A Note on Technical Efficiency, Productivity Growth and Competitiveness

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Abstract

'Productivity and efficiency growth enhances competitiveness'. Similarly formulated statements are common in the literature on the economic performance of firms, industries and nations. This conventional perception in the economic literature, originating from trade and growth theory models, however, lacks a clearly defined mathematical formulation. Earlier work by Page (1980) and Nishimizu and Page (1986) provides an elegant formalization of the relationship between the productivity growth and competitiveness measured by the Domestic Resource Costs (DRC) ratio. However, the relationship between technical efficiency and competitiveness has not been addressed in the literature. Moreover, the DRC is a biased measure of competitiveness. We propose static and dynamic decompositions of competitiveness measured by the unbiased Social Cost Benefit Ratio (SCB) indicator using a distance function approach, and demonstrate these decompositions using simulated data. These decompositions extend earlier work to formalize the relationship between technical efficiency, productivity and competitiveness, and demonstrate that competitiveness is also influenced by other factors that can override the effects of efficiency or productivity improvements.

1. Introduction

The literature on the economic performance of firms, industries, or countries has tended to be divided along two lines of analysis. The first strand of the literature focuses on the analysis of comparative advantage and/or competitiveness. Due to ambiguity on the precise meaning of these concepts, a large number of measures of competitive advantage/competitiveness[1] have been developed. Siggel (2006) provides a comprehensive survey and discussion of these measures. Among the concepts and measures surveyed, he concludes that the Domestic Resource Cost (DRC) criterion is the only measure that qualifies as a true measure of comparative advantage. The DRC is a well-known and widely applied concept (e.g. von Cramon-Taubadel et al, 2008 and 2009) first proposed by Bruno (1965) and incorporated in the Policy Analysis Matrix (PAM) framework by Monke and Pearson (1989). The DRC compares the cost of domestic resources measured at social prices to value added measured in social prices. It can be derived from the Ricardian comparative advantage framework, and the use of social (or equilibrium) prices throughout ensures that the DRC measures true comparative advantage (Siggel, 2006).

[1] Some authors (e.g. Siggel, 2006)distinguish between the competitive advantage and competitiveness concepts based on the prices used. When equilibrium or shadow prices are used, then the concept of competitive advantages is applied. When actual (distorted) market prices or some mix of shadow and market prices are used, then the concept of competitiveness is applied. In this paper for the sake of simplicity we use these two terms interchangeably. Also note, if not otherwise indicated, we consider equilibrium prices.

The second strand of literature focuses on efficiency and productivity analysis, where technical efficiency and Total Factor Productivity (TFP) change concepts have been of primary interest. Krugman (1994), for instance, argues that '… *for an economy with very little international trade, 'competitiveness' would turn out to be a funny way of saying 'productivity'*. Dollar and Wolf (1993) propose measuring the macroeconomic or national competitiveness in terms of productivity. This approach has also been heavily applied on the micro level (e.g. Zhul et al, 2008). The theoretical background of the efficiency and TFP concepts is well established (see e.g. Färe and Primont, 1995), and parametric and non-parametric methods for measuring them have been developing and converging rapidly. (e.g. Daraio and Simar, 2007; Kumbhakar et al, 2007; Simar and Zelenyuk, 2008). Inferences on comparative advantage/competitiveness are drawn based on relative rates of TFP change between the Decision Making Units (DMUs) and/or their relative distances from the 'best-practice' frontier.

How are these two strands of analysis related to one another? It is often maintained that productivity growth enhances competitiveness (e.g. Link and Siegel, 2003, p.1), but is there a formal mathematical relationship between a DMU's competitiveness/comparative advantage and its productivity level/growth or technical efficiency? Will a firm that becomes more efficient of productive necessarily become more competitive as a result? Attempts to relate technical efficiency, productivity and competitiveness go back to Page (1980) and Nishimizu and Page (1986) who proposed a DRC decomposition that formally relates improvements in productivity to improvements in a DMU's comparative advantage, thus supporting the common perception of a link between efficiency/productivity and competitiveness.

