in the milk quota market on efficiency for the Belgian dairy sector. Chapter 7 discusses the findings of chapters 2-6 and draws conclusions.

2. An aggregate resource efficiency perspective on sustainability: A Sustainable Value application to the EU-15 countries

This chapter is taken from Ecological Economics 71: 99-110 (Frederic Ang, Steven Van Passel and Erik Mathijs; 2011)

Abstract

The Sustainable Value approach integrates the efficiency with regard to environmental, social and economic resources into a monetary indicator. It gained significant popularity as evidenced by diverse applications at the corporate level. However, its introduction as a measure adhering to the strong sustainability paradigm sparked an ardent debate. This study explores its validity as a macroeconomic strong sustainability measure by applying the Sustainable Value approach to the EU-15 countries. Concretely, we assessed environmental, social and economic resources in combination with the GDP for all EU-15 countries from 1995 to 2006 for three benchmark alternatives. The results show that several countries manage to adequately delink resource use from GDP growth. Furthermore, the remarkable difference in outcome between the national and EU-15 benchmark indicates a possible inefficiency of the current allocation of national resource ceilings imposed by the European institutions. Additionally, by using an effects model we argue that the service degree of the economy and governmental expenditures on social protection and research and development are important determinants of overall resource efficiency. Finally, we sketch out three necessary conditions to link the Sustainable Value approach to the strong sustainability paradigm.

2.1. Introduction

Since the beginning of the nineties, an ardent discussion between adherents of Weak Sustainability (WS) and followers of Strong Sustainability (SS) is very prominent in the sustainability literature (Perman et al., 2003). An essential concept in this respect is the "constant capital rule" as a measure of sustainability (Solow, 1974). This rule imposes the capital stock consisting of man-made, human, natural and social capital to be at least constant over time in order to achieve sustainable development. The WS versus SS debate boils down to the following question: Can another form of capital for example offset potential natural capital losses or does natural capital need a special protection (Dietz and Neumayer, 2007)? If perfect substitutability is assumed to be possible, the WS paradigm is followed. Applications include the Environmentally Adjusted Gross Net Product (eaGNP; Repetto et al., 1989), the Genuine Savings (GS; Pearce and Atkinson, 1993) and the Index of Sustainable Economic Welfare (ISEW; Dietz and Neumayer, 2007). On the other hand, adherents of SS reject to at least some extent the possibility of perfect substitution of different kinds of capital. The Ecological Footprint (Wackernagel and Rees, 1996 and Wackernagel and Rees, 1997), the Material Flow Account (Dietz and Neumayer, 2007) and the Hybrid Indicators (Hueting, 1980) are well-known examples of SS measures. For an excellent overview of WS measures and SS measures, we refer to the work of Dietz and Neumayer, 2007 and Neumayer, 2010.

In the light of this WS versus SS debate, Figge and Hahn, 2004a and Figge and Hahn, 2004b (henceforth FH) frame this discussion from an allocative perspective instead of the classical substitutability angle. Figge and Hahn, 2004a and Figge and Hahn, 2004b present a sustainability measure that integrates economic, environmental and social resources into one monetary measure at the corporate level: the Sustainable Value (SV) approach. With the SV approach, Figge and Hahn, 2004a and Figge and Hahn, 2004b intend shifting the debate from an If-question (if a resource should be used at all) toward a Where-question (where a resource should be allocated if one has decided it could be used). The SV approach is based on opportunity cost thinking: it essentially compares the overall resource efficiency of the company to the overall resource efficiency of a predefined benchmark. Figge and Hahn, 2004a, Figge and Hahn, 2004b and Figge and Hahn, 2009 argue that the method is an application to the strong sustainability (SS) paradigm in the sense that the overall amount of resources that is being used remains at least constant at the benchmark level.

Curiously, exactly the SS feature of the SV approach has recently been subjected to serious criticism by Kuosmanen and Kuosmanen (henceforth KK, 2009a). KK (2009a) put forward that the SV approach is not conceptually in line with the SS paradigm. Following KK (2009a), due to the implicit use of linear production functions, the considered resources are in fact interchangeable so that the SV approach should be seen as a WS measure.

Note that the SV approach has also several other points of discussion. First, the SV method does not signify whether the overall resource use follows a sustainable path (FH, 2004a). In other words, the benchmark could be selected in such a way that it does not determine sustainable resource use. Second, the outcomes of the SV approach are constrained by the availability of the data. More specifically, quantification of indicators must be feasible (Hahn et al., 2007). This leads to considerable bias towards environmental resources (Ang and Van Passel, 2010). Third, as for other eco-efficiency measures, activities higher on the value chain are not included so that a high SV can still mean that environmentally harming activities in other companies earlier on are not taken into account (Schmidt and Schwegler, 2008). Finally, the use of benchmarks is heavily discussed (see Figge and Hahn, 2009 and Kuosmanen and Kuosmanen, 2009a with clarifying remarks in chapter 3).

Although the SV approach sparked several heated discussions, it is nonetheless fairly popular as evidenced by applications to the oil company British Petroleum (FH, 2005), Flemish and Finnish farms (Van Passel et al., 2007, Van Passel et al., 2009 and Kuosmanen and Kuosmanen, 2009b, respectively), the automobile production sector (Hahn et al., 2009), European manufacturing companies (ADVANCE-project, 2006 and Hahn et al., 2007) and German firms (Hahn et al., 2010).

We thus identify two gaps in the literature about the SV approach. On the one hand, the debate whether the SV approach should be regarded as a WS or SS measure is currently rather inconclusive. This issue however deserves further study as FH (2004a) exactly intend to bring a fresh wind in the WS versus SS debate. On the other hand, the SV approach has so far only been applied at the company level and not at the country level. Due to its integrative strength and its straightforward methodology and interpretation, a macroeconomic application of the SV approach could in our opinion provide interesting insights. Moreover, the allocative value-oriented perspective of the SV approach may complement current popular sustainability measures at the country level. Classical eco-efficiency measures lack the possibility of integrating multiple resources, while measures such as the eaGNP, GS and ISEW involve complex and disputable pricing procedures of environmental damage (FH, 2004a). In addition, SS applications at the country level such as the Ecological Footprint generally do not consider the economic performance, although this is clearly one of the objectives of the WCED (1987).

Consequently, this paper addresses two research questions: (1) "What can we learn from an empirical application of the SV approach at the country level?" and (2) "Is the SV approach a WS or SS measure?" An application to the EU-15 countries can tackle these two questions simultaneously due to the allocative nature of the SV approach. The EU-15 countries have to comply more and more with environmental, social and economic directives which are regulated at the European level. The SV approach allows us to compare the overall resource efficiency of the EU-15 countries to the overall resource efficiency of not only the corresponding national targets, but also the European targets and the performance of the EU-15 as a whole. Moreover, the use of EU-15 data is suitable to observe whether the SV approach adheres to the WS or SS paradigm, as the WS versus SS debate is mainly conducted on applications at the macroeconomic scale (see for example Neumayer (2010)). Concretely, we assess the use of three environmental resources (CO2-eq, acidification equivalents and municipal waste), two social resources (absolute unemployment and work accidents) and one economic resource (gross capital stock) in combination with the GDP for all EU-15 countries from 1995 to 2006 in the light of three benchmark alternatives.

This paper is further structured in the following way. Section 2 describes the methodology of the SV framework and determines the countries, resources and benchmarks to which we apply the SV approach. In addition, in order to gain interpretive power, we show the data and methodology of an econometric model to explain the overall resource efficiency performances of the EU-15. The results and discussion with an additional focus on the WS versus SS debate are presented in Section 3. Section 4 concludes the paper.

2.2. The Sustainable Value Approach

The SV methodology extends the logics of the financial market to eco-efficiency theory (Figge and Hahn, 2004a and Figge and Hahn, 2004b). The rationale is that one faces a very similar pricing problem in monetary sustainability assessment: how does one valuate resources that are not explicitly priced? Usually, one concentrates on the burden by internalising external environmental damages through complex pricing procedures. In contrast, the SV approach focuses on the value. Essentially, it introduces opportunity cost thinking to sustainability assessment: if the return an economic entity achieves through the use of resources exceeds the opportunity cost of these resources, then this economic entity contributes to sustainable resource use at the benchmark level. The opportunity cost indicates how much return the benchmark alternative would create with the same set of resources. The return of the economic entity and the return of the benchmark are then compared (Hahn et al., 2010). The SV approach accounts for how much value has been created as a result of the economic entity using the resources instead of the benchmark. It indicates how efficiently resources are being allocated between different economic entities (Figge and Hahn, 2004a and Figge and Hahn, 2004b).

In this section, we first formally describe the methodology of the SV approach. Then, we illustrate the data and variables which we will use. Finally, we present the methodology of an econometric model with the corresponding data which would serve to search for specific drivers of overall resource efficiency.

2.2.1. Methodology

KK (2009a) summarised the original SV methodology of Figge and Hahn, 2004a and Figge and Hahn, 2005 in the following way:

(1) $$SV_i = \frac{1}{R}\sum_{r=1}^{R}\left(\frac{y_i}{x_{ir}} - \frac{y^*}{x_r^*}\right)x_{ir}$$

where SV_i represents the SV of the economic entity i, R the number of considered resources, y_i the return of the economic entity i, y^* the return of the benchmark, x_{ir} the resource use of the economic entity i and x_r^* the resource use of the benchmark.

The economic entity creates a positive SV if its overall resource efficiency exceeds the overall resource efficiency of the benchmark. Following FH (2004a), such an economic entity contributes to a more sustainable resource use at the benchmark level.

We note that we so far have not taken into account the size of the economic entity. Due to the scale effect, however, larger countries tend to yield a higher absolute SV and vice versa. Therefore, FH (2005) propose the Return to Cost Ratio (RCR). The RCR compares the return of the country to the return that the benchmark would have created with the resources of the economic entity (opportunity costs). The RCR is expressed as follows:

(2) $$RCR_i = \frac{y_i}{y_i - SV_i}$$

The RCR compares the return of the economic entity to the return that the benchmark would have created with the resources of the economic entity (opportunity costs). From an interpretative point of view, RCR_i represents the factor by which the economic entity i acts more efficiently than the benchmark.

As the RCR is an aggregate measure, it does not indicate whether the variation of return, the resource use and/or the benchmark drives a shift in RCR. Although the SV approach can indicate how efficiently an economic entity uses its resources overall, it does not show how this SV is achieved. An economic entity may obtain a high positive RCR by offsetting high resource use with substantial growth of return. Moreover, it is also possible that low efficiency with regard to one resource is compensated by a higher efficiency with regard to another resource. A more detailed analysis of the underlying data, however, is necessary to see whether countries are able to really delink their resource use from economic growth. Therefore, we conduct such an analysis for our results. To discover which components exactly play an important role, Hahn et al. (2010) put forward that three according dynamic effects can be distinguished.

The return effect $E_{return,i}$ specifies the percentage change by which the RCR of economic entity i alters between t_0 and t_1 due to a change of return in the same period. Formally, this is calculated in the following way:

(3) $$E_{return,i} = \left[100 \times \left(\frac{[y_i]_{t_1} - [y_i]_{t_0}}{[y_i]_{t_0}}\right)\right]\%$$

with $[y_i]_{t_0}$ and $[y_i]_{t_1}$ the return of the economic entity i at t_0 and t_1, respectively. An increase of the return in which $E_{return,i}$ is higher than zero leads to improvements of the SV and RCR of the economic entity.

In addition, the resource effect $E_{resource,i}$ designates the percentage shift by which the RCR of economic entity i varies between t_0 and t_1 because of a change of the use of resource r in the same period. This effect is assessed as follows:

(4) $$E_{resource,ir} = \left[100 \times \left(\frac{[x_i]_{t_1} - [x_i]_{t_0}}{[x_i]_{t_0}}\right)\right]\%$$

with $[x_i]_{t_0}$ and $[x_i]_{t_1}$ the use of resource r by the economic entity i at t_0 and t_1 respectively. An increase of resource use in which $E_{resource,i}$ is higher than zero contributes to decreasing the SV and RCR of the economic entity.

Finally, the benchmark effect $E_{benchmark,r}$ specifies the percentage change by which the RCR varies between t_0 and t_1 due to a change of the benchmark efficiency with regard to resource r in the same period. This is formalised in the following way:

(5) $$E_{benchmark,r} = \left[100 \times \left(\frac{\left[\frac{y_r^*}{x_r^*}\right]_{t_1} - \left[\frac{y_r^*}{x_r^*}\right]_{t_0}}{\left[\frac{y_r^*}{x_r^*}\right]_{t_0}}\right)\right]\%$$

where $\left[\frac{y_r^*}{x_r^*}\right]_{t_0}$ and $\left[\frac{y_r^*}{x_r^*}\right]_{t_1}$ represent the benchmark efficiency with regard to resource r at t_0 and t_1, respectively. An increase of benchmark efficiency in which $E_{benchmark,r}$ is higher than zero makes it more difficult for all economic entities to improve their SV and RCR.

Compared to Hahn et al. (2010), we explain these effects in a similar albeit slightly different way. Concretely, we express all effects not in terms of factors but in terms of percentage changes. We have several reasons to make this choice. Percentage changes seem more suitable than factors in light of interpretation. The multiplication of the three effects then result into the RCR change expressed as a factor. For this, the resource effect and the benchmark effect are calculated by comparing the outcome at time t_0 to the outcome at time t_1 (we compare the outcome at time t_1 to the outcome at time t_0). Here, the benefits of clearly observing the relationship between the three effects and the RCR change outweigh the limitation in terms of interpretation (one intuitively wants to compare the new performance to the old one, while this is not the case with regard to the resource effect and the benchmark effect). As we use multiple (six, see next part) resources instead of one, this multiplication is not valid and involves weighting according to not only the relative changes of resource use, but also to the absolute changes. The relationship between the three effects and the RCR change is as a result less straightforward in our study. Therefore, we opt for expressing the shifts in percentage changes effects.

2.2.2. Data and Variables

There are four issues concerning the application of the SV methodology (Figge et al., 2006): (1) the choice of economic activity or entity, (2) the choice of resources, (3) the choice of the return figure and (4) the choice of benchmarks. We describe each of these issues in the next section.

2.2.2.1. Choice of Economic Entity

We consider the SV method for the EU-15 countries (i.e., the states that were already a member of the EU before 1 May 2004: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden and the United Kingdom) from 1995 to 2006. The data concerning these nations are accurately and readily available on several internet databases.

2.2.2.2. Choice of Resources

Adhering to the three-pillar approach towards sustainability suggested by the WCED (1987), we implement environmental (3), social (2) and economic (1) resources in our SV assessment. Note that this shows an important imbalance biased towards environmental resources and against economic resources. As the SV approach inherently tends to favour environmental resources (Ang and Van Passel, 2010), we try to approximate the environmental impacts (which are aggregations of the environmental substances) instead of the environmental substances itself. Furthermore, we remark that this is somewhat analogous to classic textbook macroeconomics in which one relates the economic output to intermediates (environmental resources), labour (social resources) and capital (economic resources), respectively (e.g., Mankiw, 2010).

As for environmental resources, we largely follow the suggestions of the ADVANCE-project (2006), choosing emissions of CO_2-equivalents (CO_2-eq), acidification equivalents and municipal waste generation[3]. The gas emission data and the data on municipal waste generation can be found in EEA (2010a) and EUROSTAT (2010a), respectively.

First, we assess the emissions of CO_2-eq (in tonnes). It is widely accepted that excessive greenhouse gas emissions (i.e., CO_2, CH_4, fluorinated gases, HFCs, N_2O, PFCs, SF_6) are the main drivers of the current global warming effect, having severe consequences for Earth's ecosystem (Bates et al., 2008). The gases are expressed in tonnes of CO_2-eq, implying that non-CO_2 gases are weighed by their global warming potential (United Nations et al., 2005).

Second, we evaluate the acidifying pollutants (i.e., NO_x, SO_x and NH_3). Acidifying pollutants can damage human health and environment (EEA, 2010b). We weigh

[3] The ADVANCE-Project (2006) suggests the following indicators with respect to natural resources: Carbon dioxide (CO_2) emissions, Methane (CH_4) emissions, Nitrogen oxides (NO_x) emissions, Sulphur oxides (SO_x) emissions, Volatile organic compounds, water use and waste generation.

the pollutants by their acidifying potential with the procedure of the United Nations et al. (2005).

Third, we include the municipal waste generation (in tonnes). Waste disposal has the potential to cause health and environmental impacts as harmful substances may infiltrate in air, surface water and groundwater (EEA, 2010c).

With respect to social resources, we take into account the number of work accidents (i.e. accidents which cause four days of absence or more). In addition, we consider the absolute levels of voluntary and involuntary unemployment (i.e. the total number of people between 15 and 64 years old not working (and not only those registered as unemployed) and. The data can be found in EUROSTAT (2010b) and AMECO (2009), respectively[4]. The seminal report *Our Common Future*, in which the most common definition of sustainable development is defined, states employment as a driver of sustainable development (WCED, 1987). From the resource efficiency perspective, Callens and Tyteca (1999) in addition put forward that the directionality of a resource (i.e. whether the resource concerned should be seen as a positive or negative impact) depends on its context, explicitly mentioning labour as an example. Although an optimal efficiency with respect to labour would mean a minimum number of employed persons for a maximum economic output from a microeconomic point of view (Varian, 2006), we argue that this is not a goal at the macroeconomic level. In the light of sustainable development, a country should thus pursue a high employment rate as this enhances national economy and social cohesion (European Commission, 2000). As a result, we consider the "unemployment efficiency" (i.e. the GDP per unemployment) as one of our two social efficiencies. We remark that this resource choice may be regarded as somewhat arbitrary, as one could argue in favour of labour efficiency instead of unemployment efficiency. However, unemployment should in our opinion be seen as a negative impact that should be minimised. One should consequently strive for attaining the maximum

[4] We calculate the absolute voluntary and involuntary unemployment by subtracting the total employment between 15 and 64 years old from the total population between 15 and 64 years old.

labour capacity from the perspective of sustainable development at the macroeconomic level.

Finally, we take into account the capital use in the SV analysis to cover the use of economic resources. Concretely, we measure this by the national gross capital stock at constant 2000 market prices. The data can be found in the AMECO (2009) database of the European Commission[5].

2.2.2.3. Choice of Return Figure

At the level of the economic entity, the gross value added is chosen as return figure in most studies (e.g., ADVANCE-project, 2006, Hahn et al., 2007, Van Passel et al., 2007 and Van Passel et al., 2009). Translated to the country level, we therefore select the Gross Domestic Product (GDP) as our return figure. More concretely, we use the GDP at constant 2000 market prices (in €) to correct for inflation. These data can be found in the AMECO (2009) database.

2.2.2.4. Choice of Benchmarks

The choice of benchmarks must reflect sound judgement as it determines the opportunity costs that the country must overcome to create sustainable value, eventually affecting the explanatory power of the analysis (FH, 2005). We use the SV approach for three benchmark alternatives keeping this in mind. Furthermore, we examine those in line with the benchmark discussion of Hahn et al. (2010).

The first benchmark alternative uses the overall EU-15 performance for each year as the benchmark efficiency to overcome (Table 1 shows the total EU-15 performance of 1995). By using the average return on resources, we thus take the investor's perspective. In this case, the SV approach gives an overview of how efficiently the resources are allocated compared with the "EU-15 portfolio" as a whole (Ang and Van Passel, 2010). Note that the yearly SV and RCR of the overall EU-15 economy per definition equal to zero and unity respectively for this benchmark. According to Hahn et al. (2010), such a cross-sector average analysis identifies the impact of the structure of the economy and the possible implications of structural change. On the other hand, they argue that this kind of benchmarking

[5] We obtain the national gross capital stock at constant 2000 prices by adding the depreciation to the net capital stock at constant 2000 prices.

does not take into account the composition of the economy. In particular, we expect that economies with a higher degree of industrialisation tend to be less resource efficient overall than economies depending more on services.

Table 1. Total EU-15 performance in 2010.

Year: 1995	Total EU-15 Performance
Return	
GDP at constant 2000 prices	€ 7596.68 billion
Environmental resources	
CO_2-eq emissions	4,130,247,211.62 tonnes
Acidification equivalents	769,752,692.24 mol H+
Municipal waste generation	188,040,000 tonnes
Social resources	
Absolute voluntary and involuntary unemployment	97,230,728.93 persons
Work accidents	4,820,451 persons
Economic resources	
Gross capital stock at constant 2000 prices	€ 23,310,587.73 billion

The second benchmark alternative employs EU-15 policy targets concerning the resources and GDP of European institutions such as the European Commission, which must be reached due 2010 (Table 2 shows the EU-15 targets by 2010). To this end, we for the most part use the EU-15 policy targets of Hahn et al. (2007). Also this benchmark alternative takes the viewpoint of an investor: here we obtain an indication how efficiently the resources are allocated with regard to the targets due 2010 for the EU-15 as a whole. Hahn et al. (2010) remark in this light that politically negotiated target benchmarks could reflect values that are too low to obtain environmental sustainability.

