Estimating trade-off between economic growth and environmental impact: An application of the modified by-production approach to European agricultural sector

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Outline

- Motivation
- By-production model
  - Conventional model
  - Modified model
- Environmental LHM indicator
- Empirical application

Motivation

- The measures of TFP are important for performance analysis. They have been revised to account for environmental pressures.
- TFP indices/indicators as per O'Donnell (2012). LHM indicator satisfies the desiderata.
- The environmental LHM indicators have been focused on the output-orientation.
- DEA models for environmental efficiency are needed for the measurement of environmental TFP.
- By-production technology satisfies theoretical requirements, yet the conventional model might require further modifications:
  - Two sets of input prices – unclear economic interpretation;
  - No connection between sub-technologies.
- We propose modified by-production DEA model.
- We propose input- and output-oriented environmental LHM TFP indicator for the by-production technology.
- The proposed approach is applied on the data set for European agriculture

Treating undesirable outputs in DEA

- Imposing no additional axioms on the productive technology:
  - Undesirables as inputs;
  - Data transformation.
- Imposing additional axioms on the productive technology:
  - Weak disposability approach (FG, 1989; K, 2004);
  - **By-production approach (Murty et al., 2012).**

By-production approach (1)

- There are *M* desirable (good) outputs and *J* undesirable (bad) by-products.
- There are *N* non-polluting (clean) inputs which only contribute to generation of the desirable outputs and *P* pollution-generating (dirty) inputs which also contribute to generation of the undesirable outputs.
- Input vectors: $\mathbf{x}_n^t \in R_+^J$, $\mathbf{x}_p^t \in R_+^p$, $\mathbf{x}^t = (\mathbf{x}_n^t, \mathbf{x}_p^t)$
- Output vectors: $\mathbf{y}^t \in R_+^M$, $\mathbf{z}^t \in R_+^J$

$$
\begin{aligned}
T_{BP}(t) &= T_1(t) \cap T_2(t) \\
&= \left\{ (\mathbf{x}_n^t, \mathbf{x}_p^t, \mathbf{y}^t, \mathbf{z}^t) \in R_+^{M+N+P+J} : (\mathbf{x}_n^t, \mathbf{x}_p^t) \text{ can produce } \mathbf{y}^t;\ \mathbf{x}_p^t \text{ can generate } \mathbf{z}^t \right\}, \\
T_1(t) &= \left\{ (\mathbf{x}_n^t, \mathbf{x}_p^t, \mathbf{y}^t) \in R_+^{M+N+P} \mid f(\mathbf{x}_n^t, \mathbf{x}_p^t, \mathbf{y}^t) \le 0 \right\}, \\
T_2(t) &= \left\{ (\mathbf{x}_p^t, \mathbf{z}^t) \in R_+^{P+B} \mid g(\mathbf{x}_p^t) \le \mathbf{z}^t \right\},
\end{aligned}
$$

By-production approach (2)

$A1:$ if $(\mathbf{x_n},\mathbf{x_p},\mathbf{y},\mathbf{z}) \in T_1$, then $(\tilde{\mathbf{x}}_\mathbf{n},\tilde{\mathbf{x}}_\mathbf{p},\tilde{\mathbf{y}},\tilde{\mathbf{z}}) \in T_1$ for all $(-\tilde{\mathbf{x}}_\mathbf{n},-\tilde{\mathbf{x}}_\mathbf{p},\tilde{\mathbf{y}}) \leq (-\mathbf{x_n},-\mathbf{x_p},\mathbf{y})$.