Nevertheless, important open questions remain to be addressed. Despite the wide acceptance of the DRC as a comparative advantage indicator in policy analysis, it is not perfect. Masters and Winter-Nelson (1995) and Siggel (2006) have shown that the DRC understates the competitiveness of activities with intensive usage of domestic factors. To correct for this, Masters and Winter-Nelson (1995) propose the Social Cost Benefit Ratio (SCB) criterion, which is essentially the unit cost ratio (UCs) proposed by Siggel (2006). This (unbiased) measure compares total domestic costs at social prices to the social value of output. An interesting question in this regard is whether there is a formal relationship between technical efficiency and competitiveness. Apart from its theoretical relevance, this issue might be important from a policy analysis perspective. Competitiveness and efficiency analysis place different demands on data, expertise, computation time etc. Deriving a formal relationship between competitiveness and efficiency could help to reduce these requirements. Hence, in section 2 of this paper, after introducing the SCB measure of competitiveness, we derive a static decomposition of the SCB into technical efficiency and other components.

A second open question is whether the relationship between the DRC and TFP growth derived by Nishimizu and Page (1986) also holds for the relationship between the SCB and TFP growth. In section 3 we explore this question in detail and derive a general dynamic decomposition of changes in the SCB into TFP growth and other components for the multiple output and input case.

Both the static and the dynamic decompositions are illustrated using simulated data in section 4, and section 5 concludes. The decompositions of SCB levels and changes presented in the rest of this paper show that while efficiency and productivity growth are positively related to competitiveness, competitiveness is also influences by other factors that can override and mask these relationships.

2 Competitiveness decomposition I (static)

Numerous indicators of competitiveness have been developed and applied by economists. In a comprehensive survey of these measures, Siggel (2006) concludes that the Domestic Resource Cost (DRC) criterion is the only measure that qualifies as a true measure of comparative advantage. He shows that the DRC can be derived from the Ricardian comparative advantage concept. The DRC measure compares the cost of domestic resources at social (shadow) prices to value added at world prices. 0 < DRC < 1 indicates comparative advantage: the social opportunity cost of domestic resources used is smaller that the corresponding social gain (value added). The opposite is true for the DRC > 1. If the DRC is smaller than 0, then the revenue does not even suffice to cover tradable input costs, let alone domestic inputs. In this case, production of the good in question is clearly not competitive.

Masters and Winter-Nelson (1995) identify weaknesses of the DRC criterion. They demonstrate that the DRC understates the competitiveness of activities with intensive usage of domestic factors instead of tradable inputs. The activity with the highest level of competitiveness does not necessarily maximize social profits, in other words its input mix is not optimal at given social prices. Siggel (2006) also shows why the DRC is not a perfect measure of competitiveness. First, he essentially restates Masters and Winter-Nelson's (1995) argument. Second, Siggel (2006) shows that there are situations in which intermediate inputs may also contribute to comparative advantage. To correct for these problems, Masters and Winter-Nelson (1995) propose the Social Cost Benefit Ratio (SCB) criterion, which is essentially the unit cost ratio (UCs) proposed by Siggel (2006). It is an unbiased measure, since it correctly identifies the socially optimal level of input use.

Assume that *n* firms operate in the sector in question. Each firm *i* $(i=\overline{1,n})$ uses *K* inputs, $x^i = (x_1^i, ..., x_K^i)' \in \Re_+^K$, to produce *M* outputs, $y^i = (y_1^i, ..., y_M^i)' \in \Re_+^M$. The SCB criterion of comparative advantages compares total costs at social prices to the social value of output:

$$SCB = \frac{wx}{py} \tag{1}$$

where $w = (w_1, ..., w_K)$ and $p = (p_1, ..., p_M)$ are the shadow (social) price vectors for inputs and outputs respectively. An SCB ratio less than or equal one indicates competitive production: the social opportunity cost of the resources used in production is smaller that the corresponding social gain (revenue). The opposite is true when the SCB is greater then one.