Table 2. EU-15 targets due in 2010.

2010 target	Relative	Absolute	Policy background	Sources
Return				
GDP at constant 2000 prices	Growth of 3% p.a.	€ 11,775.872 billion	Lisbon declaration	European Commission (2000)
Environmental resources				
CO_2-eq emissions	8% reduction compared to 1990	3,904,315.5 tonnes	EU burden sharing agreement	European Communities (2001)
Acidification equivalents	/	444,965,760 mol H+	NEC directive, Annex II	European Communities (2002)
Municipal waste generation	20% reduction compared to 2000	171,597,600,000 tonnes	Preliminary version of Decision 1600/2002/EC	European Commission (2001)
Social resources				
Absolute voluntary and involuntary unemployment	30% of all persons between 15 year and 64 year	76,827,450.19 persons	Lisbon declaration	European Commission (2000)
Work accidents	/	3,629,658.47 persons	No EU targets for work accidents available. EUROSTAT (2010b) Therefore, we use the linearly extrapolated number of work accidents in the EU-15 in 2010	EUROSTAT (2010b)
Economic resources				
Gross capital stock at constant 2000 prices	/	€ 30,837.50 billion	No EU targets for gross capital stock available. Therefore, we use the predicted total EU-15 gross capital stock in 2010[a]	AMECO (2009)

[a] This is calculated by adding the predicted stock due 2010 as calculated by AMECO to the linearly extrapolated depreciation due in 2010.

In order that the EU-15 economy could reach these goals, the European institutions imposed allocations of the resource ceilings and GDP growth in such way that each country has its own negotiated national targets. Therefore, Ang and Van Passel (2010) argue in favour of additional regional reallocations of common benchmark efficiencies. Concretely, the third benchmark alternative breaks down the European targets at the national level (Table 3 shows the national targets of Belgium for 2010). Summing up the national resource ceilings of the third benchmark alternative thus exactly results in the resource ceilings of the EU-15 of the second benchmark alternative. In this way, it is consequently possible to discuss the efficiency of the current allocation of the national resource ceilings. We provide the exact efficiencies of the three benchmark alternatives in the Appendix (Tables A.1–A.3).

Table 3. National policy targets of Belgium due in 2010.

2010 target				
	Relative	Absolute	Policy background	Sources
Return				
GDP at constant 2000 prices	Growth of 3% p.a.	€ 338.32 billion	Lisbon declaration	European Commission (2000)
Environmental resources				
CO_2-eq emissions	8% reduction compared to 1990	132,967.58 tonnes	EU burden sharing agreement	European Communities (2001)
Acidification equivalents	/	11,272,670 mol H+	NEC directive, Annex II	European Communities (2002)
Municipal waste generation	20% reduction compared to 2000	3884.8 tonnes	Preliminary version of Decision 1600/2002/EC	European Commission (2001)
Social resources				
Absolute voluntary and involuntary unemployment	30% of all persons between 15 year and 64 year	2,079,881.40 persons	Lisbon declaration	European Commission (2000)
Work accidents	/	57,974.78 persons	No EU targets for work accidents available. EUROSTAT (2010b) Therefore, we use the linearly extrapolated number of work accidents in the EU-15 in 2010	EUROSTAT (2010b)
Economic resources				
Gross capital stock at constant 2000 prices	Target efficiency = 0.36	€ 764.27 billion	No EU targets for gross capital stock available. Therefore, we use the predicted total EU-15 gross capital stock in 2010[a]	AMECO (2009)

[a] This is calculated by adding the predicted stock due 2010 as calculated by AMECO to the linearly extrapolated depreciation due in 2010.

2.2.2.5.Drivers of the RCR

To adequately interpret the results, we conduct a driver's analysis of the RCR scores of the EU-15 countries. We focus on the RCR and not on the SV as the SV does not take into account the size of the economy. Concretely, we use the results regarding the first benchmark alternative. Since the SV approach adheres to the three-pillar paradigm consisting of environmental, social and economic variables, we assume that environmental, social and economic indicators will drive the RCR. Concretely, we apply econometric techniques to study how governmental prioritisations and the composition of the economy affect the RCR with regard to the first benchmark alternative. As these kinds of indicators are not available, we will proxy those with the fraction of total governmental expenditures. As a result, we test whether governmental prioritisations on these issues effectively affect the RCR. In addition, we argue that the composition of the economy influences the RCR: an increasing service character of the economy may trigger the RCR. Since we use a panel data set, a pooled OLS regression may ignore the panel data structure in the sense that variation across economic entities or time cannot be captured in shifts of the regression yields (Wooldridge, 2002). Therefore, we use an effects model. As the Hausman test also gives a very high Chi-squared (468.08) arguing against a random effects model, we use the following fixed effects model (Wooldridge, 2002):

(6) $$RCR_{it} = \alpha_{it} + \beta_1(EnvExp_{it}) + \beta_2(RDExp_{it}) + \beta_3(SocProtExp_{it}) + \beta_4(ServiceVA_{it}) + \varepsilon_{it}$$

RCR_{it} represents the RCR of country i at year t. $EnvExp_{it}$, $RDExp_{it}$ and $SocProtExp_{it}$ stand for the governmental expenditures on environmental protection, research and development (R&D) and social protection of country i at year t, respectively. $ServiceVA_{it}$ corresponds to the value added of services of country i at year t. All independent variables are expressed as fractions of GDP. Note that we base ourselves on the work of Clarkson et al., 2004 and Sueyoshi and Goto, 2009, Lindert (2004) and Daniels (1985), who assessed the performances regarding expenditures on environmental protection, expenditures on R&D, expenditures on social protection and the service fraction, respectively. In light of these studies, we expect a positive relationship between the RCR and the expenditures on environmental protection, the expenditures on R&D and the service fraction, while the anticipated relationship between RCR and the expenditures on social protection is rather uncertain. We obtain all data from the OECD database (2010). The panel dataset is somewhat unbalanced, but we can assume that there is no selectivity bias. Finally, we correct for autocorrelation as the Durbin–Watson measure indicates accordingly.

2.3. Results and Discussion

This results and discussion section consists of three parts. First, we provide an overview of the results concerning SV and RCR. Second, we search for the drivers of the RCR outcomes conducting an econometric analysis. Finally, we discuss the results from the perspective of the WS versus SS debate.

2.3.1. Overview of SV and RCR

As explained in the Methodology section, we calculate the SV and RCR of EU-15 countries for three benchmark alternatives. For the first alternative, we benchmark the yearly average performance of the EU-15, for the second alternative we benchmark specific targets imposed by European institutions due 2010 at the European level and for the third alternative we use the national breakdowns of the latter targets.

2.3.1.1.SV Outcomes

We present the SVs for the three benchmark alternatives in Fig. 1. The second and third graph also depicts the SVs of the EU-15 average (the SV of the EU-15 as a whole divided by fifteen), the trend of the EU-15 average due in 2010 (the linear extrapolation of the EU-15 average due 2010) and the EU-15 target (the SV if all targeted resource efficiencies are reached, i.e. zero). In the first benchmark alternative, we clearly see a frontrunner (United Kingdom) and a laggard (Spain). Moreover, the SVs of the United Kingdom (from € 263.64 billion in 1995 to € 522.64 billion in 2006) and Spain (from € −295.48 billon in 1995 to € −524.12 billion in 2006) diverge considerably. In general, the SVs of most countries do not change much in time. However, Germany manages to improve its SV significantly while France and Italy show a deteriorating trend in terms of SV. Only Greece, Portugal, Italy and Spain have an SV below zero in 2006 for the first benchmark alternative and thus underperform with regard to the EU-15 average.

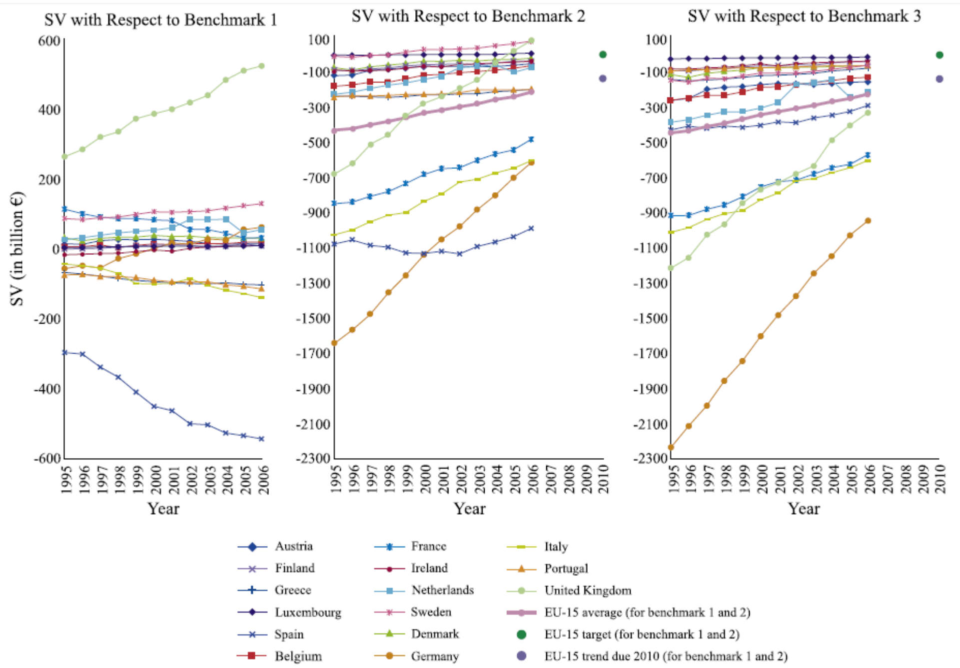

Fig. 1. SV of the EU-15 countries for the three benchmark alternatives (1995–2006).

The results considering the second benchmark alternative demonstrate that only Sweden, the United Kingdom and Luxembourg have a positive SV in 2006. Furthermore, the rise of the SVs of the United Kingdom and Germany are more visible. Interestingly, both countries initiate in 1995 with an SV below the EU-15 average.

As the third benchmark directly breaks down the EU-15 policy targets due in 2010 to national targets, we can see an indication of its redistributive nature in terms of SV. The SVs of Greece, Portugal and Spain are much higher than for the second benchmark. Conversely, the SVs of the United Kingdom and Germany start with an even lower SV with respect to the third benchmark alternative. Moreover, none of the EU-15 countries have a positive SV in 2006. Finally, we see in the second and third graph that the EU-15 as a whole unfortunately does not succeed in achieving the targeted resource efficiencies and are not expected to do so in 2010 as the projected trend of its SV is well below zero due in 2010.

2.3.1.2.RCR Outcomes

We illustrate the RCRs for the three benchmark alternatives in Fig. 2. Analogously to the first figure, we show the RCRs of the EU-15 average, the trend of the EU-15 average due 2010 and the EU-15 target (equalling unity). Here we see that also smaller countries can be found at either side of the spectrum with regard to the first benchmark alternative. In this case, the top three consists of Sweden, Luxembourg and the United Kingdom, while Greece, Portugal and Spain are the worst performers.

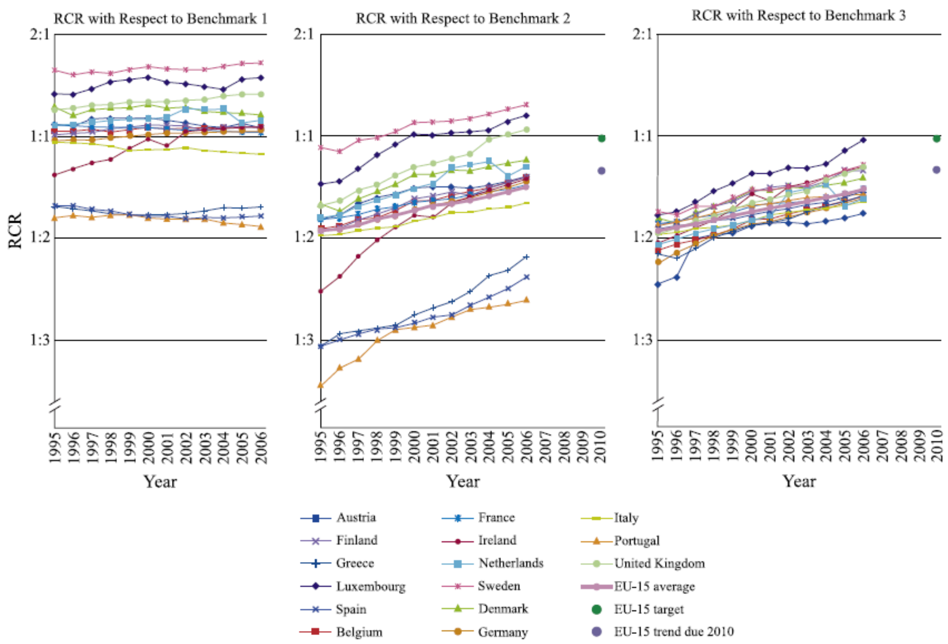

Fig. 2. RCR of the EU-15 countries for the three benchmark alternatives (1995–2006).

In addition, a comparison of the RCR with regard to the second and third benchmark alternative demonstrates the reallocative properties of the breakdown of the EU-15 targets in an even more visible way. In 2006, the RCRs vary between

1:2.50 and 1.30:1 regarding the second benchmark alternative and between 1:1.61 and 1.01:1 regarding the third one. This means that the best performer drives its economy 3.25 times more efficiently than the worst counterpart with respect to the second benchmark alternative. Employing the third benchmark alternative, this number considerably drops to 1.60:1. Furthermore, while Sweden, Luxembourg and the United Kingdom perform excellently with regard to the second benchmark, they have much lower RCRs with respect to the third benchmark. Conversely, Greece, Spain and Portugal are clear laggards regarding the second benchmark, while their RCRs are substantially higher with regard to the third benchmark.

There are thus some remarkable differences between the SV (and RCR) results of the second and third benchmark alternative. As it is also logical that countries strive for achieving national benchmarks rather than the EU-15 benchmarks as the former are the ones that are in fact implemented (for a country, the EU-15 benchmarks only exist in an artificial way as a sum of the national resource ceilings), these outcomes suggest that the breakdown of EU-15 targets to national targets due 2010 may come at an efficiency cost. While for example Greece, Portugal and Spain can hardly be considered drivers of sustainable development, they have a significantly better SV and RCR performance with respect to the third benchmark than to the second one. On the other hand, the SV and RCR of Austria and The Netherlands are worse with regard to the third benchmark than to the second one. Note that we do not argue to regard efficiency as the only important factor. We follow the claim of Rametsteiner et al. (2011) that we must recognise that sustainable development is inherently normative and linked to both social science and political reality. The current distribution of resource ceilings negotiated to the national level reflects an attempt to take into consideration efficiency as well as fairness and feasibility. As Greece, Portugal and Spain are historically lower income countries, it is negotiated through a democratic process that they can emit more. On the other hand, it remains important to consider whether a country has a real incentive to substantially improve its RCR. In conclusion, the question which countries should pursue the most ambitious reductions is a very complex issue as one must take into account the incentive as well as the intrinsic possibility to decline resource use.

2.3.1.3.Dynamic Effects on the RCR

Taking into account the size of the economy, the big jumps in SV terms of Germany, the United Kingdom, Italy and Spain with respect to the first benchmark alternative do not necessarily have a big effect on RCR. As RCRs represent factors (Hahn et al., 2010), we illustrate the concerning percentage changes in Table 4. We see that only the United Kingdom shifts its RCR with more than 10% (+ 12.00%) in twelve years among the mentioned countries with high absolute SV changes. Moreover, several countries showing only small SV shifts such as Ireland and Luxembourg trigger considerable changes in RCR (+ 33.52% and + 11.55%, respectively). Note that we only consider the percentage changes of the RCR for the first benchmark alternative as the percentage changes of the RCR of the second and third benchmark alternative would always be positive.

Table 4. Percentage changes with regard to resource use, gross domestic product and return to cost ratio for benchmark alternative 1 between 1995 and 2006.

$E_{resource,ir}$							$E_{return,i}$	RCR change
	CO_2-eq (in %)	Acidifying eq (in %)	Municipal waste generation (in %)	Absolute voluntary and involuntary unemployment (in %)	Work accidents (in %)	Gross capital stock at 2000 prices (in %)	GDP (in %)	Return to cost ratio (in %)
Austria	+12.98	−1.87	+55.24	+0.04	−50.40	+32.71	+30.12	−1.76
Belgium	−8.81	−34.31	+10.86	−6.23	−34.09	+25.29	+27.53	+4.12
Denmark	−7.55	−40.06	+35.89	−9.39	+25.96	+21.85	+27.32	−6.11
Finland	+12.56	−15.85	+23.28	−17.80	+7.20	+16.04	+49.91	+6.25
France	−2.52	−22.75	+23.32	−4.56	−5.68	+26.77	+27.44	−7.27
Germany	−8.24	−38.64	−8.78	−8.54	−44.33	+19.43	+17.16	+5.99
Greece	+20.47	−2.88	+53.97	−9.59	−41.87	+37.08	+52.09	−0.26
Ireland	+17.51	−24.64	+83.17	−12.61	+137.83	+74.18	+119.24	+33.52
Italy	+7.06	−44.54	+24.90	−15.25	−23.22	+22.30	+16.83	−6.34
Luxembourg	+28.90	−55.76	+33.75	−2.06	+3.57	+72.47	+70.82	+11.55
Netherlands	−7.37	−33.37	+20.05	−17.30	−7.73	+28.20	+34.59	+4.71
Portugal	+0.00	−24.55	+24.62	−7.32	−9.97	+46.74	+29.34	−7.34
Spain	+35.94	−10.85	+30.55	−24.06	+40.70	+56.77	+49.18	−7.73
Sweden	−10.79	−32.34	+32.16	−3.26	+23.02	+18.91	+39.16	+4.36
UK	−7.69	−49.36	+22.76	−6.28	−16.11	+29.43	+37.34	+12.00
EU-15	+0.13	−32.27	+17.18	−11.31	−18.95	+27.33	+28.98	+0.00
$E_{benchmark}$	CO_2-eq/GDP (in %)	Acidifying eq/GDP (in %)	Municipal waste generation/GDP (in %)	Absolute voluntary and involuntary unemployment/GDP (in %)	Work accidents/GDP (in %)	Gross capital stock at 2000 prices/GDP (in %)		
Benchmark 1	+28.81	+90.44	+10.06	+45.43	+59.14	+1.30		

Since the SV approach is an integrative measure and as a result inevitably erodes information concerning the underlying resource use patterns (see Methodology section), we also discuss three dynamic effects that influence the RCRs (Table 4). Considering the return effect, we see that the EU-15 as a whole shows an economic growth of circa 30% between 1995 and 2006. This aggregate GDP growth is characterised by mixed performances by its EU-15 members. While Italy and Germany establish a GDP growth of only 16.83% and 17.16%, respectively, the GDP growth of Luxembourg and especially Ireland is spectacular (70.82% and 119.24%, respectively).

As we study the use of six resources, there are six corresponding resource effects. The EU-15 as whole manages to curb the emission of acidifying pollutants, absolute unemployment and the number of work accidents (−32.27%, −11.31 and −18.95%, respectively), whereas the emission of CO2-eq, the municipal waste generation and gross capital stock rise (+ 0.13%, + 17.18% and 27.33%, respectively). Also here the distinct performances of the EU-15 countries reveal mixed outcomes. Belgium, France, The Netherlands, the UK and in particular Germany are able to generally decrease resource use. On the other hand, Ireland, Luxembourg and Spain in general increase resource use.

Finally, we illustrate the benchmark effect in Table 4. Note that we do this only for the first benchmark, as all efficiencies of the second and third benchmark alternative equal unity. Although the EU-15 as a whole shows rather mixed trends with regard to use, its GDP noticeably grew. As a result, all benchmark efficiencies (except for gross capital stock, which is deliberately kept constant) rise considerably. These rising benchmark efficiencies elevate the standards for the EU-15 countries to improve their RCR.

We summarise several remarkable country-specific trends. The considerable increase of RCR of Ireland is mainly due to an impressive increase of economic output and not due to decreasing resource use. In terms of percentage change of resource use, Ireland underperforms regarding all six resources, and it only decreases its use of acidifying equivalents and unemployment rate. In other words, Ireland is clearly not able to delink its resource use from its economic growth. This also seems to be the case for Luxembourg, which significantly improves its RCR but does not decrease its CO2-eq emission, municipal waste generation, the number of work accidents and gross capital stock. On the other hand, the RCRs of the United Kingdom and especially Germany improve steadily by increasing economic output as well as decreasing use of most resources. Note that although the relative percentage change of the latter is low compared to the economic growth of the other EU-15 countries, the absolute GDP per capita is still among the highest in the region. In conclusion, in the process of increasing the RCR, delinkage of GDP growth from resource use seems to be feasible as several countries do not necessarily have to rely on drastic increases of GDP that offset bad performances in terms of resource use.