$A2:$ if $(\mathbf{x_p},\mathbf{z}) \in T_2$, then $(\tilde{\mathbf{x}}_\mathbf{p},\tilde{\mathbf{z}}) \in T_2$ for all $(\tilde{\mathbf{x}}_\mathbf{p},-\tilde{\mathbf{z}}) \leq (\mathbf{x_p},\mathbf{z})$.

$$P_t\left(\mathbf{x}^t\right)=\left\{(\mathbf{y}^t,\mathbf{z}^t)\in R_+^{P+J}:\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{z}^t\right)\in T_{BP}\left(t\right)\right\}.$$

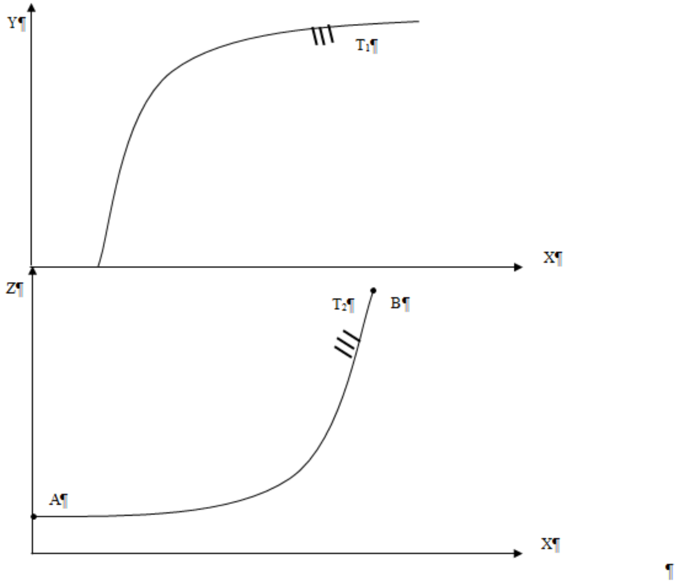


Figure 1. Graphical representation of the VRS by-production technology

By-production efficiency

- Efficiency scores are obtained by applying an improved output-oriented Färe-Grosskopf-Lovell indicator:

$$E_{FGL}(\mathbf{x}^t,\mathbf{y}^t,\mathbf{z}^t) = \frac{1}{2}\min\left\{ \frac{\sum_m \delta_m}{M} + \frac{\sum_j \theta_j}{J} \mid (\mathbf{y}^t \otimes^{-1} \boldsymbol{\delta}, \boldsymbol{\theta} \otimes \mathbf{z}^t) \in P_t(\mathbf{x}) \right\}$$

$$\mathbf{y}^t \otimes^{-1} \boldsymbol{\delta} = (y_1^{\,t} / \delta_1, \dots, y_P^{\,t} / \delta_P)$$

$$\boldsymbol{\theta} \otimes \mathbf{z}^t = (\theta_1 z_1^{\,t}, \dots, \theta_J z_J^{\,t})$$

$$\underset{\delta,\theta,\lambda,\sigma}{Min} \;\; \frac{1}{2}\left(\sum_{m=1}^{M} \delta^m / M + \sum_{j=1}^{J} \theta^j / J\right)$$

$$\begin{aligned}
s.t.\ & \sum_{k=1}^{K} \lambda_k y_k^{m,t} \ge y_{k'}^{m,t} / \delta^m, \ \forall m = 1,\cdots,M, \\
& \sum_{k=1}^{K} \lambda_k x_k^{n,t} \le x_{k'}^{n,t}, \ \forall n = 1,\cdots,N, \\
& \sum_{k=1}^{K} \lambda_k x_k^{p,t} \le x_{k'}^{p,t}, \ \forall p = 1,\cdots,P, \\
& \sum_{k=1}^{K} \sigma_k z_k^{j} \le \theta^j z_{k'}^{j}, \ \forall j = 1,\cdots,J, \\
& \sum_{k=1}^{K} \sigma_k x_k^{p,t} \ge x_{k'}^{p,t}, \ \forall p = 1,\cdots,P, \\
& \sum_{k=1}^{K} \lambda_k = 1, \\
& \sum_{k=1}^{K} \sigma_k = 1, \\
& \lambda_k \ge 0, \forall k = 1,\dots,K, \\
& \sigma_k \ge 0, \ \forall k = 1,\dots,K.
\end{aligned}$$

Some remarks on the BP model

- **Remark 1.** The model offered by Murty et al. (2012) is non-linear one and might be less operational than linear models due to existence of local optima;
- **Remark 2.** The two sub-technologies in the by-production model are not linked explicitly and might render different benchmarks;
- **Remark 3.** The production possibility sets applied in the conventional setting may not provide a clear economic interpretation.