Next assume that all n firms have access to the same technology T, defined as $T \equiv \{(x, y) : x \ can \ produce \ y\}$, that satisfies the standard regularity axioms of production theory (e.g. Färe and Primont, 1995). Following Färe and Grosskopf (1997):

$$\frac{\Pi(p, w) + wx}{py} \geq \frac{1}{D_O(x, y)} \tag{2}$$

and

$$\frac{\Pi(p, w) - py}{wx} \geq -\frac{1}{D_i(x, y)} \tag{3}$$

where $\Pi(p, w)$ is a profit frontier defined as

$$\Pi(p, w) = \sup_{x,y} \left\{ py - wx : (x, y) \in T \right\} \tag{4}$$

$D_o(x, y)$ and $D_i(x, y)$ are the Shephard (1970) output and input distance functions:

$$D_o(x, y) \equiv \inf \left\{ \theta : (x, y / \theta) \in T \right\} \tag{5}$$

and

$$D_i(x, y) \equiv \sup \left\{ \lambda : (x / \lambda, y) \in T \right\} \tag{6}$$

If $D_o(x, y) = 1$ ($D_i(x, y) = 1$), a firm is *technically* efficient, otherwise, when $D_o(x, y) < 1$ ($D_i(x, y) > 1$) it is *technically* inefficient. The reciprocal of the Shephard distance function is the Farrell (1957) technical efficiency defined as

$$TE_o(x, y) = 1 / D_o(x, y) \text{ or } TE_i(x, y) = 1 / D_i(x, y) \tag{7}$$

Combining expressions (1), (2 or 3) and (7) leads to:

$$\frac{\Pi(p, w)}{py} + SCB \geq TE_o(x, y) \tag{8}$$

and

$$\frac{1}{SCB} - \frac{\Pi(p, w)}{wx} \leq TE_i(x, y) \ . \tag{8}$$

These two equations can be transformed into equalities by introducing allocative efficiencies, i.e.:

$$\frac{\Pi(p,w)}{py} + SCB = TE_o(x,y) \cdot AE_o \tag{13}$$

and

$$\frac{1}{SCB} - \frac{\Pi(p,w)}{wx} = TE_i(x,y) \cdot AE_i \tag{14}$$

Note that AE_o (AE_i) should be greater (less) or equal 1. The product of technical and allocative efficiencies is in both cases the profit efficiency. Isolating SCB in (13) and (14) produces the following decompositions:

$$SCB = TE_o(x,y) \cdot AE_o - \frac{\Pi(p,w)}{py} \tag{15}$$

and

$$\frac{1}{SCB} = TE_i(x,y) \cdot AE_i + \frac{\Pi(p,w)}{wx} \tag{16}$$

Let us graphically demonstrate the intuition behind expressions (15) and (16). Figure 1 shows the simple one input and one output case, where a firm is producing at point B. Using the notation in the Figure 1 we can express the right-hand side parts of the equation (15) by the ratios:

$$TE_o(x,y) \cdot AE_o = \frac{OC}{OB} \cdot \frac{OD}{OC} = \frac{OD}{OB} \tag{17}$$

$$\frac{\Pi(p,w)}{py} = \frac{OA}{OB} \tag{18}$$

Substituting expressions (17) and (18) in (15) yields:

$$SCB = \frac{OD}{OB} - \frac{OA}{OB} = \frac{(OD - OA)}{OB} \tag{19}$$

Since (OD - OA) < OB, we have SCB < 1, thus production at point B is competitive at given social prices.