2.3.2. Drivers of RCR

We conduct a drivers' analysis through a fixed effects regression adapted for autocorrelation (Table 5). It is suggested that a higher degree of service value added stimulates the RCR. This seems plausible as shifting from an industry-oriented towards a service-based economy tends to lessen intensity in terms of environmental resource use. In addition, increase of expenditures on R&D and social protection seems to improve the RCR. On the other hand, the effects of proportional expenditures on environmental protection are negative but insignificant. We note that apparent spending inefficiency also occurs at the microeconomic level in the study of Van Passel et al. (2007): inquiring Flemish dairy farms, they found that farm subsidies can even have adverse effects on the RCR. Finally, the R-squared within suggests that this fixed effects model can predict almost a third of the RCR differences within the EU-15 countries.

Table 5. Panel data estimation of determinants of the return to cost ratio with a fixed effects model.

Variable	Coefficient	Standard error
Expenditures on environmental protection (as % of GDP)	−4.19	2.86
Expenditures on research and development (as % of GDP)	6.65**	2.99
Expenditures on social protection (as % of GDP)	0.99**	0.44
Service value added (as % of GDP)	0.51***	0.17
Number of observations	136	
R-squared within	0.30	
R-squared between	0.32	
R-squared overall	0.30	

It is tempting to advise national governments to increase the share of spending on R&D and focus more on providing services instead of industrial goods. However, we should be cautious making not too far-reaching conclusions due to the relatively simple setup of our model. It is possible that our selected proportional expenditures are unsatisfying proxies of prioritisation of socio-economic and environmental issues. In addition, we should accentuate that the fixed effects model only allows for explaining differences within and not between EU-15 countries. Consequently, while this model suggests that increasing the service share within an EU-15 country could increase the RCR, we cannot straightforwardly claim that the difference in service intensity between for example the United Kingdom and Germany can explain for the difference in RCR. Finally, although several factors could be controlled for, other factors are fairly static. While governments might have the power to increase or decrease the fraction of expenditures directed towards R&D and social protection, the composition of the economy is much more complex – and possibly undesirable – to manage.

2.3.3. An Overview of the Results through the Lens of the WS versus SS Debate

In the last part of Section 3.1 we suggested that substantial economic growth may compensate for worse resource use in the process of increasing the RCR (or SV). Furthermore, low return of one resource could be offset by a higher return of another resource. KK (2009a) therefore put forward that the SV approach adheres to the WS paradigm as the original SV methodology presumes perfect substitutability of resources. On the other hand, Figge and Hahn, 2004a and Figge and Hahn, 2009 claim that resource use in fact remains constant at the benchmark level which as a result still establishes a link to the SS hypothesis. Concretely, FH (2009) argue that reallocation of resources between economic entities allow for increasing the total return in the case of differing marginal products. According to Figge and Hahn, 2004a and Figge and Hahn, 2009, using the average market return as a benchmark, the SV approach is conceptually in line with the SS paradigm as the reallocation of resources necessitates overall constant resource use.

Before we further discuss the SV approach from the perspective of the WS versus SS discussion, we would like to clarify a point that is often overlooked in this debate. Despite the obvious divergence in opinion, both paradigms share an anthropological perspective on the relationship between the natural environment and human beings. Therefore, WS as well as SS supporters mostly discuss the concept of sustainability by means of capital. Ekins et al. (2003, p. 166) define capital as "the stock that possesses the capacity of giving rise to flows of goods and/or services". The natural capital stock hence yields several natural goods and ecosystem services serving human needs (de Groot et al., 2002). Interestingly, the WS versus SS debate often intermingles whether the constant capital rule should be discussed in terms of constancy of the capital stock or the constancy of the natural goods and ecosystem services flowing from the capital stock (Hinterberger et al., 1997 and Pearce and Turner, 1990).

This has several important implications for the SV approach. The discussion between Figge and Hahn, 2004a, Figge and Hahn, 2009 and Kuosmanen and Kuosmanen, 2009a concerns the substitutability of resource use. As resource use involves quantities that are measured in a time dimension, FH (2004a) therefore argue that the SV approach is a flow- and not a stock-based measure. Although resource use is in our opinion indeed a flow rather than a stock, we argue that the flow with regard to the SV approach differs from the flow with regard to the stock-flow model in the WS versus SS debate. In the stock-flow model, the natural goods and ecosystem services flowing from the natural capital stock are drivers of human well-being. Provisioning (e.g., food and fibre), regulatory (e.g., air quality regulation and climate regulation) and cultural (e.g., spiritual and aesthetic values) services all contribute positively to human ends. In contrast, the SV approach is constructed in such a way that resource use is considered to be a negative externality and should therefore be minimised. Due to this divergence of meaning with regard to flows, the SV approach is in our opinion only loosely connected to the SS (or WS) paradigm. However, one could exogenously set a certain target level of resource use by which one does not damage natural capital stock[6]. FH (2004a) therefore argue in favour of such an implementation of flow targets, which has been done in the past (ADVANCE-project, 2006 and Hahn et al., 2007). Note that the SV approach permits to benchmark at the level of the aggregation of all economic entities as well as the level of the economic entity. As the issue of scale may be important for resource use, this is very convenient. In the case that resource use causes local problems (e.g., emission of fine particles), one could choose to benchmark at the level of the economic entity. On the other hand, one could opt to benchmark at the level of the aggregation of all economic entities if reallocation of resources between the entities would not play any role. Since the SV approach focuses on the option of reallocating resources, it is in our opinion more suitable for resources that do not have a local impact.

Despite the rather limited connection to the stock-flow framework of the WS versus SS discussion, one may insert flow targets that do not violate the SS condition of preserving the natural capital stock. The possibility of the SV methodology to concentrate on fixed (whether or not targeted) resource use at the aggregate level thus remains an interesting feature. Especially when reallocation of resources is a viable option in light of sustainable development, the

[6] The SS versus WS debate boils down to the discussion of the preservation of natural capital stock. The SV approach in addition considers other capital forms such as social and economic capital. Consequently, in our discussion of the natural capital stock, we in fact also mean the social and economic stock.

reallocative logics of the SV approach should be explored in more depth. Ang and Van Passel (2010), however, put forward that the SV as calculated by means of the original methodology might be incorrect if it is considered the financial compensation that more efficient economic entities would transfer to less efficient economic entities when the latter would forego the excess resource use. In other words, if the preferred resource use at the aggregate level is held fixed, the implied reallocation scheme might yield SVs that do not take into account the link between resource use and economic performance. Solely in the case of a linear relationship between resource use and return (and hence a constant benchmark efficiency) and perfect substitutability between resources (which is oddly enough a WS condition at the level of the economic entity), the reallocation mechanism of resources results in SVs that reflect the correct financial compensation scheme. Note that this has also repercussions for the WS versus SS discussion. One may reverse the reasoning: if one argues that the SVs in the original methodology determine a financial compensation scheme, one cannot assure a fixed resource use level at the aggregate level. Hence, the SS condition may be violated if the original SV methodology is being applied as a reallocation tool. For an extensive discussion on the benchmarking process, we refer to Ang and Van Passel (2010).

In summary, we can spell out three necessary conditions to put the SV approach with benchmarking at the aggregate level conceptually in line with the SS paradigm: (1) the targeted resource use level does not harm the natural capital stock, (2) the considered resources are suitable to reallocate in the sense that they do not have a local impact and (3) the SVs can be used for a financial compensation scheme.

Clearly, the three necessary conditions for a SS linkage are violated in our study. The first benchmark represents the average market return of the resources. Here, one cannot presume that the contemporaneous resource use level does not damage the natural capital stock. In case of the second and third benchmark, the overall resource level of the EU-15 is targeted. However, these ceilings are decided by means of political negotiation. Hence, whether the natural capital stock would be damaged at the targeted level is rather uncertain. The second benchmark differs from the third one in the sense that while the former sets the standard at the EU-15 level, the latter consists of national targets that are the exact breakdowns of the second benchmark. Due to the negotiation of resource ceilings, the third alternative thus allows for lower benchmark efficiencies in some cases and higher in other. However, the level of the targeted resource use of the EU-15 as a whole is still the same regarding the second and third benchmark. If every country achieves its national benchmark efficiency for every considered resource, the resource use and GDP at the EU-15 level would be the same with respect to the second and third benchmark alternative, as summing up the SVs of all EU-15 countries then yields zero with regard to the second and third benchmark alternative. In addition, not all considered resources are suitable to reallocate. It is for example questionable that reallocation of acidifying substances and municipal waste resulting in a high use of these resources in resource efficient countries is beneficial. Note that although we benchmark at the level of the distinct economic entity with regard to the third alternative, the reallocative nature of the SV approach is thwarted. Finally, as we use the original methodology, the SVs are unlikely to produce a financial transfer scheme that keeps the resource use level at the aggregate EU-15 level constant.

2.4. Conclusions

This paper presents the first application of the SV approach at the country level. The SV approach integrates the countries' efficiency of environmental, social and economic resources into a monetary analysis so that two indicators (SV and RCR) can be calculated. Concretely, we assessed the use of three environmental (CO2-eq, acidifying potentials and municipal waste), two social (absolute unemployment and work accidents) and one economic resource (gross capital stock) in combination with the GDP for all EU-15 countries from 1995 to 2006. An essential component of the SV measure is the benchmark. We calculated the SV and RCR for three benchmark alternatives. For the first benchmark alternative we used the yearly EU-15 performance, for the second benchmark alternative we used specific targets imposed by European institutions due 2010 at the European level and for the third alternative we benchmarked the country performance with regard to the national level targets due 2010.

First of all, there is a big difference in RCR outcomes between the second and third benchmark alternative. This could be an indication that the current resource ceilings are not efficiently allocated. Nevertheless, this does not mean that the benchmark efficiency should be determined at the aggregate EU-15 level for all resources. Not only efficiency, but also the nature of the impact itself (local or global), political factors and feasibility issues such as the evolving composition of the economy (as our driver's analysis confirms) should play an important role in the setup of resource ceilings. Moreover, the results show that if the resource use trend of the global EU-15 does not change, not all European targets will be reached in 2010. It is therefore important that the identification of frontrunners will lead to insight of their strategy. While it is theoretically possible to amplify SV and RCR by GDP growth compensating for increase of resource use, countries with improving RCRs such as Germany are able to delink their resource use from their GDP growth.

Our drivers' analysis suggests that the composition of the economy and targeted governmental spending substantially impact the SV and RCR. Countries enlarging their focus on services tend to pollute less, improving their SV and RCR. Governmental expenditures on social protection and R&D have a positive effect on the SV and RCR. Nevertheless, one should still be cautionary regarding governmental spending, as the expenditures on environmental protection do not seem to impact the SV and RCR.

Although FH (2004a) introduced the SV approach as an SS measure, this is in our opinion ambiguous. The deteriorating efficiency with regard to one resource could be compensated by improving efficiency with regard to another resource. In addition, increasing resource performance of a country can be compensated by increased economic output which is clearly a WS property. However, the SV approach focuses on keeping the overall resource use at a fixed targeted level by means of a resource reallocation between different users that does not damage the natural capital stock. In order that the SV approach is conceptually in line with the SS paradigm, three necessary conditions should be fulfilled: (1) the targeted resource use level does not damage the natural capital stock, (2) the resources considered are appropriate to reallocate in the sense that they do not have a local impact and (3) the SVs represent an adequate financial compensation scheme.

According to the analysis of our results, the SV approach is in this case unlikely to be a SS measure. Despite the other interesting conclusions in light of our application at the EU-15 level, this lack of SS character somewhat hinders the reallocative assets of the SV approach.

By its practical, communicative and synthesising nature, the SV approach is a promising measure to see the global picture in the difficult sustainability debate. The development of the SV approach would therefore benefit considerably if a formalised link between the SV methodology and the SS paradigm is established.

Appendix A

Table A.1. Benchmark efficiencies of benchmark alternative 1.

Resources	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
CO_2-eq emissions (in €/g)	1.84	1.83	1.92	1.97	2.06	2.14	2.15	2.19	2.18	2.23	2.29	2.37
Acidification equivalents (in € 10^{-6}/mol H^+)	9.87	10.56	11.31	12.00	13.01	14.26	14.88	15.48	16.17	16.94	17.83	18.79
Municipal waste generation (in €/g)	40.40	39.82	39.55	40.37	40.41	40.85	41.21	41.16	41.99	42.79	43.87	44.47
Absolute voluntary and involuntary unemployment (in €/person)	78.13	79.79	82.44	86.54	91.21	97.14	100.27	101.35	102.69	105.80	108.28	113.62
Work accidents (in €/person)	1.58	1.63	1.72	1.75	1.76	1.82	1.90	2.05	2.19	2.35	2.39	2.51
Gross capital stock at constant 2000 prices (in € 10^9/€)	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33

Table A.2. Benchmark efficiencies of benchmark alternative 2.

Resources	EU-15
CO_2-eq emissions (in €/g)	3.02
Acidification equivalents (in € 10^{-6}/mol H^+)	26.46
Municipal waste generation (in €/g)	68.62
Absolute voluntary and involuntary unemployment (in €/person)	154.02
Work accidents (in €/person)	3.24
Gross capital stock at constant 2000 prices (in € 10^9/€)	0.36

Table A.3. Benchmark efficiencies of benchmark alternative 3.

	CO_2-eq emissions (in €/g)	Acidification equivalents (in € 10^{-6}/mol H^+)	Municipal waste generation (in €/g)	Absolute voluntary and involuntary unemployment (in €/person)	Work accidents (in €/person)	Gross capital stock at constant 2000 prices (in € 10^9/€)
Austria	3.83	38.00	75.04	168.05	6.46	0.36
Belgium	2.54	30.01	87.09	162.66	5.84	0.36
Denmark	3.67	27.32	82.24	217.69	3.12	0.36
Finland	2.72	19.85	85.46	168.96	2.81	0.36
France	3.74	25.76	77.53	162.92	2.76	0.36
Germany	2.45	38.79	65.61	169.09	4.65	0.36
Greece	1.90	6.51	51.48	85.36	9.31	0.36
Ireland	2.76	14.76	77.28	161.65	4.41	0.36
Italy	3.37	26.24	69.09	137.78	3.25	0.36
Luxembourg	2.44	38.11	129.68	321.33	2.69	0.36
Netherlands	2.88	38.10	71.87	170.77	6.42	0.36
Portugal	3.02	10.45	42.68	76.98	1.12	0.36
Spain	3.20	13.55	39.95	94.71	0.91	0.36
Sweden	5.40	41.33	117.90	204.87	6.45	0.36
UK	3.05	35	79.27	187.79	6.74	0.36

3. The Sustainable Value approach: A clarifying and constructive comment

This chapter is taken from Ecological Economics 69: 2303-2306 (Frederic Ang and Steven Van Passel; 2010)

Abstract

Recently, the original benchmarking methodology of the Sustainable Value approach became subjected to serious debate. While Kuosmanen and Kuosmanen (2009b) critically question its validity introducing productive efficiency theory, Figge and Hahn (2009) put forward that the implementation of productive efficiency theory severely conflicts with the original financial economics perspective of the Sustainable Value approach. We argue that the debate is very confusing because the original Sustainable Value approach presents two largely incompatible objectives. Nevertheless, we maintain that both ways of benchmarking could provide useful and moreover complementary insights. If one intends to present the overall resource efficiency of the firm from the investor's viewpoint, we recommend the original benchmarking methodology. If one on the other hand aspires to create a prescriptive tool setting up some sort of reallocation scheme, we advocate implementation of the productive efficiency theory. Although the discussion on benchmark application is certainly substantial, we should avoid the debate to become accordingly narrowed. Next to the benchmark concern, we see several other challenges considering the development of the Sustainable Value approach: (1) a more systematic resource selection, (2) the inclusion of the value chain and (3) additional analyses related to policy in order to increase interpretative power.

3.1. Introduction

The Sustainable Value (SV) approach developed by Figge and Hahn (henceforth FH, 2004) gained considerable traction as evidenced by various applications at the firm level (e.g., Figge and Hahn, 2005, Figge and Hahn, 2008, Kuosmanen and Kuosmanen, 2009a, Van Passel et al., 2007, Van Passel et al., 2009 and Yu et al., 2009). The method integrates environmental, social and economic indicators into a monetary analysis based on opportunity costs. Eventually, this indicates how efficient a company uses its resources compared to a predefined benchmark. The measure intends to answer the question how much value a company would create with a predefined set of resources compared to the use of these resources by a benchmark.

Figge and Hahn, 2005 and Figge et al., 2006, Van Passel et al., 2007 and Hahn et al., 2007, the ADVANCE-project, 2006 and Yu et al., 2009 used the benchmark methodology of the original paper of FH (2004) in the calculation of SV. On the other hand, recent studies of Van Passel et al. (2009) and Kuosmanen and Kuosmanen (henceforth KK, 2009a) introduced productive efficiency theory in the SV calculation. This dichotomy concerning benchmark use culminated in an ardent discussion between Kuosmanen and Kuosmanen, 2009b and Figge and Hahn, 2009 in Ecological Economics Volume 69, Issue 2. Remarkably, Kuosmanen and Kuosmanen, 2009b and Figge and Hahn, 2009 framed this debate in a different manner. While the former claimed that the original SV approach did not distinguish the theoretical concept from the estimator, the latter defended their original approach arguing that this distinction was futile and, moreover, that KK (2009b) totally misspecified the problem as they drew on productive efficiency theory instead of the intended perspective of financial economics theory.

In this paper, we therefore intend to (1) shed light on the interesting debate on the SV approach and (2) provide concrete recommendations for its further development. The paper is structured as follows. Section 2 shortly describes the mechanism of the SV approach. In 3 and 4 we illustrate the critique of KK (2009b) and the response of FH (2009), respectively. In Section 5, we discuss this difference of opinions and draw conclusions. Finally, we lay out constructive suggestions for further development of the SV approach in Section 6.

3.2. The Original SV Approach

Basing on eco-efficiency theory, FH (2004) developed the SV approach, a sustainability measure that integrates social, environmental and economic resource efficiencies into a monetary assessment. Put formally, the SV is calculated in the following way:

(1) $$SV_i = \frac{1}{R}\sum_{r=1}^{R}\left(\frac{y_i}{x_{ir}} - \frac{y^*}{x_r^*}\right)x_{ir}$$

where SV_i stands for the SV of company i, R for the number of considered resources, y_i for the economic output of company i, y^* for the economic output of the benchmark, x_{ir} for the resource of company i and x_r^* for the resource of the benchmark.

The company i uses x_i resources to produce economic output y_i. In order to create SV, the company must have a higher economic output than the benchmark would create with the same amount of resources x_i. Concretely, at $x_i = x_i^*$, the benchmark would generate the economic output y_i^*. In this case, the SV thus equals y_i minus y_i^*. According to FH (2004), this company contributes to a more sustainable resource use at the benchmark level.

Figge et al. (2006) illustrate the explanatory power of the SV in an explanatory guide. First, the SV measures the value that has been created or destroyed because the firm has used a determined set of resources instead of the benchmark would create or destroy with the same set of resources. Second, the SV approach shows the value that could be gained if resources were reallocated from inefficient to efficient users. Moreover, the overall resource use remains constant at the macroeconomic benchmark level. FH (2004) therefore claims that the SV approach adheres to the strong sustainability paradigm. Finally, the SV approach integrates social, environmental and social resource efficiencies into one monetary measure.

3.3. The Critique of Kuosmanen and Kuosmanen (2009b)

KK (2009b) sharply criticise the SV approach as put forward by FH (2004). The rationale of KK is that FH do not draw a distinction between the theoretical concept and the estimator. According to KK, the theoretical concept of the SV should in fact be assessed in the following way:

$$SV_i = y_i - f(x_i) \quad (2)$$

where SV_i represents the SV of company i, y_i the economic output of company i, $x_i = (x_{i1} \dots x_{iR})^T$ the vector of R resources the firm i uses with the production function of the benchmark technology $f(x_i): \mathbb{R}_+^R \rightarrow \mathbb{R}_+$. Eq. (2) is very similar to Eq. (1), except for the fact that $f(x_i)$ allows for a flexible form contrary to the rigid, linear $\frac{y^*}{x_r^*}x_{ir}$ in Eq. (1).