Dual formulation of the directional BP model

$$D^b(\mathbf{x}^a,\mathbf{y}^a,\mathbf{z}^a;\mathbf{0},\mathbf{g}_y^a,\mathbf{g}_z^a) = \max_{\delta,\lambda_k,\sigma_k} \delta$$

$$s.t. \sum_{k=1}^{K}\lambda_k y_k^{m,b} \geq y_{k'}^{m,a} + \delta g_y^{m,a},\ \forall m=1,\cdots,M,$$

$$\sum_{k=1}^{K}\lambda_k x_k^{n,b} \leq x_{k'}^{n,a} \quad \forall n=1,\cdots,N,$$

$$\sum_{k=1}^{K}\lambda_k x_k^{p,b} \leq x_{k'}^{p,a},\ \forall p=1,\cdots,P,$$

$$\sum_{k=1}^{K}\sigma_k z_k^{j,b} \leq z_{k'}^{j,a} - \delta g_z^{j,a},\ \forall j=1,\cdots,J,$$

$$\sum_{k=1}^{K}\sigma_k x_k^{p,b} \geq x_{k'}^{p,a},\ \forall p=1,\cdots,P,$$

$$\sum_{k=1}^{K}\lambda_k = 1,$$

$$\sum_{k=1}^{K}\sigma_k = 1,$$

$$\lambda_k \geq 0,\ \forall k=1,\ldots,K,$$

$$\sigma_k \geq 0, \forall k=1,\ldots,K,$$

$$D^b(\mathbf{x}^a,\mathbf{y}^a,\mathbf{z}^a;\mathbf{0},\mathbf{g}_y^a,\mathbf{g}_z^a) = \max_{\pi_y^m,\pi_x^n,\pi_x^p,\omega_x^p,\omega_z^j,v_1,v_2} \Big(\sum_{m=1}^{M}\pi_y^m y_{k'}^{m,a} - \sum_{n=1}^{N}\pi_x^n x_{k'}^{n,a} - \sum_{p=1}^{P}\pi_x^p x_{k'}^{p,a} + v_1\Big) + \Big(\sum_{p=1}^{P}\omega_x^p x_{k'}^{p,a} - \sum_{j=1}^{J}\omega_z^j z_{k'}^{j,a} + v_2\Big)$$

$$s.t. \sum_{m=1}^{M}\pi_y^m y_k^{m,b} - \sum_{n=1}^{N}\pi_x^n x_k^{n,b} - \sum_{p=1}^{P}\pi_x^p x_k^{p,b} + v_1 \leq 0,\ \forall k=1,\cdots,K,$$

$$\sum_{p=1}^{P}\omega_x^p x_k^{p,b} - \sum_{j=1}^{J}\omega_z^j z_k^{j,b} + v_2 \leq 0,\ \forall k=1,\cdots,K,$$

$$\sum_{m=1}^{M}\pi_y^m g_y^{m,a} + \sum_{j=1}^{J}\omega_z^j g_z^{j,a} = 1,$$

$$\pi_y^m \geq 0 \quad \forall m=1,\ldots,M,$$

$$\pi_x^n \geq 0 \quad \forall n=1,\ldots,N,$$

$$\pi_x^p \geq 0 \quad \forall n=1,\ldots,P,$$

$$\omega_z^j \geq 0 \quad \forall j=1,\ldots,J,$$

$$v_1, v_2 \text{ unrestricted},$$

Remark 4. These two sets of different shadow prices of pollution-generating inputs across sub-technologies represent their dual role as inputs and outputs.