In the same manner, and with reference to Figure 2:

$$TE_i(x,y) \cdot AE_i = \frac{OB}{OA} \cdot \frac{OC}{OB} = \frac{OC}{OA} \tag{20}$$

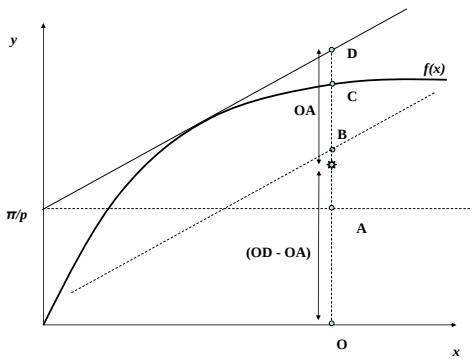
$$\frac{\Pi(p,w)}{wx} = \frac{OD}{OA} \tag{21}$$

Substituting expressions (20) and (21) in (16) yields:

$$\frac{1}{SCB} = \frac{OC}{OA} + \frac{OD}{OA} = \frac{(OC + OD)}{OA} \tag{22}$$

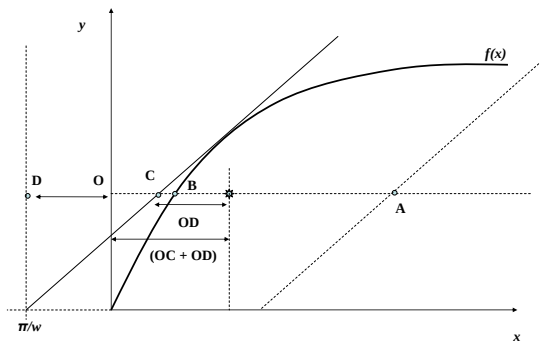
Since (OC + OD) < OA, we have $\frac{1}{SCB} < 1$, or SCB > 1. Thus, production at point A is not competitive at given social prices.

Figure 1: SCB decomposition – output orientation



Source: Own depiction

Figure 2: SCB decomposition – input orientation



Source: Own depiction

Summarizing the above discussion, we have demonstrated analytically that technical efficiency positively contributes to competitiveness. Equally important, the equations (15) and (16) provide information about two additional determinants of competitiveness. Allocative efficiency refers to whether a firm chooses the profit maximizing input or output mix. Technical and allocative efficiencies are micro- or firm-level determinants of competitiveness, since they are under the control of firms. The y in $\frac{1}{py}$ in equation (15) is also a micro-level determinant of competitiveness. The profit frontier, $\Pi(p,w)$ in (15), is a macro- or sector-level determinant. As expression (7) shows, this frontier is defined by input and output prices and by available technology. Prices in the competitive market setting are given for firms. Technology, by assumption, is accessible to all firms, and therefore also given. To what extent a firm makes use of this technology is reflected in its technical and allocative efficiencies.

Whether a farm's lack of competitiveness is mainly due to micro- or macro-level factors can have important policy implications. If micro-level determinants prevail, then competitive market forces will either force the farm to adjust its behavior, or they will force it out of the market. Policy makers might want to use investments in agricultural training and extension to ease adjustment, or early retirement schemes,

retraining and other measures to ease exit. If macro-level determinants such as price distortions prevail, then some form of market intervention may be in order.

The proposed decomposition of the SCB criterion in equations (15) and (16) could serve as a basis for statistical inference on individual farm SCB scores.[2] In (15) and (16), note that the variation in SCB scores comes from the superposition of the technology and profit frontiers variations.

3 Competitiveness decomposition II (dynamic)

Using notation of the previous section we can rewrite the SCB criterion in sums form as:

$$SCB = \frac{\sum_{k}^{K} w_k x_k}{\sum_{m}^{M} p_m y_m} \tag{23}$$

Taking the total differential and rewriting the resulting expression in relative changes, the percentage change in the SCB can be expressed as:

$$\frac{dSCB}{SCB} = \sum_{k}^{K} s_k \frac{dw_k}{w_k} + \sum_{k}^{K} s_k \frac{dx_k}{x_k} - \sum_{m}^{M} r_m \frac{dp_m}{w_m} - \sum_{m}^{M} r_m \frac{dy_m}{y_m} \tag{24}$$