KK argue that the SV_i in Eq. (1) must be seen as an estimator as it concerns "a rule, strategy, or formula for calculating the value of an unknown parameter of interest" (KK, 2009b, p. 236), and not the theoretical concept itself. For this reason, they define the FH's estimator of SV_i as $\widehat{SV}_i^{FH}$:

$$\widehat{SV}_i^{FH} = \frac{1}{R}\sum_{r=1}^{R}\left(\frac{y_i}{x_{ir}} - \frac{y^*}{x_r^*}\right)x_{ir} \quad (3)$$

This can be rearranged to:

$$\widehat{SV}_i^{FH} = y_i - \frac{1}{R}\sum_{r=1}^{R}\left(\frac{y^*}{x_r^*}\right)x_{ir} \quad (4)$$

According to KK, the production function should also be specified with the estimator $\hat{f}$. Combining Eqs. (2) and (4) results in:

$$\hat{f}^{FH}(x) = y_i - \frac{1}{R}\sum_{r=1}^{R}\left(\frac{y^*}{x_r^*}\right)x_{ir} \quad (5)$$

KK state that $\hat{f}^{FH}(x)$ is a fundamentally flawed estimator of production function $f(x)$. First, this estimated production function is implicitly based on the unrealistic assumption of linearity with constant marginal opportunity costs. As the resources are thus perfectly substitutable, this violates the strong sustainability paradigm. Second, as $\hat{f}(x)$ also represents the estimated opportunity cost of x, an estimated opportunity cost independent on company properties that increases linearly with

x is assumed. KK regard this as unlikely, as the opportunity cost of x should depend on a properly estimated production function that in general differs for each firm. Moreover, even if one makes the strong assumption of a linear production function using Eq. (3), the results are likely to become biased and inconsistent, as β_r is estimated by single data points. KK (2009b) present this shortcoming by conducting several Monte Carlo simulationns and re-examining the results of the ADVANCE-project (2006).

3.4. The Response of Figge and Hahn (2009)

FH (2009) argue that the critique of KK completely misspecifies the underlying theory of the SV approach. Following the tradition of financial economics, FH (2004) developed the SV approach from the perspective of an investor. According to FH, two questions play a decisive role for investors as well as for policy makers regarding sustainability: the question if the resource should be used at all and the question where the resources should be allocated. As for sustainability measures, there exist many cost–benefit analyses attempting to answer the if-question. However, there were no sustainability measures tackling the where-question. The SV approach intended to fill in this gap by considering the allocation of environmental, social and economic resources. In addition, FH suggest that investors are basically risk averse. As a consequence, they will diversify their economic capital among many economic entities in uncertain circumstances. This implies that investors try to maximise their value added keeping economic, environmental and social capital constant from the overarching perspective of the investor and not from the viewpoint of the individual firm. FH note that the SV approach adheres to the paradigm of strong sustainability as the resources are held constant at the benchmark level.

According to FH, therefore, the benchmark should be chosen from the holistic position of the investor. Following FH, questions about the actual feasibility of SV creation for the firm, resulting in the selection of a firm-based benchmark should not be answered by the approach, as this addresses the how-question in which the individual firm searches for an optimal technology and not the where-question in which the risk averse investor tries to allocate its economic, environmental and social resources in an optimal way while at the same time coping with an uncertain environment. According to FH (2009), KK's concept of production functions and opportunity costs are thus futile and defined at the wrong level (at the firm level instead of the societal level), respectively.

Moreover, FH suggest a number of implications. First, they assert that there remains room for optimisation at the societal level even if efficiency is reached at the firm level. Second, they assert that the perspective of financial economics serves the necessities of sustainability assessment in a superior way than the viewpoint of productive efficiency analysis as (1) sustainable development is considered as a societal concept, (2) the pricing problem of economic, social and environmental resources is circumvented with the original SV approach and (3) the FH assumption that all firms face the same risk is less restrictive than the KK assumption that the use of resources is risk free.

3.5. Discussion and Conclusion

The calculation of the SV seems straightforward as it merely is the difference between the economic output of a company and the economic output of what the benchmark would create with the same amount of resources. In their original paper, FH (2004) proposed a twofold interpretation of the SV. On the one hand, the SV reflects in monetary terms the overall resource efficiency of the concerned company compared to a predefined benchmark in which the total amount of resources is kept constant. This viewpoint originates from the theory of financial economics. In this case, one takes the perspective of an investor who wants to find out the performance of a firm in terms of overall resource efficiency compared to the portfolio of all considered firms with a limited, scarce amount of resources. As a result, the average return on resources can be regarded as a valuable benchmark alternative such as in Eq. (1). We then interpret the SV as an investor's measure: while we do not seek concrete policy advice to reallocate resources in an optimal way, we solely want to have an overview of how the resources are distributed compared to the portfolio as a whole. FH (2009) define this as the where-question and reject the notion of estimated production functions put forward by KK (2009b).

On the other hand, FH (2004) suggest that the SV at the same time also precisely reflects the financial transfer from more efficient resource users to less efficient resource users if the latter would give up excess resource use. The critique of KK implementing productive efficiency theory is in this regard reasonable. If one aspires to construct a prescriptive tool implementing some kind of feasible reallocation scheme, it is absolutely necessary to consider the impact of a change of resource combination on the economic output. In other words, an accurate estimation of the production function is required. Benchmarks determined through productive efficiency analysis do take into account the relation between a change in resource use and the economic output. Following this rationale, it is relevant to explore how a firm could allocate its resources. In our opinion the how-question as postulated by FH could however be more precise. We do not agree with the claim of FH that the how-question concerns the individual firm level, boiling down to an issue of production technology choice, instead of the societal level. The implementation of productive efficiency theory presupposes a common production technology choice, as one intends to estimate a production function of the benchmark identical for each company. Although the resource efficiency of the benchmark could vary in accordance with the economic output, the production function of the benchmark estimated at the individual firm level per definition coincides with the societal level. Therefore, the argument of FH that the use of production functions in SV applications means a stance away from the allocative perspective is in our opinion also inaccurate. Although the ambition of applying the SV approach as a prescriptive tool does not necessarily imply an embracement of the perspective of financial economics, it still envisions a distributional mechanism of financial compensation. Adhering to the paradigm of financial economics, one searches in the original methodology proposed by FH (2004) "where environmental and social resources *should* be allocated in order to achieve an optimal overall return" (FH, 2009, p. 249, emphasis added). We may define the SV calculation with the introduction of production theory by KK (2009b) as an indication "where environmental and social resources *could* be allocated in order to achieve an optimal overall return". Even if the difference between the application as an investor and a prescriptive tool strips down to the notion of feasibility, both interpretations of the SV thus concern an allocative matter.

In conclusion, we find the recent debate on the SV approach utterly confusing. Initially, FH (2004) themselves argue that the SV (1) is a monetary measure that compares the overall resource efficiency of the concerned company to a predefined benchmark in which the total amount of resources is kept constant and (2) at the same time also exactly represents the financial compensation that more efficient resource users would pay to less efficient resource users if the latter would forego the excess resource use. In other words, they claim in their original paper that the proposed SV methodology can be used as both an investor's and a prescriptive measure. Although the original SV methodology is useful for the objectives of an investor taking a financial economics perspective, we put forward that the introduction of production efficiency theory is imperative for prescriptive goals. The SV equivalence is thus only correct if the benchmark production function increases linearly. KK (2009b) effectively attack the implicit strong assumption of a linear production function in the original methodology conducting several Monte Carlo simulations and re-examining the results of the ADVANCE-project. Nevertheless, they do not recognise the fact that the original SV measure promises two largely incompatible objectives as the original SV methodology still holds if it is used as an investor's measure. FH (2009) rightly claim that the statistical tests of KK (2009b) are not relevant if one takes the investor's perspective following the paradigm of financial economics. However, FH (2009) moreover state that the SV approach never intended to answer the how-question. Despite a rather inaccurate definition of this how-question, FH (2009) mean that they never intended to apply the original SV approach as a prescriptive tool creating some sort of reallocative scheme. This is incorrect as evidenced by their original contribution of 2004. We note that FH (2004) implicitly hinted at the difficulty of using linear production functions for investor's as well as prescriptive purposes[7].

[7] FH (2004, p. 179) stated the following in a footnote with regard to a figure in which they presented the SV calculation for the single impact case: “The curves are given as lines as we assume that eco-efficiency, i.e. the amount of value created per impact added remains unchanged independent both of the level of value creation and resource consumption. In other words for the sake of ease and comprehensibility we assume constant marginal products per EIA [Environmental Impact Added].” Clearly, this assumed constant eco-efficiency can be interpreted as an assumed linear production function.

3.6. Recommendations for Further Development of the SV Approach

The mainstream research on sustainability indicators focused on burden-oriented measures internalising externalities, and relative measures. While the former require complicated and assumptive pricing procedures, the latter lack the possibility of integrating environmental, social and economic factors. FH (2004) handily overcame these problems introducing the concept of opportunity costs with the SV approach. In this way, FH for the first time framed the debate on resource use from a distributional perspective. Notwithstanding the current controversy surrounding the SV approach, we want to accentuate this merit and see many possibilities for its further development.

SV practitioners should consider which research goal they attempt to pursue. As Van Passel et al. (2009) put forward, the benchmark choice is indeed essential, but must always be measured up to the initial decision situation and research question. If one, on the one hand, aims to use the SV approach as an investor's tool giving a clear overview of company performances concerning overall resource efficiencies, the average return on the resources may be a correct benchmark. If one, on the other hand wants to apply the SV approach as a prescriptive tool creating some sort of reallocation scheme, an implementation of productive efficiency theory could be appropriate. In the latter case, we need a sufficient amount of data points in order to estimate the production function of the firms. Note that also other alternative benchmark definitions could be worked out into more detail. Policy targets, even in the case of regional reallocation, could in addition be valuable in the SV approach[8]. The use of marginal products can be another promising track. In this way, resources can be weighted with relative marginal products of the firms (reflecting the marginal willingness to pay for an extra unit of resource). In conclusion, we advocate a pragmatic standpoint instead

[8] The benchmarking of policy targets remains a political procedure in which many international stakeholders participate. Rametsteiner (2011) suggest that we must be aware of the fact that the development of sustainability indicators has an inherently normative character, bound to social science as well as political reality. Through a democratic process key stakeholders try to find common ground also taking into account issues not related to efficiency such as equity, the composition of the economic entity, and the historical and current resource allocations. In reality, this predominantly comes down to the creation of distinct regional benchmarks (e.g., the EU-15 targets in the Kyoto Protocol are in reality reallocated into negotiated national targets).

of an argument whether a financial economics perspective or productive efficiency analysis paradigm should prevail.

As the current debate on the SV approach is concentrated on the benchmark choice, we accordingly restricted our discussion. Nonetheless, in our opinion, the current ardent debate on the SV approach inclines to impoverish towards an exclusive focus on the benchmark choice, while the concept of the SV approach still enriches the sustainability assessment debate by concentrating on the value of resources instead of the burden.

Recognising the danger of a debate solely focused on benchmark development, we want to call attention to other key challenges in the light of future studies with the SV approach. First, the indicators should be selected in a more systematic way. As the SV approach is founded on eco-efficiency theory, it is restricted to resources and the minimisation of the intensity hereof. Even though FH claim that the SV method adheres to the three-pillar approach inventorying environmental, social and economic resources, not every resource could be assessed in an ample, adequate and/or applicable way. Concretely, there are much more relevant environmental than social data. Furthermore, the aspired resource minimisation implies suitability for negative rather than positive externalities. In reality this results in a considerable weighting towards environmental resources in all past SV studies. In general, we consequently recommend a structured resource choice. Niemeijer and de Groot, 2008a and Niemeijer and de Groot, 2008b present interesting insights from this point of view proposing a conceptual framework for the selection of environmental indicators.

Second, as mentioned briefly by Van Passel et al. (2007), we should find a way to overcome the difficulty that the SV approach does not take into account other companies in the value chain. Fundamentally, there remains a problem that companies with a high SV could achieve their positive score by buying up cheap goods from firms with a low SV in the pre-chain and thereafter selling them at high prices (Schmidt and Schwegler, 2008). We should as a consequence additionally consider the value chain in order to fully attribute the SV to the responsibility of the concerned company. The most popular method to include the value chain is the Life Cycle Assessment (a recent state-of-the-art can be found in Finnveden et al., 2009). This measure assesses the resource use of a product from cradle to grave. Nonetheless, it focuses on the product and not on the production at the firm level as in the SV approach. Schmidt and Schwegler (2008) recently developed a recursive ecological indicator system that does concentrate on the company level. Therefore, some sort of implementation of this approach in the SV methodology could provide useful new insights.

Third, the allocative resource-based perspective is the biggest strength of the SV approach, but also its limitation; in general no sustainability measure can grasp the inherent complex nature of "sustainability". In most studies the SV approach is for this reason used as a black-box in which we do not explore why certain companies have a higher SV than other. As a result, the emphasis of the concerned studies is rather on the ranking than on the interpretation of the results. In the light of policy advice, however, explanatory power is indispensable. In fact, the results of the SV methodology can be linked to policy models to analyse the impact of different policy measures on the sustainable value creation of firms. Therefore, we advocate additional comprehensive analyses and complementary applications of other sustainability measures (e.g., Ecological Footprint and Cost–Benefit Analyses) in order to offer more fine-tuned policy recommendations.

4. Theoretical Background of Dynamic Approach

Frederic Ang

This Chapter presents the theoretical background of the dynamic approach of Chapters 5-6 and is a dynamic extension of the static set representation shown in section 1.3.1. We consider (1) the set representation of the adjustment-cost technology, (2) its representation in a directional distance function framework, and (3) its dual relationship with dynamic profit maximization, yielding a decomposition of dynamic profit inefficiency into technical and allocative components. This Chapter follows the dynamic extension in Chapter 2 ("Primal Analytical Foundations of Dynamic Production Analysis") and Chapter 4 ("Dynamic Decision Making, Distance Functions and Productive Efficiency") in Silva et al. (2012), but uses the structure, terminology and notation of section 1.3.1 to make the analogy with the static perspective clear. For an elaborate theoretical treatment with proofs, we refer accordingly. Moreover, we add a novel section where the technology set is conditional on a given vector of variable inputs and capital stock to improve readability. We only provide figures for technological relationships that include investments, but note that the input-output set (static graph), variable input requirement set and producible output set are the same for the dynamic approach and thus already presented in section 1.3.1. Section 4.1 builds on section 1.3.1.1 and section 4.2 builds on section 1.3.1.2 and could be read in conjunction.

4.1. Adjustment-Cost Production Possibilities Sets

Consider a firm that produces a vector of $n = 1 \dots N$ outputs, $y \in \mathbb{R}_+^N$, using a vector of $m = 1 \dots M$ variable inputs, $x \in \mathbb{R}_+^M$ and a vector of $f = 1 \dots F$ quasi-fixed inputs, $K \in \mathbb{R}_+^F$ with corresponding vector of dynamic factors (gross investments) $I \in \mathbb{R}_+^F$. We represent the variable inputs, quasi-fixed inputs, investments and outputs as a technology set in terms of (1) the primitive characterization given the capital stock vector (the "dynamic graph"), (2) investments and variable inputs for a given level of outputs and the capital stock vector (the "adjustment-cost input requirement set"), and (3) investments and outputs for a given level of variable inputs and capital stock vector (the "adjustment-cost production function").

Dynamic Graph

The dynamic graph $DGR(K)$, *i.e.*, the set of feasible variable input-investment-output vectors for a given capital stock vector, can be defined as follows:

(9) $DGR(K) = \{(y, x, I): (x, I)\ can\ produce\ y\}$

This is the most general representation of the adjustment-cost production possibility set. We assume that the following properties hold:

DG.1. $DGR(K)$ is closed.

DG.2. $DGR(K)$ is bounded from above.

DG.3. Inactivity is possible: $(0, x, I) \in DGR(K)$.

DG.4. There is no free lunch: $(y, 0,0) \in DGR(K) \Rightarrow y = 0$.

DG.5. Outputs are strongly disposable: $(y, x, I) \in DGR(K) \wedge y' \leq y \Rightarrow (y', x, I) \in DGR(K)$.

DG.6. Variable inputs are strongly disposable: $(y, x, I) \in DGR(K) \wedge x' \geq x \Rightarrow (y, x', I) \in DGR(K)$.

DG.7. Investments congest outputs: $(y, x, I) \in DGR(K) \wedge I' \leq I \Rightarrow (y, x, I') \in DGR(K)$.

DG.8. Quasi-fixed inputs increase outputs: $(y, x, I) \in DGR(K) \wedge K' \geq K \Rightarrow (y, x, I') \in DGR(K')$

DG.9. $DGR(K)$ is convex.

DG.1-DG.6 and DG.9 are equivalent for the static approach, whereas DG.7 and DG.8 characterize the dynamic approach.

Adapting the directional distance function $\vec{D}_T(.)$ (Chambers et al., 1998) to a dynamic context, this yields:

(10) $\vec{D}_T(y, x, I; g_y, g_x, g_I) = \max_{\beta} \{\beta: (y + \beta g_y, x - \beta g_x, I + \beta g_I) \in DGR(K)\}$

where $g = (g_y, g_x, g_I)$ with $g_y \in \mathbb{R}_+^N$, $g_x \in \mathbb{R}_+^M$ and $g_F \in \mathbb{R}_+^F$. $\vec{D}_T(.)$ measures the distance to the technological frontier in the direction of $(g_y, -g_x, g_I)$, simultaneously contracting inputs and expanding outputs and investments. In line with Chambers et al. (1998), it can be shown that $\vec{D}_T(.)$ and $DGR(K)$ are equivalent representations.

Adjustment-cost input requirement set

The second characterization of the production possibilities describes the feasible variable input and investment vectors for a given output and capital stock vector as $DL(y: K)$:

(11) $DL(y: K) = \{(x, I): (x, I)\ can\ produce\ y\}$

Assuming that DG.1-DG.9 hold and given that $DL(y: K)$ is defined in terms of $DGR(K)$, the following properties hold:

DL.1. $DL(y: K)$ is closed.

DL.2. $DL(y: K)$ is bounded from below.

DL.3. Inactivity is possible: $(x, I) \in DL(0_N: K)$.

DL.4. There is no free lunch: $(0_M, 0_F) \notin DL(y: K)$.

DL.5. Variable inputs are strongly disposable: $(x, I) \in DL(y: K) \wedge x' \geq x \Longrightarrow (x', I) \in DL(y: K)$.

DL.6. Outputs are strongly disposable: $(x, I) \in DL(y: K) \wedge y' \geq y \Longrightarrow DL(y': K) \subseteq DL(y: K)$.

DL.7. Investments congest outputs: $(x, I) \in DL(y: K) \wedge I' \leq I \Longrightarrow (x, I') \in DL(y: K)$.

DL.8. Quasi-fixed inputs increase outputs: $(x, I) \in DL(y: K) \wedge K' \geq K \Longrightarrow DL(y: K) \subseteq DL(y: K')$.

DL.9. $DL(y: K)$ is convex.

Figure 1 shows a one investment – one investment example obeying these properties, also holding the vector of variable inputs constant. $DL(y, x\colon K)$ is negative monotonic in I: The marginal product of each investment is negative, and there are no upward-sloping isoquants. Analogous to the primitive characterization in $DGR(K)$, it is possible to represent $DL(y, x\colon K)$ by a directional distance function. Since the vector of outputs, variable inputs and capital stock is held fixed, the directional vector can be defined in terms of investments. In our example, $g_I = (g_{I_1}, g_{I_2})$. If firm A would maximally reduce its technical inefficiency along g_I, then the investment level would be $B(I_1^*, I_2^*)$.

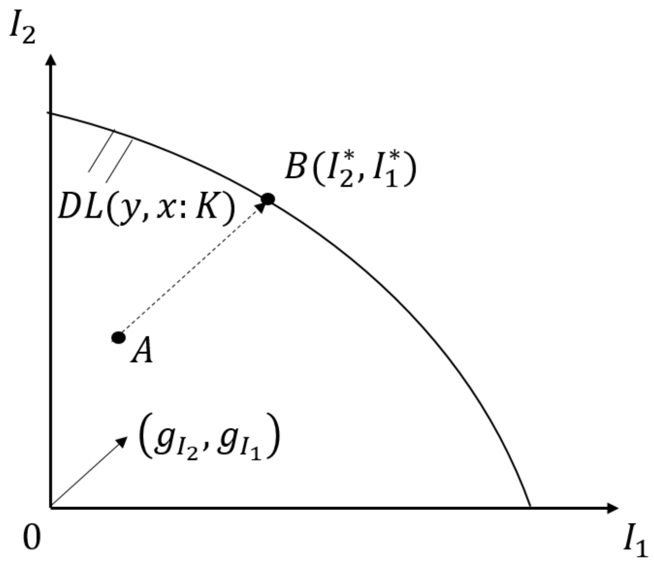

Fig.1. The directional distance function in the investment-investment space.

Figure 2 shows a one variable input – one investment example obeying properties DL.1-DL.9. The isoquant is downward-sloping for $DL(y\colon K)$. In our example, $g = (g_I, g_x)$. If firm V would maximally reduce its technical inefficiency along (g_I, g_x), then it would use a level produce at $W(x^*, I^*)$.