A refined BP model (1)

$$D^b(\mathbf{x}^a,\mathbf{y}^a,\mathbf{z}^a;\mathbf{0},\mathbf{g}_y^a,\mathbf{g}_z^a) = \max_{\delta,\theta,\lambda,\sigma} \ \delta$$

$$s.t. \ \sum_{k=1}^{K}\lambda_k y_k^{m,b} \geq y_{k'}^{m,a} + \delta g_y^{m,a}, \ \forall m=1,\cdots,M,$$

$$\sum_{k=1}^{K}\lambda_k x_k^{n,b} \leq x_{k'}^{n,a}, \ \forall n=1,\cdots,N,$$

$$\sum_{k=1}^{K}\lambda_k x_k^{p,b} \leq x_{k'}^{p,a} \ ,\forall p=1,\cdots,P,$$

$$\left.\begin{aligned}&\sum_{k=1}^{K}\sigma_k z_k^{j,b} \leq z_{k'}^{j,a} - \delta g_z^{j,a}, \ \forall j=1,\cdots,J,\\ &\sum_{k=1}^{K}\sigma_k x_k^{p,b} \boxed{=\sum_{k=1}^{K}\lambda_k x_k^{p,b}}, \ \forall p=1,\cdots,P,\end{aligned}\right\} \text{T2}$$

$$\sum_{k=1}^{K}\lambda_k = 1,$$

$$\sum_{k=1}^{K}\sigma_k = 1,$$

$$\lambda_k \geq 0, \ \forall k=1,\ldots,K,$$

$$\sigma_k \geq 0, \ \forall k=1,\ldots,K,$$

$$\delta^m \geq 0, \ \forall m=1,\cdots,M.$$

$$D^b(\mathbf{x}^a,\mathbf{y}^a,\mathbf{z}^a;\mathbf{0},\mathbf{g}_y^a,\mathbf{g}_z^a) = \max_{\pi_y,\pi_x^n,\pi_x^p,\omega_x^p,\omega_z,v_1,v_2} [\sum_{m=1}^{M}\pi_y^m y_{k'}^{m,a} - \sum_{n=1}^{N}\pi_x^n x_{k'}^{n,a} \boxed{-(\sum_{p=1}^{P}\psi_x^p x_{k'}^{p,a} + \sum_{p=1}^{P}\omega_x^p x_{k'}^{p,a})} + v_1] + (\sum_{p=1}^{P}\omega_x^p x_{k'}^{p,a} - \sum_{j=1}^{J}\omega_z^j z_{k'}^{j,a} + v_2)$$

$$s.t. \sum_{m=1}^{M}\pi_y^m y_k^{m,b} - \sum_{n=1}^{N}\pi_x^n x_k^{n,b} \boxed{-(\sum_{p=1}^{P}\psi_x^p x_k^{p,b} + \sum_{p=1}^{P}\omega_x^p x_k^{p,b})} + v_1 \leq 0, \ \forall k=1,\cdots,K,$$

$$\sum_{p=1}^{P}\omega_x^p x_k^{p,b} - \sum_{j=1}^{J}\omega_z^j z_k^{j,b} + v_2 \leq 0, \ \forall k=1,\cdots,K,$$