Here, $s_k = \frac{w_k x_k}{\sum_{k}^{K} w_k x_k}$ denotes the cost share of input x_k, and $r_m = \frac{p_m y_m}{\sum_{m}^{M} p_m y_m}$ denotes the revenue share of output y_m. The last and the second terms in (24) comprise a (negative) conventional Divisia index of productivity growth defined as $T\dot{F}P = \sum_{k}^{K} s_k \frac{dx_k}{x_k} - \sum_{m}^{M} r_m \frac{dy_m}{y_m}$ for a multi-output, multi-input setting. Hence, equation (24) transforms into:

$$\frac{dSCB}{SCB} = \sum_{k}^{K} s_k \frac{dw_k}{w_k} - \sum_{m}^{M} r_m \frac{dp_m}{p_m} - T\dot{F}P \tag{25}$$

Bruemmer et al. (2002) decompose $T\dot{F}P$ further into different sources of productivity growth. From (7), the output distance function D_o is equal to the inverse of the Farrell output efficiency measure. In logarithmic form, this can be expressed as $0 = \ln D_o - \ln TE$. If *TE* is modeled via a non-negative variable *u*, TE = exp*(-u)*, this can be expressed as $0 = \ln D_o + u$. Using these definitions, the decomposition of TFP growth index takes the following form (Bruemmer et al, 2002):

[2] Methods for generating inferences on aggregate SCB scores are proposed in Nivievskyi and von Cramon-Taubadel (2009).

$$T\dot{F}P = \sum_m^M (r_m - \mu_m)\frac{dy_m}{y_m} + \sum_k^K (\lambda_k - s_k)\frac{dx_k}{x_k} + (RTS - 1)\sum_k^K \lambda_k \frac{dx_k}{x_k} - \frac{\partial \ln D_o(\cdot)}{\partial t} - \frac{\partial u}{\partial t}$$

(26)

The complete decomposition of the SCB growth index is then as follows:[3]

$$\begin{aligned}\frac{dSCB}{SCB} = & \sum_k^K s_k \frac{dw_k}{w_k} - \sum_m^M r_m \frac{dp_m}{p_m} \\ & - \sum_m^M (r_m - \mu_m)\frac{dy_m}{y_m} - \sum_k^K (\lambda_k - s_k)\frac{dx_k}{x_k} \\ & - (RTS - 1)\sum_k^K \lambda_k \frac{dx_k}{x_k} \\ & + \frac{\partial \ln D_o(\cdot)}{\partial t} + \frac{\partial u}{\partial t}\end{aligned} \tag{27}$$

Equation (27) decomposes SCB growth into the following components. The first two components, using Nishimizu and Page's (1986) terminology, are the 'factor costs effect' ($\sum_k^K s_k \frac{dw_k}{w_k}$) and 'term of trade effect' ($\sum_m^M r_m \frac{dp_m}{p_m}$). The next two components are an 'output allocative efficiency effect' ($\sum_m^M (r_m - \mu_m)\frac{dy_m}{y_m}$) and an 'output allocative efficiency effect' ($\sum_k^K (\lambda_k - s_k)\frac{dx_k}{x_k}$), where $\frac{\partial \ln D_o(\cdot)}{\partial \ln y_m} = \mu_m$ and $\frac{\partial \ln D_o(\cdot)}{\partial \ln x_k} = -\lambda_k RTS$. RTS denotes returns to scale (see Färe and Primont, 1994). As Bruemmer et al. (2002) explain in detail, if firms choose their inputs and output bundles to maximize profits, then $r_m - \mu_m = 0$ and $\lambda_k - s_k = 0$. Otherwise they allocate their resources inefficiently. A 'scale effect' is captured by the next component ($(RTS - 1)\sum_k^K \lambda_k \frac{dx_k}{x_k}$). Technical change and efficiency change effects are captured by the last two components, $\frac{\partial \ln D_o(\cdot)}{\partial t}$ and $\frac{\partial u}{\partial t}$, respectively.

4. Empirical Illustration

4.1. Multivariate Simulated Data

In this example we simulate a data set of n = 100 observations with *q = 2* inputs and *p = 2* outputs using the scenario proposed in Simar (2003) and slightly modified for our

[3] The same decomposition results from incorporating distance functions in (23) and taking the total differential of the resulting identity.

purposes. In this scenario the function that describes the efficient frontier is given by the following relationship:

$y_{t,2} = 1.0845(x_1)^{0.3}(x_2)^{0.5} - y_{t,1}$,

where $y_{t,p}$, (x_q) denotes the ith component of y (of x), for $p,q = 1,2$ in period $t = 1,2$. Note that the quantities of inputs do not change over the time.