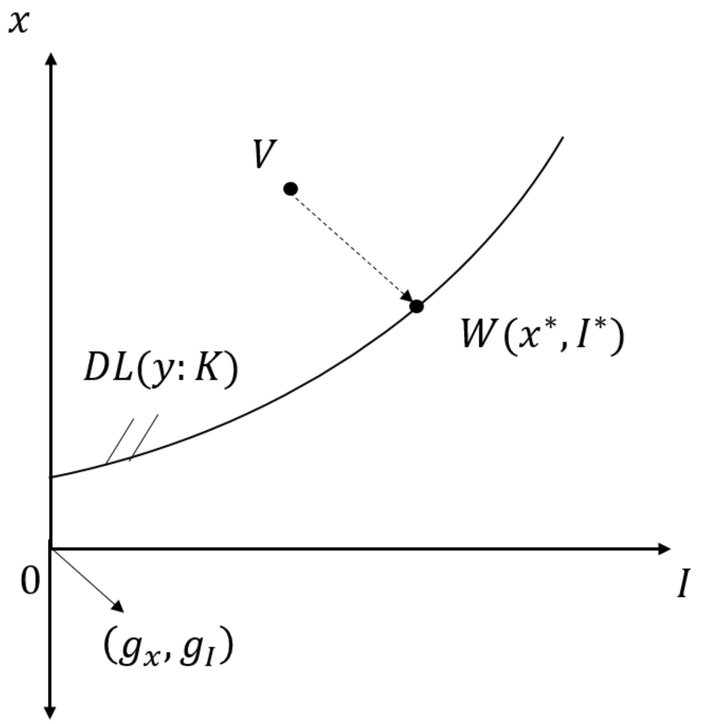

Fig. 2. The directional distance function in the variable input-investment space.

Adjustment-cost investment – producible output requirement set

The third characterization of the production possibilities describes the feasible investment and output vectors for a given variable input and capital stock vector:

(12) $DP(x\colon K) = \{(y, I)\colon (x, I)\ can\ produce\ y\}$

Assuming that DG.1-DG.9 hold and given that $DP(x\colon K)$ is defined in terms of $DGR(K)$, the following properties hold:

DP.1. $DP(x\colon K)$ is closed.

DP.2. $DP(x\colon K)$ is bounded from above.

DP.3. Inactivity is possible: $(0_N, I) \in DP(x\colon K)$.

DP.4. Variable inputs are strongly disposable: $(y, I) \in DP(x\colon K) \wedge x' \geq x \Longrightarrow DP(x\colon K) \subseteq DP(x'\colon K)$.

DP.5. Outputs are strongly disposable: $(y, I) \in DP(x: K) \wedge y' \leq y \Longrightarrow (y', I) \in DP(x: K)$.

DP.6. Investments congest outputs: $(y, I) \in DP(x: K) \wedge I' \leq I \Longrightarrow (y, I') \in DP(x: K)$.

DP.7. Quasi-fixed inputs increase outputs: $(y, I) \in DL(y: K) \wedge K' \geq K \Longrightarrow DL(x: K) \subseteq DL(x: K')$.

DP.8. $DL(x: K)$ is convex.

Figure 3 shows a one investment – one output example complying with these properties. Again, we can represent $DP(x: K)$ by a directional distance function. Since the vector of variable inputs and capital stocks is held fixed, the directional vector is defined in terms of output and investment. In our example, $g = (g_y, g_I)$. If firm Q would maximally reduce its technical inefficiency along g_y, then it would use a level produce at $R(y_2^*, y_1^*)$.

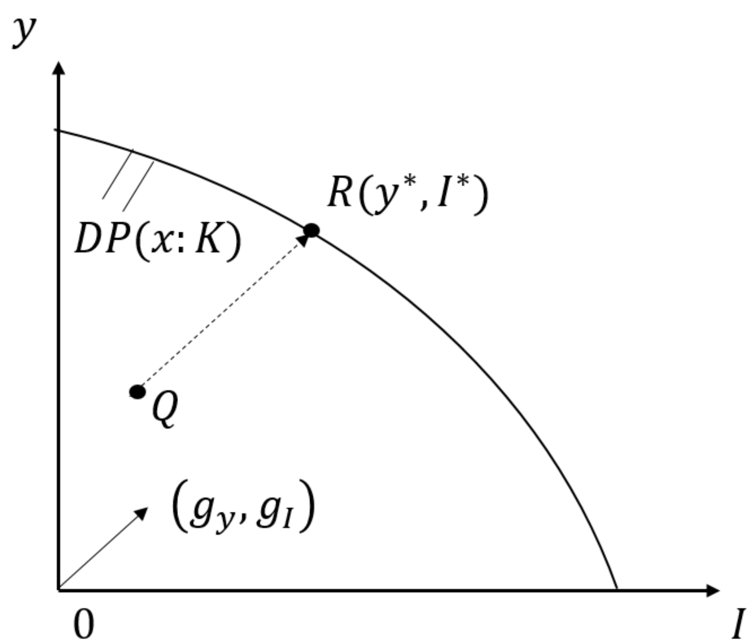

Fig. 3. The directional distance function in output-investment space.

4.2. Dynamic Profit Inefficiency, Dynamic Technical Inefficiency and Dynamic Allocative Inefficiency

Let $p \in \mathbb{R}_+^N$ be a vector of output prices, $w \in \mathbb{R}_+^M$ be a vector of variable input prices, $c \in \mathbb{R}_+^F$ be a vector of capital prices of the capital stock vector $K \in \mathbb{R}_+^F$ with the corresponding vector of depreciation rates $\delta \in \mathbb{R}_+^F$. The intertemporal profit maximization problem assumes that the firm maximizes the discounted flow of profits over time at any base period $t \in [0, +\infty[$, while being restricted by the adjustment-cost directional technology distance function. The firm faces competitive variable input, output and capital markets in the sense that all corresponding prices cannot be affected by the firm. It updates its expectations regarding these prices as the base period changes. In addition, all firms have identical, static expectations on the discount and depreciation rates. Formally, the intertemporal profit maximization problem is defined as follows:

(13) $$J(p, K_t, w, c) = \max_{y,x,I} \int_{t_0}^{+\infty} \mathrm{e}^{-rs}[p_s{}'y_s - w_s{}'x_s - c_s{}'K_s]\, ds$$

s.t.

$\dot{K}_s = I_s - \delta' K_s$ with $K_t = K_{t_0}$

$\vec{D}_T(x_s, I_s, y_s, K_s;\ g_x, g_I, g_y) \geq 0$ with $s \in [0, +\infty[$

$J(.)$ is the present value form of dynamic profit maximization. (5) can be represented by the current-value Hamilton-Jacobi-Bellman equation:

(14) $$rJ(p, K, w, c) = \max_{\{y,x,I\}} \{p'y - w'x - c'K + J_K(p, K, w, c)'(I - \delta' K)\}$$

s.t. $\vec{D}_T(x, I, y, K;\ g_x, g_I, g_y) \geq 0$

Analogous to the static representation in section 1.3.1, it can be shown that the dynamic profit function in (5) is dual to the directional distance function in (4) in line with Chambers et al. (1998). This duality allows for a decomposition of dynamic profit inefficiency DPI into dynamic technical inefficiency DTI and dynamic allocative inefficiency DAI:

(15) $DPI = DTI + DAI$

where $DPI = \frac{rJ(.)-[p'y-w'x-c'K+J_K(.)'(I-\delta'K)]}{p'g_y+w'g_x+J_K(.)'g_I}$ and $DTI = \vec{D}_T(.)$.

5. Dynamic Profit Inefficiency: A DEA Application to Belgian Dairy Farms

Frederic Ang and Alfons Oude Lansink

Abstract

Using a nonparametric framework, we analyze dynamic profit inefficiency for a sample of Belgian, specialized dairy farms from 1996–2008. Profit inefficiency is decomposed into contributions of output, input, and investment. Moreover, we identify the contributions of technical and allocative inefficiency in each input and output. The results suggest substantial profit inefficiency under the current dairy-quota system, mainly driven by an average underproduction of approximately 50 percent and an average underuse of variable inputs of approximately 60 percent, due to allocative inefficiency. Consequently, abolishing the dairy-quota system in 2015 may considerably increase demand for variable inputs and supply of output.

5.1. Introduction

The milk-quota system will be abolished in 2015, which is expected to trigger a substantial structural change in the European dairy sector. The milk-quota system has been in place since 1984. It was incorporated in the European Common Agricultural Policy (CAP) to curb overproduction of milk and reduce budgetary deficits (Naylor, 1987). The price support for milk producers, aiming to protect dairy farmers' income, was the largest driver of these two problems. The milk-quota system holds for all member states of the European Union. It constrains milk production to farm-level quota by levying surplus production (Boots et al., 1997).

The dairy-quota system's inherent weakness is that it protects inefficient producers and harms more efficient producers (who are obliged to buy/rent quota if they want to increase their output). Numerous studies analyzed technical inefficiency under a milk milk-quota regime, using either output- or input-oriented approaches. Areal et al. (2012) and Latruffe et al. (2012) are examples of the output approach, and Sauer (2010) and Steeneveld et al. (2012) are examples of the input approach. As the dairy-quota system constrains milk production, the input approach seems to be exclusively used by those not only interested in the technical inefficiency, but also in dairy farmers' allocative and economic inefficiency.

The vast majority of studies analyzing the economic efficiency of the dairy sector use a static approach, in which firms are assumed to instantaneously adjust inputs and outputs to their long-run optimal levels. However, firms often incur costs when adjusting the quantity of quasi-fixed inputs. Such adjustments may negatively affect production in the short run, but are necessary to enhance productivity in the long run. Silva and Stefanou (2003; 2007) implement the adjustment-cost technology in an inter-temporal cost-minimization problem. They assess the economic, technical, and allocative inefficiency through a nonparametric dynamic approach. This approach is also applied by parametric reduced-form estimations (Ahn and Sickles, 2000; Emvalomatis et al., 2010; Tsionas 2006) and parametric structural estimations (Rungsuriyawiboon and Stefanou 2007; Serra et al., 2011).

Furthermore, the radial input-oriented approach to measuring inefficiency that currently dominates the literature has limitations. Although there is a constraint on the output production under a quota regime, firms can still expand/limit production by acquiring/selling quotas. The output level is also a choice variable, even in a quota context. We were surprised that, to our knowledge, no study assumes profit-maximizing behavior and investigates the profit inefficiency, and its allocative and technical inefficiency components. Such an analysis would assess the effect of the current quota system on output supply and input demand. The current milk-quota system is expected to drive a wedge between profit-maximizing allocation of inputs and outputs on the one hand, and technically optimal input and output allocation on the other hand (Lovell and Sickles, 1983).

Given the drawbacks of a static approach, and the possibilities of assuming profit-maximizing behavior, our research objective was to analyze the dynamic profit inefficiency of the Belgian dairy farms under the current milk-quota system and decompose dynamic profit inefficiency in two novel ways. First, we determined the contributions of outputs, variable inputs and dynamic factor inputs to dynamic profit inefficiency. Second, we calculated the contributions of technical and allocative inefficiency in each output and input inefficiency. Doing so allowed us to identify the degree of underproduction of output and under- or overuse of inputs.

The empirical application focuses on Belgian specialized dairy farms from 1996–2008. The dynamic profit inefficiency measure Silva et al. (2015) developed compares the firm's actual long-run profit to the maximally possible (benchmarked) long-run profit. It is calculated by a nonparametric Data Envelopment Analysis (DEA) framework. In summary, this study contributes to the literature by being the first study to apply the dynamic profit inefficiency framework and analyzing the distorting effects of the current milk-quota system in a framework that separately disentangles technical and allocative inefficiency in the production of outputs and use of inputs.

The remainder of the paper is structured as follows. In the next section, we describe the theoretical background of the dynamic profit inefficiency measure and translate this theory to a DEA model. The third section describes our data.

The fourth section shows the results. We discuss these results in the fifth section. Finally, the sixth section concludes this paper.

5.2. Dynamic Profit Inefficiency

We start from a dynamic, inter-temporal, profit-maximization problem to assess allocative inefficiency and technical inefficiency of outputs and variable, dynamic factor inputs. The intertemporal profit-maximization problem assumes that the firm maximizes the discounted flow of profits over time at any base period $t \in [0, +\infty[$, while being restricted by the adjustment-cost directional technology distance function. The firm faces competitive variable input, output, and capital markets in that all corresponding prices cannot be affected by the firm. It updates its expectations regarding these prices as the base period changes. In addition, all firms have identical, static expectations on the discount and depreciation rates. The inter-temporal profit maximization problem is defined as follows:

(1) $$J(p, K_t, w, c) = \max_{\{y,x,I\}} e^{-rs} \int_t^{+\infty} [p_s{}'y_s - w_s{}'x_s - c_s{}'K_s]\, ds$$

s.t.

$\dot{K}_s = I_s - \delta' K_s$ with $K_t = K_{t_0}$

$\vec{D}_T(x_s, I_s, y_s, K_s;\ g_x, g_I, g_y) \geq 0$ with $s \in [0, +\infty[$

where $J(.)$ is the present value form of dynamic profit maximization, $y \in \mathbb{R}_+^M$ is the output vector, $x \in \mathbb{R}_+^N$ is the input vector, $K_t \in \mathbb{R}_+^F$ is the initial capital vector, $I \in \mathbb{R}_+^F$ is the investment vector, $p \in \mathbb{R}_+^M$ is the vector of output prices, $w \in \mathbb{R}_+^N$ is the vector of input prices, $c \in \mathbb{R}_+^F$ is the vector of capital prices, $\vec{D}_T(.)$ is the adjustment-cost directional technology distance function, (g_x, g_I, g_y) is the corresponding directional vector in terms of inputs, investment and outputs, respectively, $r \geq 0$ is the rental rate, and $\delta \in \mathbb{R}_+^F$ is the depreciation rate. The directional distance function $\vec{D}_T(.)$ provides a measure of the distance of y, x and I to the frontier in the direction defined by the directional vectors g_y, g_x and g_I, respectively. The characterization of the directional distance function follows Silva et al. (2015) who develop the directional input distance function.

In what follows, it is convenient to use the current value formulation of (1), i.e. the Hamilton-Jacobi-Bellman (H-J-B) equation (Caputo, 2005: 528):

$$(2) \qquad rJ(p,K,w,c) = \max_{\{y,x,I\}}\{p'y - w'x - c'K + J_K(p,K,w,c)'(I - \delta'K)\}$$

s.t. $\vec{D}_T(x,I,y,K;\ g_x,g_I,g_y) \geq 0$

where K is a vector of quasi-fixed factors in the base period.

The H-J-B equation in (2) is represented by the following DEA problem:

$$(3) \qquad rJ(p,K,w,c) = \max_{\{y,x,I,\gamma\}}\{p'y - w'x - c'K + J_K(.)'(I - \delta K)\}$$

s.t.

$$y_m \leq \sum_{j=1}^{J} \gamma^j y^j, m = 1, \dots, M$$

$$\sum_{j=1}^{J} \gamma^j x^j \leq x_n, n = 1, \dots, N$$

$$(I_f - \delta_f K_f) \leq \sum_{j=1}^{J} \gamma^j (I_f^j - \delta_f K_f^j), f = 1, \dots, F$$

$$\sum_{j=1}^{J} \gamma^j L^j \leq L_z, z = 1, \dots, Z$$

$$\sum_{j=1}^{J} \gamma^j = 1$$

$$\gamma^j \geq 0, j = 1, \dots, J$$

$$y_m \geq 0, m = 1, \dots, M$$

$$x_n \geq 0, n = 1, \dots, N$$

$$I_f \geq 0, f = 1, \dots, F$$

The first four constraints impose restrictions on the outputs, inputs, investments and fixed factors, respectively. The fifth constraint allows for a variable returns to scale technology. The last four constraints ensure non-negativity of the optimal choice variables.

Following Silva et al. (2015), we define the dynamic profit inefficiency (PI) as:

$$(4) \qquad PI = \frac{rJ(.) - [p'y - w'x - c'K + J_K(.)'(I - \delta' K)]}{p'g_y + w'g_x + J_K(.)'g_I}$$

PI is a normalized deviation between the maximum shadow profit and the shadow profit of the actual choices. The normalizing factor is the shadow value of the direction vector. Consequently, PI is a dimensionless measure.

The dynamic directional distance function measures dynamic technical inefficiency (TI) for each firm[9]. The overall TI for each observation i is calculated by the following linear programming problem:

$$(5) \qquad \vec{D}_T(x, I, y, K, L;\ g_x, g_I, g_y) = \max_{\beta,\gamma} \beta$$

s.t.

$$y_m + \beta g_{y_m} \leq \sum_{j=1}^{J} \gamma^j y^j, m = 1, \dots, M$$

$$\sum_{j=1}^{J} \gamma^j x^j \leq x_n - \beta g_{x_n}, n = 1, \dots, N$$

$$(I_f - \delta_f K_f) + \beta g_{I_f} \leq \sum_{j=1}^{J} \gamma^j (I_f^j - \delta_f K_f^j), f = 1, \dots, F$$

[9] In this study, we assume that the directional vectors of variable inputs, investment and outputs are equal to $g_{x_n} = x_n$, $g_{I_f} = I_f$ and $g_{y_m} = y_m$, respectively. This means that $\vec{D}_T(.)$ can be interpreted as the maximum proportional contraction of variable inputs and simultaneously the maximum proportional expansion of dynamic factors and outputs.

$$\sum_{j=1}^{J} \gamma L^j \leq L_z^j, z = 1, \dots, Z$$

$$\sum_{j=1}^{J} \gamma^j = 1$$

$$\gamma^j \geq 0, j = 1, \dots, J$$

This maximization problem solves for each firms dynamic technical inefficiency β and the vector of firm weights γ. The first, second and third constraint imply strong disposability of outputs, inputs, and investments, respectively. The fourth constraint defines the fixed factors of production. The assumption of variable returns to scale is reflected by the fifth constraint. The sixth constraint guarantees non-negativity of γ.

This paper decomposes overall profit inefficiency to identify the contributions of outputs, inputs and investments. (4) can be rewritten to identify the contributions of output (PI_{py}) variable input (PI_{wx}) and investments ($PI_{J_K I}$) to profit inefficiency:

$$(6) \qquad PI = PI_{py} + PI_{wx} + PI_{J_K I}$$

where $PI_{py} = \frac{p'(y^* - y)}{p'g_y + w'g_x + J_K(.)'g_I}$, $PI_{wx} = \frac{w'(x - x^*)}{p'g_y + w'g_x + J_K(.)'g_I}$, $PI_{J_K I} = \frac{J_K(.)'(I^* - I)}{p'g_y + w'g_x + J_K(.)'g_I}$.

PI_{py}, PI_{wx} and $PI_{J_K I}$ are the normalized deviations of actual from optimal output y^*, input x^* and investments I^*, respectively.

Following Chambers et al. (1996) for the proof in the static case, profit inefficiency can also be decomposed into the contributions of allocative inefficiency (AI) and technical inefficiency (TI):

$$(7) \qquad PI = AI + TI$$

with $TI = \vec{D}_T(.)$

Analogous to the decomposition of profit inefficiency in (6), PI_{py}, PI_{wx} and $PI_{J_K I}$ are further decomposed into the contributions of allocative and technical inefficiency in each output, variable input and quasi-fixed factor of production. Respectively denoting allocative inefficiency of outputs, inputs and investments as AI_{py}, AI_{wx} and $AI_{J_K I}$ and corresponding technical inefficiency components as TI_{py}, TI_{wx} and $TI_{J_K I}$, we have:

(8) $$PI_{py} = AI_{py} + TI_{py}$$

with $TI_{py} = \frac{p' g_y}{p' g_y + w' g_x + J_K(.)' g_I} TI$

(9) $$PI_{wx} = AI_{wx} + TI_{wx}$$

with $TI_{wx} = \frac{w' g_x}{p' g_y + w' g_x + J_K(.)' g_I} TI$

(10) $$PI_{J_K I} = AI_{J_K I} + TI_{J_K I}$$

with $TI_{J_K I} = \frac{J_K(.)' g_I}{p' g_y + w' g_x + J_K(.)' g_I} TI$

The sum of the partial technical inefficiencies is equal to the total technical inefficiency:

(11) $$TI_{py} + TI_{wx} + TI_{J_K I} = TI$$

Likewise, the sum of the partial allocative inefficiencies is equal to the total allocative inefficiency:

(12) $$AI_{py} + AI_{wx} + AI_{J_K I} = AI$$

The shadow value of capital $J_K(.)$ is implicit and endogenous. We find values for $J_K(.)$ by estimating a normalized quadratic functional approximation of $J(.)$ with the price of the variable inputs w as the *numéraire*, eventually enabling a calculation of $J_K(.)$[10].

5.3. Data and Descriptive Statistics

This study uses data from Belgian specialized dairy farms from 1996–2008. Data on quantities of outputs, variable inputs, quasi-fixed capital inputs, investments, and fixed factors are obtained from the Farm Accountancy Data Network (FADN). We only select specialized dairy farms that obtained an average 80 percent of their total output from milk production, in order to achieve a homogenous sample of farms. We consider two outputs (milk and meat), four variable inputs (seed, fertilizer, feed, and energy), two quasi-fixed capital inputs with their corresponding investments (buildings and machinery), and two fixed factors (agricultural land and total labor).

Labor is assumed to be a fixed factor because the procedure of hiring additional workers is sluggish and since a large proportion of labor comes from family members. The expenditures of outputs, variable inputs and capital and investment in dynamic factors are expressed in constant 1996 price. Agricultural land and total labor are respectively expressed in hectares and annual working hours. Price indexes of outputs, variable inputs and capital are obtained from the EUROSTAT (2015) database and aggregated to Törnqvist price indexes. These price indexes

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[10] $$J(p,K,w,c,L) = A_0 + \begin{bmatrix} A_p & A_K & A_w & A_c & A_L \end{bmatrix} \begin{bmatrix} \frac{p}{w} \\ K \\ 1 \\ \frac{c}{w} \\ L \end{bmatrix} + \frac{1}{2} \begin{bmatrix} \frac{p}{w} & K & 1 & \frac{c}{w} & L \end{bmatrix} \begin{bmatrix} A_{pp} & A_{pK} & A_{pw} & A_{pc} & A_{pL} \\ A_{Kp} & A_{KK} & A_{Kw} & A_{Kc} & A_{KL} \\ A_{wp} & A_{wK} & A_{ww} & A_{wc} & A_{wL} \\ A_{cp} & A_{cK} & A_{cw} & A_{cc} & A_{cL} \\ A_{Lp} & A_{LK} & A_{Lw} & A_{Lc} & A_{LL} \end{bmatrix} \begin{bmatrix} \frac{p}{w} \\ K \\ 1 \\ \frac{c}{w} \\ L \end{bmatrix}$$

To ensure symmetry of the matrix with the quadratic coefficients, we assume that $A_{pK} = A_{Kp}$, $A_{pw} = A_{wp}$, $A_{pc} = A_{cp}$, $A_{pL} = A_{Lp}$, $A_{Kw} = A_{wK}$, $A_{Kc} = A_{cK}$, $A_{KL} = A_{LK}$, $A_{wc} = A_{cw}$, $A_{wL} = A_{Lw}$, and $A_{cL} = A_{Lc}$.

vary over years, but not over farms. This implies that differences in the composition of outputs, variable inputs and capital or quality differences are revealed by the quantity (Cox and Wohlgenant 1986). The implicit aggregated quantity indexes of outputs, variable inputs, and capital, which are implemented in the DEA models, are generated as the ratio of the value to the price index. Following Serra et al. (2011), the rental cost price of capital is defined as $c_i = (r + \delta_i)z_i$, where r is the interest rate, δ_i is the depreciation rate and z_i is the Törnqvist price index for capital. The interest rate r is the average annual interest-rate for ten-year government bonds over the period 1996-2008, and is equal to 4.69% (EUROSTAT 2015). The depreciation rate of buildings and machinery is assumed to be 15 percent in both cases. The final dataset contains 1,295 observations for 254 dairy farms. Table 1 presents the descriptive statistics of the dataset.

Table 1. Descriptive Statistics of the Dataset (1,295 Observations for 254 Dairy Farms).

Variables	Unit	Mean	Minimum	Maximum	Std. dev.
Output quantities	Constant 1996 €	123,267	17,185	310,620	45,344
Variable input quantities	Constant 1996 €	29,680	6,933	92,896	13,157
Capital	Constant 1996 €	114,243	4,032	623,049	84,040
Investment	Constant 1996 €	16,680	0	531,643	40,305
Total labor	Hours	4,564	1,560	12,743	1,255
Agricultural land	Hectares	42	12	111	18
Price index of output	Dimensionless	0.949	0.842	1.032	0.059
Price index of variable inputs	Dimensionless	0.967	0.898	1.201	0.072
Price index of capital	Dimensionless	1.042	1.000	1.166	0.056

5.4. Results

Table 2 shows the average, dynamic profit inefficiency scores and its components of outputs, variable inputs, and dynamic factor inputs from 1996–2008. The dynamic profit inefficiency is an average 0.405. The decomposition of profit inefficiency into the contributions of outputs, inputs, and investments in dynamic factor inputs shows that dynamic inefficiency is mainly caused by underproduction of outputs (0.482) and underuse of variable inputs (-0.081). The contribution of the investment in dynamic factors only plays a very minor role (0.005), implying that Belgian dairy farmers' actual investments in dynamic factor inputs are close to optimal investments. For this reason, we only decompose the inefficiency of output production and variable input use. The average dynamic profit inefficiency varies between 0.311 and 0.478 (standard deviation = 0.049).

Table 2. Profit Inefficiency Disentangled in Output Inefficiency, Input Inefficiency and Investment Inefficiency.

Year	Profit Inefficiency	Output Inefficiency	Input Inefficiency	Investment Inefficiency
Average	0.405 (0.049)	0.482 (0.048)	-0.081 (0.024)	0.005 (0.009)
1996	0.333	0.414	-0.083	0.003
1997	0.363	0.453	-0.089	-0.001
1998	0.425	0.498	-0.069	-0.004
1999	0.464	0.503	-0.052	0.013
2000	0.478	0.578	-0.105	0.005
2001	0.390	0.532	-0.143	0.000
2002	0.311	0.393	-0.085	0.003
2003	0.403	0.478	-0.071	-0.004
2004	0.392	0.483	-0.091	0.000
2005	0.408	0.473	-0.087	0.021
2006	0.427	0.456	-0.048	0.019
2007	0.460	0.518	-0.069	0.012
2008	0.416	0.487	-0.067	-0.003

Note: Standard deviations of average inefficiencies between parentheses

Table 3 presents the decomposition of output inefficiency in output technical inefficiency and output allocative inefficiency. On average, allocative inefficiency (0.370) made a larger contribution to dynamic profit inefficiency (0.482) than did technical inefficiency (0.112). Furthermore, Table 3 shows that output would, on average, have expanded by €46,014 (in constant 1996 €) if all firms were allocatively efficient in terms of their output production. In relative terms, this means an average potential increase of output of 46.46 percent.

Table 3. Output Inefficiency Disentangled in Output Technical Inefficiency and Output Allocative Inefficiency, and Relative Allocative Output Expansion and Absolute Allocative Output Expansion if Firms Were Allocatively Efficient.

Year	Output Inefficiency	Output Technical Inefficiency	Output Allocative Inefficiency	Relative Allocative Output Expansion (in %)	Absolute Allocative Output Expansion (in constant 1996 €)
Average	0.482 (0.048)	0.112 (0.014)	0.370 (0.049)	46.46 (5.95)	46,014 (8,109)
1996	0.414	0.118	0.295	37.46	31,732
1997	0.453	0.107	0.347	42.88	37,586
1998	0.498	0.115	0.383	46.99	41,142
1999	0.503	0.137	0.366	45.02	43,929
2000	0.578	0.119	0.459	56.35	57,426
2001	0.532	0.093	0.439	53.63	59,140
2002	0.393	0.102	0.291	35.94	38,343
2003	0.478	0.114	0.363	45.08	53,087
2004	0.483	0.086	0.397	49.81	50,131
2005	0.473	0.108	0.365	46.08	47,614
2006	0.456	0.129	0.327	42.75	39,986
2007	0.518	0.122	0.396	50.25	48,529
2008	0.487	0.102	0.385	51.71	49,535

Note: Standard deviations of average inefficiencies between parentheses

Table 4 presents variable input inefficiency and its decomposition into input technical inefficiency and input allocative inefficiency. This table shows the relative allocative input expansion and absolute allocative input expansion if firms were allocatively efficient in terms of their variable input use. The overuse of variable inputs due to technical inefficiency (0.031) is cancelled out by the underuse due to allocative inefficiency (-0.112), resulting in an input inefficiency of an average -0.081. Variable input use would, on average, have expanded by €13,659 (in constant 1996 €) if all firms were allocatively efficient in terms of their variable input use. This corresponds to a relative expansion of the use of variable inputs by 62.47 percent.

Table 4. Input Inefficiency Disentangled in Input Technical Inefficiency and Input Allocative Inefficiency, and Relative Allocative Input Expansion and Absolute Allocative Input Expansion if Firms Were Allocatively Efficient.

Year	Input Inefficiency	Input Technical Inefficiency	Input Allocative Inefficiency	Relative Allocative Input Expansion (in %)	Absolute Allocative Input Expansion (in constant 1996 €)
Average	-0.081 (0.024)	0.031 (0.005)	-0.112 (0.021)	62.47 (13.53)	13,659 (3,647)
1996	-0.083	0.037	-0.121	61.92	13,454
1997	-0.089	0.030	-0.120	67.33	13,258
1998	-0.069	0.030	-0.098	60.75	11,488
1999	-0.052	0.033	-0.085	51.09	9,988
2000	-0.105	0.030	-0.135	77.36	17,387
2001	-0.143	0.024	-0.166	96.27	22,994
2002	-0.085	0.027	-0.112	64.31	13,839
2003	-0.071	0.031	-0.102	58.65	14,390
2004	-0.091	0.024	-0.115	63.51	15,069
2005	-0.087	0.028	-0.114	64.50	14,387
2006	-0.048	0.037	-0.085	42.92	9,504
2007	-0.069	0.034	-0.103	56.24	12,415
2008	-0.067	0.036	-0.103	47.23	9,389

Note: Standard deviations of average inefficiencies between parentheses

Table 5 shows the technical and allocative inefficiency scores for groups of small, medium and large farms. We follow the FADN guidelines for the size classification of our dataset. Small farms are 16–40 Economic Size Units (ESUs), medium farms are 40–100 ESUs, and large farms are > 100 ESUs. Dynamic profit inefficiency of small, medium, and large farms is, respectively, an average 0.473, 0.452 and 0.208. The output allocative inefficiency of small, medium, and large farms is, respectively, 0.490, 0.421 and 0.153. If the farms were producing allocatively efficiently in terms of their output, then output would respectively expand by €34,279 (60.43 percent), €52,196 (52.56 percent) and €25,567 (19.72 percent) expressed in constant 1996 €. The output technical inefficiency is, respectively, 0.091, 0.123 and 0.070 for small, medium, and large farms. The variable input allocative inefficiency of small, medium, and large farms is, respectively, -0.132,

-0.129 and -0.044. The underuse of variable inputs thus decreases with farm size. If the farms were producing in an allocatively efficient way with respect to variable inputs, then variable input use would respectively expand by €9,790 (75.10 percent), €15,907 (71.82 percent) and €6,161 (25.83 percent), expressed in constant 1996 €. The variable input technical inefficiency respectively changes from 0.025, to 0.033, and back to 0.020 for small, medium, and large farms.

Table 5. Inefficiency Classified by Size.

Inefficiency Characteristics	Small Size (16 – 40 ESU)	Medium Size (40 – 100 ESU)	Large Size (> 100 ESU)	Full Sample
Total Profit Inefficiency	0.473 (0.467)	0.452 (0.294)	0.208 (0.271)	0.408 (0.313)
Output Allocative Inefficiency	0.490 (0.562)	0.421 (0.327)	0.153 (0.302)	0.374 (0.350)
Relative Allocative Output Expansion (in %)	60.43 (67.67)	52.56 (40.91)	19.72 (43.32)	46.74 (44.54)
Absolute Allocative Output Expansion (in constant 1996 €)	34,279 (35,111)	52,196 (35,296)	25,567 (36,947)	46,576 (37,120)
Output Technical Inefficiency	0.091 (0.104)	0.123 (0.088)	0.070 (0.072)	0.112 (0.088)
Input Allocative Inefficiency	-0.132 (0.157)	-0.129 (0.100)	-0.044 (0.103)	-0.113 (0.108)
Relative Allocative Input Expansion (in %)	75.10 (97.71)	71.82 (60.06)	25.83 (51.50)	63.34 (62.96)
Absolute Allocative Input Expansion (in constant 1996 €)	9,790 (10,810)	15,907 (11,437)	6,161 (15,638)	13,867 (12,888)
Input Technical Inefficiency	0.025 (0.031)	0.033 (0.029)	0.020 (0.026)	0.031 (0.029)
Observations	48	1,006	241	1,295

Note: The size is expressed in terms of Economic Size Units (ESUs). The standard deviations are between parentheses.

5.5. Discussion

The results of this study suggest that there is high dynamic profit inefficiency under the current dairy-quota system. The inefficiency is mainly caused by allocative inefficiency in producing outputs and using variable inputs. Assuming cost-minimizing behavior, many studies also decompose economic inefficiency of dairy farms into technical and allocative inefficiency. Several studies established that allocative inefficiency is the main driver of economic inefficiency, in line with our results. Kelly et al. (2012) applied nonparametric techniques and obtained a technical inefficiency of 0.23 and an allocative inefficiency of 0.26 for a sample of Irish dairy farms. Sauer (2010) used a Bayesian distance approach and found a technical inefficiency of 0.01–0.08, and an allocative inefficiency of 0.64–0.70, for a sample of Danish dairy farms.

Our results contrast with results found from a number of other studies. For a sample of Italian dairy farms, Maietta (2000) obtained a technical inefficiency of 0.45 and an allocative inefficiency of 0.17, using the stochastic frontier approach. Reinhard and Thijssen (2000) also used the stochastic frontier approach and found a technical inefficiency of 0.15 and an allocative inefficiency of 0.05 for a sample of Dutch dairy farms. Serra et al. (2011) parametrically estimated a directional distance function for a sample of Dutch dairy farms. They found a technical inefficiency of 0.10 and an allocative inefficiency of 0.02. The ambiguity regarding the importance of allocative inefficiency may not only be explained by differences in policy but also by the fact that the radial input-orientation of the cost-minimizing behavioral assumption does not take into account the considerable allocative inefficiency in production of outputs due to the distortion effects of the milk-quota system. Therefore, our results are not directly comparable with the results of the studies mentioned.

Several studies solely concentrated on the technical inefficiency of dairy farms. Reinhard et al. (2000) calculated an output-oriented technical inefficiency of 0.11 (when stochastic frontier analysis was used) and 0.22 (when DEA was used) for a sample of Dutch dairy farms. Another study of Dutch dairy farms used nonparametric techniques and derived an input-oriented technical inefficiency of 0.22–0.24 (Steeneveld et al., 2012).

For a milk-quota market that is free of restrictions, economic theory argues that efficient firms will be net purchasers of milk quota and inefficient firms will be net sellers of milk quota (Alvarez et al., 2006). However, the Belgian milk-quota system has mixed-market regulations. The administration sets the price of, and regulates, transfers (prioritizing younger farmers) of forty percent of the total milk quota. Sixty percent of the total market quota can be traded between the producers within the distinct trading regions of Flanders and Wallonia. Moreover, there are strict regulations within each trading region. In Flanders, dairy farmers can only trade within a radius of 30 km (with the exception of family members). Walloon dairy farmers are constrained geographically by cadre. Although there is a market for milk quota, as opposed to in France, there are strict regulations that make the Belgian milk-quota system less competitive than in the Netherlands and the United Kingdom (DG Agriculture 2008). Sauer (2010) showed that the Danish deregulatory measure of setting up a bi-annual milk-quota exchange in 1997 decreased the allocative inefficiency of dairy farms, while the effect on technical inefficiency was insignificant. The lack of competition in the Belgian milk-quota market may exacerbate the allocative inefficiency problem, so that removing the milk-quota system could result in a larger expansion of dairy output and use of variable inputs.

Our results also showed that dynamic profit inefficiency decreases as farm size increases. This is driven by allocative, rather than technical, inefficiency. The relationship between technical inefficiency and farm size is unclear. Maietta (2000) also found that there was a negative relationship between allocative inefficiency and farm size, and an uncertain relationship between technical inefficiency and farm size. As a consequence, in combination with the compounding problems of efficiency losses associated with the highly regulated dairy-quota system, abolishing the dairy-quota system would likely be coupled with a substantial decrease of allocative inefficiency. This would result in a considerable expansion of variable inputs use and output production. Relatively smaller farms are particularly susceptible to these changes. Note that our analysis does not take into account the likely decreases of milk prices after the milk quota abolishment. Therefore, the actual decrease in allocative inefficiency and subsequent increase in demand for variable inputs and supply of output after the milk quota abolishment will probably be lower.

This paper complements other recent research on the potential impact of abolishing the milk-quota system. An applied general equilibrium analysis by Lips and Rieder (2005) predicted a modest output growth of 3 percent, and a decline of the milk price of 22 percent in the EU-15 as a whole. In Belgium, output would decline by 0.2 percent, and the milk price would decrease by 19.5 percent. By means of the Dutch Regional Agricultural Model, Jongeneel et al. (2010) forecasted a 10 percent increase of Dutch milk output. Estimating the marginal cost curve for a panel of Belgian dairy farms, de Frahan et al. (2011) put forward that quota removal would increase aggregate milk supply if milk prices remain the same. In accordance with our results, the predicted output expansion decreases for increasing farm size. Using the same size classifications, their simulation indicates a respective expansion of output production of 58 percent and 22 percent for small and medium farms, and a decline of 19 percent for large farms.

5.5. Conclusions

Using a DEA framework, we analyze the dynamic profit inefficiency for a sample of Belgian specialized dairy farms for 1996–2008. In contrast to the static efficiency measures that dominate in the literature, the dynamic perspective starts from an inter-temporal optimization framework, in which long-run decisions about investment are taken into account. The results point out that many Belgian dairy farmers are inefficient in dynamically maximizing their inter-temporal profit. A more detailed analysis indicates that the allocative inefficiency of variable input use and output production is the biggest driver of this dynamic profit inefficiency. Over- and under-investment in dynamic factors, such as buildings and machinery, are unimportant. We estimate an average underproduction of approximately 50 percent and an average underuse of variable inputs of approximately 60 percent due to allocative inefficiency. However, this effect is much more pronounced for small and medium farms than for large farms.

These results should be seen in light of the current milk-quota system. Abolishing the milk-quota system in 2015 will have a significant effect on the Belgian dairy sector. This study shows that allocative, rather than technical, inefficiency is the source of dynamic profit inefficiency. For small farms, removing the milk-quota system may result in a drastic expansion of variable input use and output production.

This research could be extended in several ways. First, it would be interesting to calculate the dynamic profit inefficiencies for other countries. The milk-quota system holds for all member countries of the European Union. Nevertheless, as each country individually decides about concrete implementation, there is a substantial heterogeneity in the organization of the milk quota. A comparison of Belgium's mixed-market system to a competitive market system (for example, the Netherlands) and a system in which quotas are distributed top-down from the administration to the farmers (for example, France) would shed additional light on the relationship between competitiveness and efficiency. Second, a more elaborate analysis of the drivers of dynamic profit inefficiency could provide more guidance to policy makers. Finally, this research could be used to conduct a simulation exercise for various future scenarios. Because we essentially study the past behavior of farmers, a focus on future scenarios taking into account plausible future developments (such as price dynamics) could be worthwhile.

6. Quota and Dynamic Inefficiency: An Application to Belgian Dairy Farms

Frederic Ang, Steven Van Passel, Erik Mathijs and Alfons Oude Lansink

Abstract

Using Data Envelopment Analysis, this paper assesses the impact of quota trade on technical and scale inefficiency for a sample of Belgian, specialised dairy farms from 2004-2008. We use the subsample bootstrap method of Simar et al. (2012) to estimate bias-corrected directional distance functions which are employed for assessing the impact of quota trade by means of an ordinary least squares, differenced and fixed-effects model. The results show that purchasing milk quota does not significantly affect technical inefficiency, but significantly decreases scale inefficiency.

6.1.Introduction

Output and input quota are frequently used by policy makers to curb pollutant generation or overproduction. Well-known examples include the Kyoto protocol and production quota in the agricultural sector (e.g., milk and sugar quota). Implementation of quota increases the sector's economic inefficiency. Particularly command-and-control regulations have a detrimental impact. According to economic theory, the inefficiency due to quota can however be diminished by allowing for quota trade such that the more efficient firms can buy permits from inefficient firms (Alvarez et al., 2006).

Various applications draw on nonparametric techniques to assess the impact of a quota system on inefficiency at the industrial and firm level. Färe et al. (2013) compute the transaction costs of the US SO_2 permit market by *ex post* by comparing the technical inefficiency of a sample of coal fired power plants to (simulated) command-and-control conditions. Several studies focus on the agricultural sector. Andersen and Bogetoft (2007) assess the potential gains from the individual fish quota trade in Denmark. Nielsen (2012) and Oude Lansink and van der Vlist (2008) respectively apply a similar framework to nitrogen quota in Danish fresh water aquaculture and CO_2 quota in Dutch glasshouses. Bogetoft et al. (2007) calculate the optimal reallocation of sugar beet contracts in Denmark under the current sugar quota regime.

Although these applications evaluate a quota system by analysing the firm's and industry's inefficiency, they do not take into account the impact of quota trade itself on the firm's performance. Purchasing, leasing, selling and renting quota may affect the individual farm's technical and scale inefficiency. Next to a *macro*-perspective on quota markets, a *micro*-perspective that considers activity in a quota market would increase the understanding of the relationship between quota markets and inefficiency.