First we generate independent uniforms $X_{q,i}$ on the interval $(1,2)$, $i = \overline{1,100}$ and independent uniforms $\tilde{Y}_{p,i}$ on the interval $(0.2,5)$ for the first period. The random rays in output space would be characterized by the slopes $S_i = \tilde{Y}_{2,i} / \tilde{Y}_{1,i}$. The frontier points in both periods are defined then as:

$$Y^*_{1,i,t} = \frac{1.0845(X_{1,i})^{0.3}(X_{2,i})^{0.5}}{S_i + 1}$$

$$Y^*_{2,i,t} = 1.0845(X_{1,i})^{0.3}(X_{2,i})^{0.5} - Y^*_{1,i,t}$$

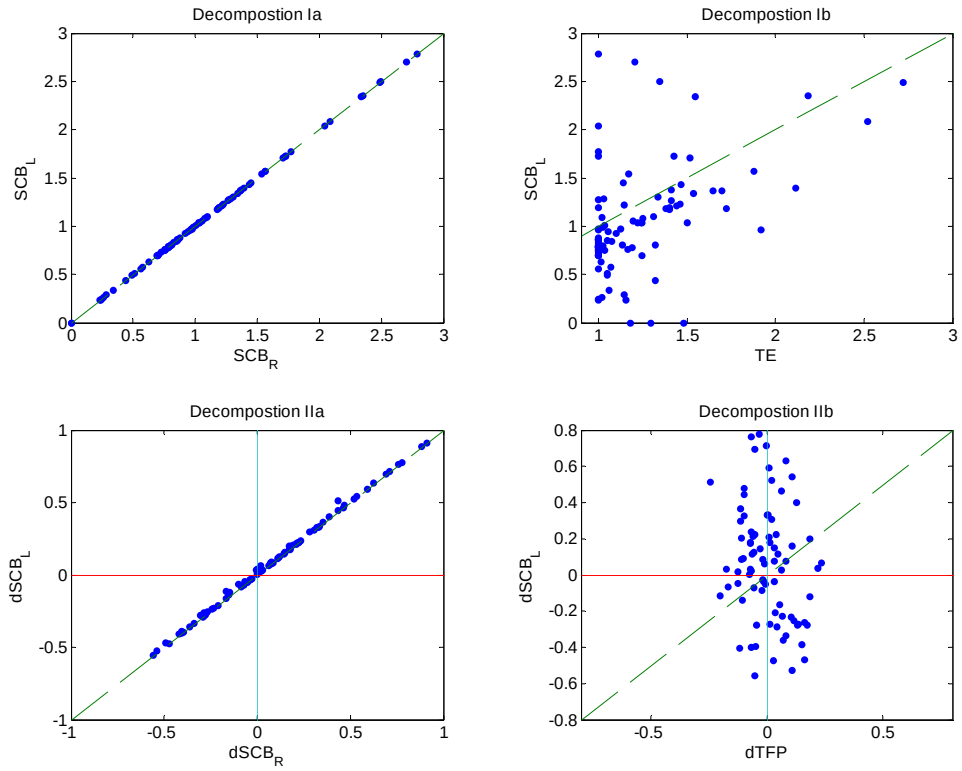
The (in)efficiency scores in the first period are generated by $ineff_{1,i} = \exp(-U_i)$, where U_i are drawn from the exponential distribution with the mean equal 1/3. In the second period we allow for random (normal) efficiency changes, i.e. $ineff_{2,i} = ineff_{1,i} \times \phi(1, 0.1)$, where $\phi(1, 0.1)$ is a normal distribution with mean and standard deviation equal to 1 and 0.1, respectively. Basically we assume that the productivity change stems solely from efficiency change. In both periods the final simulated points are generated by: $Y_{p,i,t} = Y^*_{p,i,t} \times ineff_{t,i}$, $p,q = 1,2$, $t = 1,2$, $i = \overline{1,100}$.