In contrast to the high number of studies focusing on the macro-perspective, there are to our knowledge only two studies that establish the link between the quota market and (in)efficiency at the micro level. Breustedt et al. (2011) directly include milk quota ownership as non-discretionary fixed factors in a nonparametric framework. Although this methodology does not directly assess the impact of milk quota on efficiency, it is able to compare profit efficiency scores with and without milk quota use. They conclude that milk quota use increases profit potential.

Using Stochastic Frontier Analysis, Areal et al. (2012) directly include purchases, sales, leasing-in and leasing-out of milk quota as conventional inputs and outputs in their calculation of the technical efficiency of UK dairy farms. They conclude that being efficient is correlated with purchasing milk quota, but are careful to not claim that this correlation is in fact a causal relationship. Indeed, as they point out, there is a major reverse causality concern since more efficient farmers are inherently inclined to buy milk quota from inefficient farmers. Moreover, although Areal et al. (2012) allow for Variable Returns to Scale by choosing a Translog functional form, they do not only analyse the scale efficiency.

However, insight in the impacts of quota trade on farm's performance is particularly relevant in the light of the abolishment of the milk quota system in 2015. Ang and Oude Lansink (2014) pointed out that such an abolishment may lead to a substantial increase in allocative efficiency and as a result a considerable expansion of production and variable input use. Dairy farmers can choose to continue to operate at a small scale and sell milk quota, or not to participate to the milk quota market. They can also opt to purchase milk quota and prepare for expansion of milk production after abolishment of the quota system. However, investments in additional dairy quota and scale increases may cause substantial adjustment costs such as search costs and costs of learning to use new technologies or costs to learn to operate the expanded farm. These adjustment costs may decrease the farms' economic and technical performance in the short-term, but may confound with technical inefficiency increases if not accounted for properly. On the other hand, scale expansion may allow farms to produce at a more efficient scale. This ambiguity clarifies the importance of analysing technical *and* scale efficiency and the need of accounting for the adjustment costs in analysing the impacts of dairy quota trade. The existing literature on analysing the impacts of dairy quota trade used a static production economics framework that does not explicitly account for dynamic interlinkages of production decisions over time. Such interlinkages can be accounted for by using a dynamic framework such as the one developed by Silva et al (2015), Kapelko et al. (2014) and Serra et al. (2012).

The objective of this paper is to investigate the impact of activity in the milk quota market on dynamic technical and scale inefficiency. The empirical application focuses on panel data of Belgian dairy farms over the period 2004-2008. The paper uses Data Envelopment Analysis (DEA), to estimate dynamic technical and scale inefficiency. Next, we employ the novel sub-sampling bootstrap method of Simar et al. (2012) to correct for the downward bias of the DEA estimates. Finally, we estimate the relationship between quota purchases and the bias-corrected technical and scale inefficiency using ordinary least squares model, first-differenced and fixed effects models. We contribute to the existing literature by (1) assessing the causal relationship between activity in the milk quota market and dynamic technical and scale inefficiency by using a novel bootstrapping procedure (2) by taking into account the costs of adjustment associated with investments in quota.

The remainder of this paper is organised as follows. In the next section, we describe the methodology of assessing dynamic technical and scale inefficiency and the impact of milk quota purchases hereon. This is followed by a description of the data in the third section. The results are discussed in the fourth section. Finally, the fifth section concludes this paper.

6.2.Methodology

6.2.1. Technical and Scale Inefficiency

The dynamic directional distance function measures dynamic technical inefficiency β for each firm[11]. This measure extends Chambers (1998) by also considering investments in quasi-fixed capital. We refer to Ang and Oude Lansink (2014) and Silva et al. (2015) for a more elaborate description of the dynamic production theoretical framework. It is in this context useful to define the production set Ψ that represents all technically feasible combinations of P input quantities x, Q

[11] We will use the terms (dynamic) directional distance function and (dynamic) technical inefficiency interchangeably.

output quantities y, and R quasi-fixed capital factors K with corresponding depreciation rates δ and investments I:

$$\Psi = \{(x, y, I) \in \mathbb{R}_{+}^{P+Q+R} | (x, I) \text{ } can \text{ } produce \text{ } y\}$$

The dynamic directional distance function is inferred as follows[12]:

$$d(x, y, I, K | g_x, g_y, g_I, \Psi) = \sup\{d | (x - \beta g_x, y + \beta g_y, (I - \delta K) + \beta g_I) \in \Psi\}$$

We calculate the corresponding DEA estimator $\hat{d}_{DEA}$ for each farm by solving the following linear programming problem:

$$(1) \qquad \hat{d}_{DEA}(x, I, y, K, L;\ g_x, g_I, g_y) = \max_{d,\gamma} \mathrm{d}$$

s.t.

$$\sum_{j=1}^{J} \gamma^j x^j \leq x_p - d g_{x_p}, p = 1, \dots, P$$

$$y_q + d g_{y_q} \leq \sum_{j=1}^{J} \gamma^j y^j , q = 1, \dots, Q$$

$$(I_r - \delta_r K_r) + d g_{I_r} \leq \sum_{j=1}^{J} \gamma^j (I_r^j - \delta_r K_r^j), r = 1, \dots, R$$

$$\sum_{j=1}^{J} \gamma^j L^j \leq L_s, s = 1, \dots, S$$

$$\gamma^j \geq 0, j = 1, \dots, J$$

$$d \geq 0$$

[12] We assume that the directional vectors of variable inputs, outputs and investments are respectively equal to $g_x = x$, $g_y = y$, and $g_I = I$. This means that $d(.)$ can be interpreted as the maximum proportional contraction of variable inputs and simultaneously is the maximum proportional expansion of outputs and dynamic factors.

This maximisation problem solves for each firm's dynamic directional distance function d and the vector of firm weights γ. The first, second, and third constraints respectively imply strong disposability of outputs, inputs, and investments. The fourth constraint defines the fixed factors of production. The last two constraints ensure non-negativity of γ^j and d. In this linear program, the production set is defined by the observed $(x, y, I - \delta K, L)$.

This representation supposes that the production frontier follows Constant Returns to Scale (CRS). Figure 1 shows that the CRS assumption would be the most productive scale, as the average product (output-input ratio) would be at its maximum. However, one would expect in a context of substantial market imperfections (e.g., milk quota and subsidies) that the average product would decline after a certain point (Banker et al., 2004). Given these concerns, we also calculate the technical inefficiency under the less restrictive Variable Returns to Scale (VRS) assumption. This entails an additional constraint for the maximisation problem of (1). The sum of the firm weights should be equal to unity: $\sum_{j=1}^{J} \gamma^j = 1$. For smaller scales ($x \leq A$), the VRS average product is lower than the CRS average product. As a result, VRS technical inefficiency is also lower to CRS technical inefficiency. Larger scales ($x > A$) result in diverging average product and technical inefficiency. The wedge between the dynamic directional distance functions under CRS and VRS assumptions is the 'scale inefficiency'. Since milk quota generally decrease scale, we also analyse scale inefficiency.

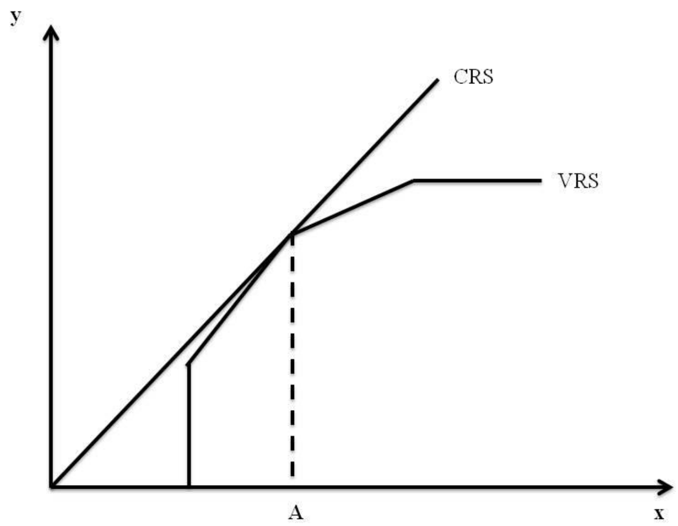

Fig. 1. Technical Inefficiency under CRS and VRS Assumptions.

6.2.2. Impact of Milk Quota

The effect of dairy quota trade on technical inefficiency is ambiguous a priori. The increase in production associated with the quantity of purchased milk quota may lead to learning inefficiencies, although our model takes these adjustment costs explicitly into account.

Milk quota purchases are expected to decrease scale inefficiency of farms that are operating in the region of increasing returns to scale. Large-scale farms are penalised in terms of technical inefficiency for the CRS assumption as the distance between the VRS and CRS specification is larger, it is theoretically possible that milk quota purchases will increase scale inefficiency. This is a likely scenario if the individual milk quota exceeds A of Figure 1. However, it is much more plausible that the milk quota system forces down the scale under the optimal scale due to the constraint on production. Larger scale leads in this case to more optimal return-to-scale characteristics, resulting in smaller scale inefficiency. This may occur if the individual milk quota is lower than A.

There are several issues that complicate assessing the relationshipo between technical inefficiency and quota purchases. First, technical inefficiency scores obtained by DEA are biased downward due to unfavourable small-sample characteristics (Simar and Wilson, 1998). Second, technical inefficiency scores are serially correlated in a complicated and unknown way (Simar and Wilson, 2007). Third, there may be reverse causality between technical inefficiency and quota purchases as more efficient farmers may be more inclined to buy milk quota, whereas less efficient farmers tend to sell them (Alvarez et al., 2006). As a result, the impact of buying/selling quota on reducing inefficiency is likely overestimated if one does not take into account this endogeneity problem.

Simar and Wilson (1998) propose to bootstrap the DEA estimators to counter the bias problem in radial distance functions. The difficulty of this exercise lies in the fact that a naïve bootstrapping procedure does not yield consistent estimators. Kneip et al. (2008) prove that both double-smoothing and sub-sampling techniques result in consistent estimators. The former procedure is computationally heavy, and although Kneip et al. (2011) provide a simplified consistent methodology, the latter procedure is significantly more practical. Simar et al. (2012) illustrate how both procedures can also be applied to directional distance functions by modifying the procedure for the radial counterpart. We opt for their sub-sampling bootstrap to ensure computational facility. The bias-corrected estimator for each farm i is calculated as follows:

(2) $$\hat{d}_{BC} = \hat{d}_{DEA} - (M/J)^{2/(P+Q+R+S+1)} \frac{1}{B} \sum_{b=1}^{B} \left(\hat{d}_b^* - \hat{d}_{DEA} \right)$$

where $\hat{d}_{DEA}$ is the DEA estimator of the directional distance function, $\hat{d}_{BC}$ is the bias-corrected estimator of the directional distance function, $\hat{d}_b^*$ is the naïve bootstrap estimator of the directional distance function for the sub-sample size M, B is the size of the bootstrap sample J is the full sample size, P is the number of inputs, Q is the number of outputs, R is the number of quasi-fixed capital factors, and S is the number of fixed factors. $\hat{d}_b^*$ is inferred by calculating the DEA estimators for the production set $\hat{\Psi}_b^*$, which is constructed by resampling a subsample of the observed $(x, y, I - \delta K, L)$ of size M, with replacement. Following Simar and Wilson (2011), M is chosen in such a way that the median volatility of the bias-correction term is minimised[13]. In order to check whether the bias-corrected estimates should be employed instead of the uncorrected estimates, we use the conservative rule of Efron and Tibshirani (1993), which states that the estimated bias should be larger than $\frac{1}{4}\sigma(\hat{\beta}_{DEA})$. We set $B = 1000$.

We make use of a differenced and fixed-effects model, controlling for unobserved heterogeneity. These models assume that this heterogeneity is correlated with the independent variables, but remains constant in time. We estimate the following regression by Ordinary Least Squares, First-Differencing and Fixed Effects:

$$\hat{d}_{BC,jt} = \beta_0 + \beta_1' X_{jt} + \beta_2' C_{jt} + v_j + \varepsilon_{jt} \quad (3)$$

where β_0 is the slope, X_{jt} is the vector of milk quota activities and β_1' is the corresponding vector of coefficients, C_{jt} is the vector of control variables and β_2' is the corresponding vector of coefficients, v_j is a time-constant unobservable firm-specific effect, and ε_{jt} is an i.i.d. error term. We calculate $\hat{d}_{BC,jt}$ per year, which implies year effects are not necessary in this specification.

6.3. Data and Descriptive Statistics

Data on Belgian specialised dairy farms[14] come from the European Farm Accountancy Data Network (FADN). The Belgian FADN dataset concerns an unbalanced panel that largely rotates the sample every five years. Therefore, we analyse a balanced panel dataset of 71 dairy farms per year for the period 2004-2008. We take into account two outputs (milk and meat), four variable inputs (seed, fertiliser, feed, and energy), two quasi-fixed capital inputs with their corresponding investments (buildings and machinery), and two fixed factors

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[13] In line with Simar and Wilson (2011), we calculate the standard deviation of the bias around $(M - k, \dots, M, \dots, M + k)$. We evaluate each $M \in \{1 + k, \dots, J - k\}$ for each farm separately. Following Hampf and Rodseth (2014), we set $k = 2$.

[14] Dairy farms that obtained an average 80 percent of their total output from milk production.

(agricultural land and total labour). Outputs, variable inputs and quasi-fixed capital inputs are calculated as implicit quantities. They are measured as expenditures deflated by Törnqvist price indexes (EUROSTAT, 2014). Because we restrict our analysis to specialised dairy farms and only analyse the dairy farms that are in the dataset for the entire period of five years, the dataset is skewed towards buyers and renters of milk quota (only two percent of the dairy farmers are sellers or leasers for this period). Consequently, we only consider milk quota purchases. Following Zhu and Oude Lansink (2010), we control for degree of subsidy dependency (ratio of farm subsidies to total farm revenues), farm size (in terms of European Size Units), family labour (ratio of family labour to total labour), rented land (ratio of rented land to total land), long-term debt (ratio of long and intermediate term loans to total assets) and short-term debt (ratio of short term loans to total assets). Table 1 presents the descriptive statistics of the dataset.

Table 1. Descriptive Statistics of the Dataset (355 Observations for 71 Dairy Farms)

Variables	Unit	Mean	Minimum	Maximum	Std. dev.
Output quantities	1,000 € (constant 1996 prices)	128.638	47.560	310.620	47.700
Variable input quantities	1,000 € (constant 1996 prices)	30.272	9.081	85.969	12.642
Capital	1,000 € (constant 1996 prices)	118.449	12.257	623.049	81.130
Investment	1,000 € (constant 1996 prices)	23.230	0	531.643	54.144
Total labour	Hours	4.555	1.560	10.200	1.340
Agricultural land	Hectares	46	12	106	19
Milk quota purchases	1,000 € (constant 1996 prices)	6.000	0	236.223	21.654
Rented land	Percentage	72.5	3.6	100	20.0
Family labour	Percentage	98.7	52.7	100	4.7
Long-term debt	Percentage	23.6	0	99.6	1.74
Short-term debt	Percentage	0.2	0	19.6	1.2
Subsidy dependence	Percentage	14.6	5.2	8.48	7.6

6.4. Results and Discussion

6.4.1. Technical and Scale Inefficiency

We present the summary statistics regarding technical and scale inefficiency in Table 2. $\hat{d}_{DEA,CRS}$ is on average 0.163. Following our selection of directional vectors, this means that farms can on average simultaneously expand production and investment in quasi-fixed capital and contract variable input use by 16.3% if one assumes CRS. On average, $\hat{d}_{DEA,VRS}$ is 0.121, which has an analogous interpretation for a VRS assumption. As a result, $\hat{d}_{DEA,SI}$ is on average 0.042.

In line with a priori expectations, the bootstrapped technical inefficiency scores are slightly higher, i.e., $\hat{d}_{BC,CRS}$, $\hat{d}_{BC,VRS}$ and $\hat{d}_{BC,SI}$ are on average 0.201, 0.154 and 0.047, respectively. Following the conservative rule of Efron and Tibshirani (1993), all bias-corrected inefficiencies are preferred for statistical inference.

Table 2. Technical Inefficiency under Constant Returns to Scale Assumption, Technical Inefficiency under Variable Returns to Scale Assumption and Scale Inefficiency

Year	Technical Inefficiency under Constant Returns to Scale Assumption		Technical Inefficiency under Variable Returns to Scale Assumption		Scale Inefficiency	
	$\hat{d}_{DEA,CRS}$	$\hat{d}_{BC,CRS}$	$\hat{d}_{DEA,VRS}$	$\hat{d}_{BC,VRS}$	$\hat{d}_{DEA,SI}$	$\hat{d}_{BC,SI}$
2004	0.151	0.190	0.107	0.135	0.044	0.055
2005	0.184	0.224	0.130	0.166	0.054	0.059
2006	0.150	0.187	0.121	0.151	0.029	0.036
2007	0.156	0.193	0.121	0.154	0.036	0.039
2008	0.173	0.210	0.128	0.163	0.045	0.048
Average	0.163	0.201	0.121	0.154	0.042	0.047

6.4.2. Impact of Milk Quota

Tables 3, 4 and 5 present the parameter estimates and the bias-corrected standard errors (between brackets) for $\hat{d}_{BC,CRS}$, $\hat{d}_{BC,VRS}$ and $\hat{d}_{BC,SI}$ respectively. We use the following specifications: Ordinary Least Squares (OLS) without size (1a) and with size (1b), First-Differenced (FD) without size (2a) and with size (2b) and Fixed Effects (FE) without size (3a) and with size (3b).

Tables 3 and 4 present the parameter estimates and the bias-corrected standard errors with respectively $\hat{d}_{BC,CRS}$ and $\hat{d}_{BC,VRS}$ being the dependent variable. There are only a few qualitative differences between the two tables. The estimations under both assumptions arrive at the main result that milk quota purchases solely have a significant negative impact on technical inefficiency for the OLS specification that excludes the size variable, and that the FD and FE specifications including and excluding the size variable. The degree of subsidy dependence and size are robustly significant variables for all relevant specifications for $\hat{d}_{BC,VRS}$, but not for the FE specification in $\hat{d}_{BC,CRS}$. Whereas land rent is significant for all OLS specifications for $\hat{d}_{BC,CRS}$, it is only significant for the OLS specification without the size variable for $\hat{d}_{BC,VRS}$. In addition to the OLS specifications, long-term debt is also significant for the FE specification without the size variable for $\hat{d}_{BC,CRS}$. The latter is not the case for $\hat{d}_{BC,VRS}$.

As mentioned in Section 2, assuming VRS may be more realistic due to the many market imperfections in the dairy sector and other constraints to attain an optimal size (e.g., capital, motivation and land). In what follows, we therefore only discuss the results for the VRS assumption. Whereas quota purchases, land rent, family labour and long- and short-term debt are not robustly significant for the various specifications, dairy farms that decrease technical inefficiency are characterised by being more dependent on subsidies and increasing in size. Column (1a) shows that milk quota purchases significantly decrease $\hat{d}_{BC,CRS}$ when the OLS specification is applied. The marginal effect of € 1,000 of quota purchases for the pooled sample across farms and time leads to a decrease of 0.06% in technical inefficiency. Although including size as an independent variable generally does not drastically change the outcomes, it does absorb the effect of milk quota purchases: milk quota purchases become an insignificant variable and size significantly decreases technical inefficiency. Interestingly, this means that operating at a larger scale is generally beneficial for farmers in terms of efficiency, but that large farms that have to incur extra costs of acquiring milk quota are generally not subjected to efficiency gains. There is no robust evidence that land rent would decrease technical inefficiency. Considering a sample of German, Dutch and Swedish farms, Zhu and Oude Lansink (2010) also did not obtain significant variables for the effect of the change of land rent on the change of technical efficiency. A change in family labour does not significantly affect technical inefficiency change, which is also arrived at in the study on Greek sheep farms by Karagiannis and Tzouvelekas

(2005), and Zhu and Oude Lansink (2010). Farms that incur more long-term debt, tend to be more technically inefficient, although this effect disappears in the FD and FE specifications. Short-term debt does not play a significant role for all specifications. Zhu and Oude Lansink (2010) also did not find significant coefficients for either debt variables, whereas Karagiannis and Tzouvelekas (2005) did find a negative impact of the change in debt level on the change in technical inefficiency. The finding that the degree subsidy dependence increases technical inefficiency confirms the study on beef cow/calf farms in Alberta by Samarajeewa et al. (2012), the study on Welsh and English dairy farms by Areal et al. (2012) and Zhu and Oude Lansink (2010). A lower technical inefficiency is characterised by a larger farm size for the OLS, FD and FE specification. This is also the case for Samarajeewa et al. (2012) and the sample of German dairy farms in Zhu and Oude Lansink (2010).

Table 3. Regression Results – Dep. Var.: $\widehat{d}_{BC,CRS}$.

	OLS		FD		FE	
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Quota Purchases	-0.0006*	-0.0002	-0.0001	-0.0001	-0.0004	-0.0003
	(0.0004)	(0.0004)	(0.0003)	(0.0003)	(0.0004)	(0.0004)
Land Rent	0.1174***	0.0987***	-0.1026	-0.0801	-0.0417	-0.0337
	(0.0367)	(0.0352)	(0.1153)	(0.1135)	(0.1080)	(0.0959)
Family Labour	-0.0553	-0.1709	0.3017	0.2802	0.2324	0.1885
	(0.1728)	(0.1497)	(0.2097)	(0.1813)	(0.3324)	(0.3049)
Long-Term Debt	-0.1537***	-0.1183***	-0.2207*	-0.1641	-0.0436	-0.0545
	(0.0418)	(0.0422)	(0.1135)	(0.1097)	(0.0636)	(0.0611)
Short-Term Debt	-0.7508	-0.5505	0.1510	0.1203	-0.0040	-0.0652
	(1.1070)	(1.0736)	(0.7062)	(0.6027)	(1.1814)	(1.0541)
Subsidy Dependence	0.4208**	0.4395**	0.7347***	0.7079***	0.3001	0.3426
	(0.1678)	(0.1920)	(0.2443)	(0.2585)	(0.2530)	(0.2531)
Size		-0.0013***		-0.0028***		-0.0015
		(0.0003)		(0.0011)		(0.0010)
Constant	0.1545	0.3865**	-0.0150*	-0.0050	-0.0251	0.1386
	(0.1806)	(0.1638)	(0.0086)	(0.0092)	(0.3512)	(0.3341)

Table 4. Regression Results – Dep. Var.: $\hat{d}_{BC,VRS}$.

	OLS		FD		FE	
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Quota Purchases	-0.0006*	-0.0004	0.0002	0.0003	-0.0001	0.0000
	(0.0003)	(0.0003)	(0.0002)	(0.0002)	(0.0003)	(0.0003)
Land Rent	0.0674*	0.0554	-0.1280	-0.1032	-0.0725	-0.0617
	(0.0367)	(0.0366)	(0.1064)	(0.1052)	(0.1032)	(0.0877)
Family Labour	-0.0036	-0.0774	0.2044	0.1807	0.0896	0.0301
	(0.1901)	(0.1711)	(0.1944)	(0.1625)	(0.3325)	(0.2952)
Long-Term Debt	-0.1244***	-0.1018**	-0.1640	-0.1018	-0.0303	-0.0451
	(0.0383)	(0.0401)	(0.1112)	(0.1037)	(0.0617)	(0.0584)
Short-Term Debt	-0.2696	-0.1417	0.2891	0.2554	0.1556	0.0729
	(1.3575)	(1.3362)	(0.9297)	(0.8115)	(1.1785)	(0.9991)
Subsidy Dependence	0.4504***	0.4623***	0.8610***	0.8314***	0.4131**	0.4706**
	(0.1586)	(0.1734)	(0.2165)	(0.2315)	(0.2093)	(0.2077)
Size		-0.0008***		-0.0031***		-0.0020**
		(0.0003)		(0.0010)		(0.0008)
Constant	0.0769	0.2251	-0.0145*	-0.0034	0.0658	0.2872
	(0.1967)	(0.1815)	(0.0082)	(0.0086)	(0.3478)	(0.3121)

Table 5 presents the results for $\hat{d}_{BC,SI}$. Following column (1a), land rent is the sole variable that has a significant impact (positive) on $\hat{d}_{BC,SI}$. Including size to the OLS specification does not change the outcomes qualitatively and size itself has a significant negative effect on $\hat{d}_{BC,SI}$. Interestingly, quota purchases significantly decrease $\hat{d}_{BC,SI}$ for all FD and FE specifications, whereas size is not significantly different from zero. Dairy farms that become more dependent on subsidies significantly decrease $\hat{d}_{BC,SI}$, which is the opposite effect compared to technical inefficiency. According to column (2b), long-term debt may have a significant negative impact on $\hat{d}_{BC,SI}$, but this result is not robust for the other specifications. The FE specifications suggest that family labour significantly increases $\hat{d}_{BC,SI}$, but this does not hold for the OLS and FD specifications. Short-term debt does not differ from zero in all specifications.

Table 5. Regression Results – Dep. Var.: $\hat{d}_{BC,SI}$.

	OLS		FD		FE	
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Quota Purchases	0.0000	0.0002	-0.0004***	-0.0004***	-0.0003***	-0.0003***
	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Land Rent	0.0500**	0.0433*	0.0254	0.0231	0.0308	0.0280
	(0.0240)	(0.0223)	(0.0534)	(0.0540)	(0.0509)	(0.0523)
Family Labour	-0.0518	-0.0935	0.0973	0.0995	0.1429*	0.1584*
	(0.0639)	(0.0710)	(0.1019)	(0.1026)	(0.0732)	(0.0817)
Long-Term Debt	-0.0293	-0.0165	-0.0566	-0.0624*	-0.0132	-0.0094
	(0.0282)	(0.0251)	(0.0349)	(0.0375)	(0.0235)	(0.0241)
Short-Term Debt	-0.4812	-0.4088	-0.1382	-0.1350	-0.1596	-0.1380
	(0.3456)	(0.3524)	(0.2807)	(0.2774)	(0.4789)	(0.5026)
Subsidy Dependence	-0.0296	-0.0228	-0.1263**	-0.1236**	-0.1130*	-0.1280**
	(0.0321)	(0.0382)	(0.0598)	(0.0600)	(0.0596)	(0.0651)
Size		-0.0005**		0.0003		0.0005
		(0.0002)		(0.0004)		(0.0004)
Constant	0.0776	0.1614**	-0.0006	-0.0016	-0.0909	-0.1486
	(0.0680)	(0.0764)	(0.0037)	(0.0039)	(0.0725)	(0.0996)

6.5. Conclusions and Discussion

This paper investigates the impact of dairy quota trade on the farm's dynamic technical and scale inefficiency. We focus on the Belgian milk quota market over the period 2004-2008. Using a nonparametric framework, we first estimated dynamic technical and scale inefficiency. Then, we employed the novel subsample bootstrap of Simar et al. (2012) to correct for the downward bias in the directional distance functions. This methodology proved to be relatively easy to implement and computationally fast. Finally, we estimated the effect of quota purchases on the bias-corrected estimates by a pooled ordinary least squared, differenced and fixed effects model.

The results suggest that purchasing more milk quota did not have a significant impact on CRS and VRS technical inefficiency. We controlled for subsidy dependency, farm size, family labour, rented land, long-term debt and short-term debt. On the other hand, purchasing milk quota significantly decreased scale inefficiency, suggesting that farms that invest in milk quota can adapt to a more productive scale.

Literature provides considerable evidence that technical inefficiency is highly persistent (e.g., Tsionas, 2006, Emvalomatis et al., 2011). Ang and Oude Lansink (2014) found that technical inefficiency of Belgian dairy farms did not play an important role for the period of 1995-2008. Moreover, they inferred very high allocative inefficiency and therefore argued that the milk quota abolishment may lead to substantial expansion of production and variable input use. This paper provides additional evidence of scale expansion after quota abolishment as smaller farms may have a larger incentive to increase production up to the most productive scale. We are nonetheless cautious concerning our findings since our sample was restricted to the buyers' market and did not include quota sellers.

This research could be extended in several ways. First, it could be worthwhile to apply our approach to different contexts and datasets that include the sellers' market. An interesting application would for example be the CO_2 quota market. Second, we deem it important for policy makers to monitor the scale and efficiency changes after the abolishment of the milk quota system.

7. General Discussion and Conclusions

The first objective of this PhD thesis was to analyze the WS-SS debate for the SV approach. The SV approach intends to allow for substitutability of resources between economic entities, while simultaneously constraining this possibility in a way such that the overall level of use does not damage the natural capital stock. As such, this measure has been introduced by FH (2004) as in line with the WS paradigm at the individual level of the economic entity, but in line with the SS paradigm at the aggregate level. FH (2004) argue that the aggregate level is more relevant than the individual level, so that the SV approach is in essence an SS measure. We analyzed the SV approach for the EU-15 countries covering the period of 1995-2008 in chapter 2. Chapter 3 contributed to the methodological and conceptual debate about this measure.

Second, we used the dynamic approach to analyze profit inefficiency, technical inefficiency and allocative inefficiency. Chapter 4 provided a theoretical background of the dynamic approach. In chapter 5, we used DEA techniques to assess the dynamic profit inefficiency for a sample of Belgian dairy farms. We decomposed profit inefficiency into the contributions of input and output specific technical and allocative inefficiency. Chapter 6 analyzed the impact of activity in the quota market on the DEA-inferred technical and scale inefficiency for a sample of Belgian dairy farms.

This Chapter discusses the connections between the SV approach used in Chapters 2-3 and a production economics approach used in Chapters 4-6. We argue that the weak conceptual connection between the WS-SS link introduced by Figge and Hahn (2004a) and the SV approach can be strengthened substantially by employing a production economics approach. We also turn to the broader discussion how sustainability indicators can be implemented rigorously in a production economics framework. We draw policy conclusions in the final section.

7.1. The SV Approach and Production Economics

7.1.1. Conceptual Problems

The starting point of FH (2004) is that efficiency measures follow the WS paradigm. Their rationale is that resources are substitutable in the calculation of efficiency scores. In line with the WS paradigm, increased use of environmental resources at a level that would damage the natural capital stock can be compensated by lower use of another type of resources. FH (2004) put forward that the focus should shift from the individual level to the aggregate level. FH (2004, 2009) and Figge et al. (2014) distinguish three questions that are in their opinion essential in sustainability measurement: (1) *If* resource use contributes to sustainability, (2) *Where* a resource should be allocated, and (3) *How* a resource should be used. According to FH (2004), the If-question is linked to SS. If one sets up suitable flow targets, the overall resource use does not damage the natural capital stock, following the SS paradigm. They put forward that sustainability research is mainly concerned with this If-question. FH (2004) introduced the SV approach from the perspective of the Where-question, while intending to be consistent with the If-question. Assuming that the If-question follows the SS paradigm, the SV approach is constructed to calculate some sort of optimal resource reallocation scheme in which "victims" of inefficient production are financially compensated by more efficient resource users. FH (2009) and Figge et al. (2014) argue that the How-question identifies the potential of an economic entity to optimize resource use. In contrast to the Where-question that focuses on the aggregate level, the How-question supposedly solely focuses on the individual level of the economic entity. This reasoning is a response to KK (2009), who criticize the SV approach's substitutability possibilities between resources and as a result its lack of SS characteristics.

Figge et al. (2014) claim that the three questions are linked to three separate theoretical traditions. Whereas the If-question is addressed by welfare economics, the Where-question is addressed by financial economics and the How-question is addressed by production economics. They warn for not making the underlying assumptions explicit. While there are some "linkages" between the theoretical traditions, they state that answering a question from one theoretical tradition cannot answer a question from another theoretical tradition. In their opinion, answering the How-question in line with production economics does not answer the Where-question in line with financial economics. FH (2009) frame the SV approach as a sustainability measure that reallocates resources from the investor's perspective in the presence of risk. On the other hand, according to FH (2009), KK (2009a) take the perspective of the individual firm following the production economics viewpoint and do not take into account risk.

In chapter 3, we have argued that much of the confusion about the SV approach is caused by the original contribution of FH (2004) itself. The main problem is that the original SV approach is designed to deal with two objectives. It is intended as a tool from the *investor's* perspective as well as a *prescriptive* tool intending to set up an optimal resource reallocation scheme. Although the original SV approach arguably is an investor's tool, it does not succeed in being a prescriptive tool at the same time. Both the Where- and the How-question should however be tackled to reach the two objectives simultaneously. Separating these two questions implies the failure of the original SV approach. Moreover, note that the Where-question is also treated in the economic geography literature: Especially in the new trade theory, this has been done extensively (Krugman, 1979).

Chapter 2 spells out three conditions to align the SV approach with the SS paradigm: (1) the targeted resource use level does not harm the natural capital stock, (2) the considered resources are suitable to reallocate in the sense that they do not have a local impact, and (3) the SVs can be used for a financial compensation scheme.

7.1.2. Solutions

We have argued in the previous section that especially the third condition is problematic for the original SV approach. In what follows, we show that the production economics perspective enables the connection to the WS paradigm at the individual level of the economic entity, while still being in line the SS paradigm at the aggregate level. Since this was the intention of the original contribution of FH (2004), this is relevant.

As KK (2009b) mention, production economics can deal with the individual as well as the aggregate level. Although there are more applications that focus on the individual level, this does not mean that an aggregate focus does not exist or is impossible. It is in this light possible to use the DEA techniques of chapter 5 and 6.

If one assumes that resources could not be reallocated among firms, then the technical efficiency of the group equals the ratio of the sum of all individually produced outputs to the sum of all potential individual outputs. This is the main concern of FH (2004). The How-question would in this case not allow for answering the Where-question focusing on reallocation of resources. Nesterenko and Zelenyuk (2007), however, formally demonstrate that in the case that resources could be reallocated, the maximum output of the group could be increased. Constraining the overall environmental resource use in a way such that the natural capital stock does not decline, would thus be consistent with WS at the individual level and SS at the aggregate level. In contrast to the original SV approach, the production economics perspective can thus simultaneously answer the Where- and How-question. Interestingly, Brännlund et al. (1998), Andersen and Bogetoft (2007) and Oude Lansink and van der Vlist (2008) have set up such a reallocation scheme in a quota context.

The maximal aggregate profit when environmental resources can be reallocated could be constructed in the following way:

$$\pi_{DEA}(x,y,e,\gamma) = \max_{x,y,e,\gamma}\left(\sum_{b=1}^{B}\sum_{k=1}^{K} p_{bk}y_{bk} - \sum_{a=1}^{A}\sum_{k=1}^{K} p_{ak}y_{ak}\right)$$

s.t.

(1) $y_b \leq \sum_{j=1}^{J} \gamma^j y^j\,, b = 1, \dots, B$

(2) $\sum_{j=1}^{J} \gamma^j x^j \leq x_a, a = 1, \dots, A$

(3) $\sum_{j=1}^{J} \gamma^j e^j = e_r, r = 1, \dots, R$

(4) $\sum_{j=1}^{J} e^j = \bar{E}$

(5) $\gamma^j \geq 0, j = 1, \ldots, J$

where $y \in \mathbb{R}_+^Q$ is the output vector, $x \in \mathbb{R}_+^P$ is the input vector, $e \in \mathbb{R}_+^R$ is the environmental resource vector and $\bar{E}$ is the target level of environmental resources.

This linear program solves for the aggregate profits, the optimal level of environmental input use x^*, output use y^*, resource use e^* and firm weights γ, by maximally expanding aggregate output while keeping environmental resource use constant at the aggregate level $\bar{E}$ (thus allowing for reallocation of environmental resources between firms). The target level of environmental resources is chosen sufficiently low to not damage the natural capital stock. In contrast to the objective of the initial SV approach, DEA thus allows for a flexible specification in which only the relevant (environmental) resources can be reallocated, whereas other resources can be fixed at the individual level. We believe that this approach is more useful in the WS-SS characterizations in an efficiency context.

Reallocation of resources would incur extra adjustment costs. From this perspective, it would be interesting to take into account the investment in dynamic quasi-fixed factors in the same way as chapters 5 and 6. Since efficiency scores obtained by DEA techniques tend to be biased, we should use bootstrapping procedures. Chapter 6 showed how the subsample bootstrap of Simar et al. (2012) can be implemented for statistical inference of directional distance functions.

7.1.3. Recommendations for Future Research

It would be interesting to dig in deeper about the reallocation properties. While several environmental resources that do not have a local impact may be reallocated, several environmental factors may be worthwhile to focus on. Biodiversity seems to be a relevant example. Is it a good idea to reallocate key bird species to the most "bird-efficient" farms, or should this always be integrated in each farm? Chavas (2009) and Chavas and Di Falco (2012) provide interesting insights on the trade-off between biodiversity and production. The suitable scale of reallocation is also important in this light.

Furthermore, we recommend implementation of parametric and non-parametric methodologies in the SV approach. Van Passel et al. (2009) and KK (2009a), on the one hand, and Hou et al. (2014), on the other hand, are interesting examples of respectively the former and the latter.

7.2. Sustainability and Production Economics

Although the WS-SS debate about the SV approach is relevant and interesting, we would like to emphasize that one should not lose sight of the main goal of the SV approach, *i.e.,* creating an efficiency-based measure that can integrate factors along the three pillars of sustainability. In what follows, we show how negative and positive externalities can be implemented directly in a production economics framework and provide suggestions for future research.

7.2.1. Negative Externalities

Various methods have been proposed to include negative externalities in an efficiency framework. Earlier contributions include negative externalities as inputs (e.g., Hailu and Veeman, 2001) or as weakly disposable outputs (e.g., Färe et al., 1989). Despite their popularity, these methods have recently been subjected to criticism when used in a context of pollution. Coelli et al. (2007) argue that these methods may violate the material balance condition (MBC) and introduce an environmental efficiency measure that is consistent with this condition. Murty et al. (2012) claim that these methods may inappropriately account for abatement options and propose a network approach where the by-production of pollutants is explicitly modelled.

7.2.2. Positive Externalities

Recently, the implementation of positive externalities in a production framework has been a subject of study. In an agricultural context, this may for example be a biodiversity proxy. Typical examples include the ratio of permanent grassland to total agricultural land (Areal et al., 2012), the Shannon index for crop diversification (Sipilainen and Huhtala, 2013), public land conservation (Färe et al., 2001) and wetland conditions (Bostian and Herlihy, 2014). A common approach is the insertion of a biodiversity measure as a conventional output in a distance function framework.

7.2.3. Recommendations for Future Research

In contrast to the rich literature on the realistic representation of negative and positive externalities in an efficiency framework, only little attention has been paid to how input and output levels should be changed to reach the frontier. The directional distance function approach provides a flexible way to compute (in)efficiency scores, as the directional distance vector can be chosen freely. As such, it is more general than the radial efficiency measure, where there is either an output orientation or an input orientation. However, this flexibility is a double-edged sword: inefficiency scores hinge critically on the choice of the directional vector. Therefore, several studies recently focus on endogenously determining the directional vector in a nonparametric framework. Zofio et al. (2013) select a directional distance vector that would steer inefficient Decision Making Units (DMUs) to the profit-maximizing benchmarks. Färe et al. (2013) introduce a slacks-based measure by which the directional vector maximizes the inefficiency for each DMU. Hampf and Krüger (2015) apply this method to assess the reduction potential of greenhouse gases for a sample of countries in the world. They treat greenhouse gas emission as a weakly disposable output. We believe that a rigorous selection of "sustainable" directional vectors would be essential in the context of efficiency assessment.

With regard to augmenting an efficiency framework by a biodiversity proxy, we believe that it is necessary to study whether biodiversity can be treated as a conventional output. Novel findings in the literature point out that the relationship between biodiversity and outputs can be complicated, as there can be complementarities between biodiversity and production (see for example Hodge, 2008; Sauer and Wossink, 2013). This suggests that biodiversity should perhaps be treated as a *weakly disposable* output rather than a conventional output.

This PhD thesis has focused on environmental indicators that are flows. However, in line with the model of capital accumulation in production economics in chapters 4 and 5, it would be worthwhile to study the dynamic changes of natural capital stock in time. In this light, KK (2013) provided an original contribution. They introduced a soil capital stock with nutrient inflows and outflows. Implementation of such nutrient dynamics in an efficiency framework would be worthwhile.

7.3.Policy Implications

It is difficult to make general policy implications, as this thesis has dealt with macroeconomic as well as microeconomic applications. However, the efficiency measures did prove to offer interesting policy implications for both levels. Chapter 2 provided a *macroeconomic* application by using the original SV approach for the EU-15 countries. We assessed environmental, social and economic resources in combination with the GDP for the EU-15 countries covering the period of 1995-2006 for three benchmark alternatives. The results indicated that several countries manage to adequately delink resource use from GDP growth. Furthermore, the remarkable difference in outcome between the national and EU-15 benchmark suggested a possible inefficiency of the current allocation of national resource ceilings imposed by the European institutions.

Chapter 5 and 6 focused on a *microeconomic* application. In chapter 4, we used a DEA framework to analyze dynamic profit inefficiency for a sample of Belgian dairy farms from 1996–2008. Profit inefficiency is decomposed into contributions of output, input, and investment. We identified the contributions of technical and allocative inefficiency in each input and output. The results suggested substantial profit inefficiency under the current dairy-quota system, mainly driven by an average underproduction of approximately 50 percent and an average underuse of variable inputs of approximately 60 percent, due to allocative inefficiency. We concluded that abolishing the dairy-quota system in 2015 may considerably increase demand for variable inputs and supply of output.

Using DEA, chapter 6 assessed the impact of activity in the quota market on technical and scale inefficiency for a sample of Belgian dairy farms covering the period of 2004-2008. The results showed that purchasing milk quota does not significantly affect technical inefficiency, but significantly decreased scale inefficiency. In line with chapter 4, it was suggested that the milk quota abolishment will likely be linked with scale expansion, as smaller farms may have a larger incentive to increase production up to the most productive scale.

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