To demonstrate the static and dynamic competitiveness decompositions, e.g. equations (25) and (15), we need the corresponding shadow prices. For this we utilize the weight-restricted Data Envelopment Analysis (DEA) model, e.g. see Kuosmanen et al (2004). According to this method the optimal weights (ρ,*w*) in the dual representation of the distance functions (see the linear programming formulation in equation (28) below) represent the 'shadow prices' of outputs and inputs with respect to the corresponding technology. The observed input-output mix 'reveals' indirectly the economic prices underlying the production decisions (Kuosmanen et al, 2004). The restrictions on the weights (the upper ybu_p, xbu_q, and lower ybl_p, xbl_q bounds on implicit output and input value shares in equation (28)) are introduced so as to avoid zero shadow prices.

$$\begin{aligned}
&D(y,x) = \min_{\rho,w} wx \\
&s.t. \\
&\rho y = 1 \\
&\rho_p y_p \le ybu_p, \rho_p y_p \ge ybl_p; p = 1,2 \qquad (28) \\
&w_q x_q \le xbu_q, w_q x_q \ge xbl_q; q = 1,2 \\
&\rho Y - wX \le 0 \\
&\rho \ge 0, w \ge 0
\end{aligned}$$

Solving (28) for each pair of (y, x) we find their corresponding shadow prices (ρ, w) in both periods. Using this information we first estimate SCB as in (1) and then as in (15) for the first period (we name them as SCB_L and SCB_R respectively). The 'Decomposition Ia' subplot in Figure 3 shows a scatter plot of SCB_L versus SCB_R. Since all the points lie on the 45 degree line through the origin, the static decomposition identity in (15) indeed holds. In our particular example, the AE_o and py components equal 1. We assume that the output-input mix is allocatively efficient so that the optimal weights (ρ, w) can be considered shadow prices (see Kuosmanen et al, 2004 for details). $py = 1$ is a restriction in (28). As a result, equation (15) identity simplifies to $SCB_R = TE_o(x, y) - \Pi(p, w)$. The 'Decomposition Ib' subplot shows a scatter plot of SCB_L versus technical efficiency (TE). It demonstrates that firms with similar technical efficiencies scores can nevertheless display very different degrees of competitiveness.

Figure 3 Demonstration of decompositions of competitiveness levels and changes



Source: Own presentation; Notes: dashed lines are the 45 degree lines through the origin

Next we check the dynamic decomposition identity in (25) with our simulated data. We calculate the relative change in competitiveness directly using SCB scores in two periods, i.e. $dSCB = SCB_2 / SCB_1 - 1$ and then calculate the relative change dSCB as in (25), we name them as $dSCB_L$ and $dSCB_R$ respectively. The 'Decomposition IIa' subplot demonstrates that the estimated $dSCB_L$ and $dSCB_R$ are almost perfectly correlated; the estimated correlation coefficient is 0.99. The 'Decomposition IIb' subplot shows that relative changes in TFP do not translate into identical changes in

competitiveness. Since the cloud of points extends over all four quadrants of the plot, improvements in TFP can be associated with both improvements and deterioration of competitiveness.

5 Conclusions

In the paper we derive static and dynamic decompositions of competitiveness measured by the Social Cost-Benefit indicator using a distance function approach. The static decomposition shows a positive relationship between the levels of technical efficiency and competitiveness, thus confirming the conventional perception about the relationship in the economic literature. Micro (firm-level) and macro (sector-level) determinants of competitiveness are distinguished. Firm-level determinants are mostly under the firm managers' control, while sector-level sources are are exogenous for the manager.

The dynamic decomposition of competitiveness shows a positive relationship between the TFP and competitiveness growth. The determinants of competitiveness growth include: i) a factor costs effect; ii) a terms of trade effect; iii) a scale effect; iv) technical change; v) technical efficiency changes; and vi) allocative effects.

Both the static and the dynamic decompositions are confirmed and illustrated using simulated data. To our knowledge this is the first rigorous analysis of the relationship between competitiveness and efficiency and productivity. While efficiency and productivity growth are positively related to competitiveness, the results presented here demonstrate that other determinants of competitiveness can override and mask these relationships.

References

Bruemmer, B., T. Glauben, and G. Thijssen (2002). Decomposition of Productivity Growth Using Distance Functions: The Case of Dairy Farms in Three European Countries. *American Journal of Agricultural Economics*, 84(3): 628-644.

Chambers, R. G., Chung, Y. and R. Färe (1998) Profit, Directional Distance Functions, and Nerlovian Efficiency. *Journal of Optimization Theory and Applications* Vol 98(2), pp. 351-364

Färe, R. and S. Grosskopf (1997) Profit efficiency, Farrell decompositions and the Mahler inequality. *Economics Letters* Vol 57, pp. 283-287

Färe, R. and D. Primont (1995).Multi-Output Production and Duality: Theory and Applicaions. Boston: Kluwer Academic Publishers.

Farrell, M.J. (1957) The Measurement of Productive Efficiency, *Journal of Royal Statistical Society*, Vol. 129A, pp. 253-281

Krugman, P. B. (1994): Competitiveness: A dangerous obsession. *Foreign Affairs*, March/April 1994.

Kumbhakar, S.C., Park, B.U., Simar, L. and E.G. Tsionas (2007): Nonparametric stochastic frontiers: a local likelihood approach, *Journal of Econometrics*, 137, 1, pp. 1-27

Kuosmanen, T., Post, T., Sipilänen, T. (2004) . Shadow Price Approach to Total Factor Productivity Measurement: With an Application to Finnish Grass-Silage Production. *Journal of Productivity Analysis*, 22, 95–121.

Masters, W.A., and A. Winter-Nelson. (1995), Measuring the Comparative Advantage of Agricultural Activities: Domestic Resource Costs and the Social Cost-Benefit Ratio, *American Journal of Agricultural Economics*, Vol 77: 243-50.

Monke, E. A. and S. R. Pearson (1989), The Policy Analysis Matrix for Agricultural Development, Ithaca NY: Cornell University Press

Nishimizu, M. and J.M. Jr. Page (1986): Productivity change and dynamic comparative advantage. The Review of Economics and Statistics, Vol 68 (2), pp. 241-247

Nivievskyi, O., and S. von Cramon-Taubadel (2009): Measuring and Comparing the Competitiveness of Heterogeneous Production Systems in Agriculture: a Note. *Outlook on Agriculture*, Vol 38, No 1, 2009, pp 31–37

Page, J.M. Jr. (1980): Technical efficiency and economic performance: some evidence from Ghana. *Oxford Economic Papers*, Vol 32(2), pp. 319-339

Shephard, R.W.(1970) *Theory of Cost and Production Functions*. Princeton

Siggel, E. (2006): International Competitiveness and Comparative Advantage: A Survey and a Proposal for Measuremen. *Journal of Industry Competition and Trade*. Vol 6(2), pp. 137-159

Simar, L. and Zelenyuk, V. (2008): Stochastic FDH/DEA estimator for Frontier Analysis.Discussion Paper 0820, Institut de Statistique, UCL, Belgium.

Simar L. (2003): Detecting Outliers in Frontier Models: A Simple Approach. *Journal of Productivity Analysis*, 20, 391–424

von Cramon Taubadel, S., Grueninger M., Nivyevskiy, O., and D. Prokhodko (2009), 'Belarus: Boosting agricultural productivity and competitiveness. Options and Impact of State Support' World Bank Policy Note No. 48335-BY.

von Cramon Taubadel, S., Nivyevskiy, O., and M. Gruenninger (2008), `Ukraine: Agricultural Competitiveness´ World Bank Policy Note No. 44843-UA.

Zhu1, X., Demeter M. R., A.O. Lansink (2008): Competitiveness of dairy farms in three countries: the role of CAP subsidies. Contributed paper at the EAAE 2008 Conference, Ghent, Belgium.