$$\sum_{m=1}^{M}\pi_y^m g_y^{m,a} + \sum_{j=1}^{J}\omega_z^j g_z^{j,a} = 1,$$

$$\pi_y^m \geq 0, \ \forall m=1,\ldots,M,$$

$$\pi_x^n \geq 0, \ \forall n=1,\ldots,N,$$

$$\psi_x^p \geq 0, \ \forall n=1,\ldots,P,$$

$$\omega_x^p \geq 0, \ \forall n=1,\ldots,P,$$

$$\omega_z^j \geq 0, \ \forall j=1,\ldots,J,$$

$$v_1,v_2 \ \text{unrestricted.}$$

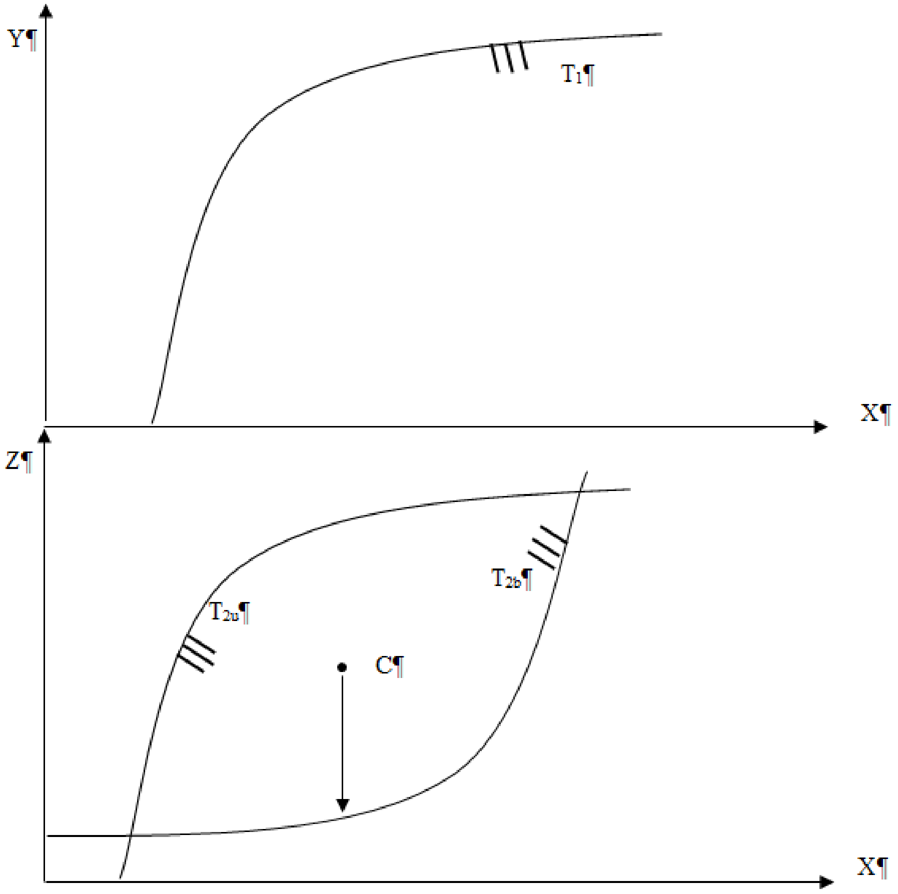


Figure 2 Illustration of a refined by-production model

Environmental LHM indicator

- LHM indicator is calculated as:

$$LHM^{t,t+1}=\frac{1}{2}\begin{pmatrix}[D^{t}(\mathbf{x}_k^{t},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{0},\mathbf{g}_y^{t},\mathbf{g}_z^{t})-D^{t}(\mathbf{x}_k^{t},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{0},\mathbf{g}_y^{t+1},\mathbf{g}_z^{t+1})]\\ -[D^{t}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{g}_x^{t+1},\mathbf{0},\mathbf{0})-D^{t}(\mathbf{x}_k^{t},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{g}_x^{t},\mathbf{0},\mathbf{0})]\\ +[D^{t+1}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{0},\mathbf{g}_y^{t},\mathbf{g}_z^{t})-D^{t+1}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{0},\mathbf{g}_y^{t+1},\mathbf{g}_z^{t+1})]\\ -[D^{t+1}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{g}_x^{t+1},\mathbf{0},\mathbf{0})-D^{t+1}(\mathbf{x}_k^{t},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{g}_x^{t},\mathbf{0},\mathbf{0})]\end{pmatrix}$$

- LHM indicator decomposes as:

$$LHM^{t,t+1}=TEC^{t,t+1}+TP^{t,t+1}+SEC^{t,t+1}$$

$$TEC^{t,t+1}=D^{t}(\mathbf{x}_k^{t},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{0},\mathbf{g}_y^{t},\mathbf{g}_z^{t})-D^{t+1}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{0},\mathbf{g}_y^{t+1},\mathbf{g}_z^{t+1})$$

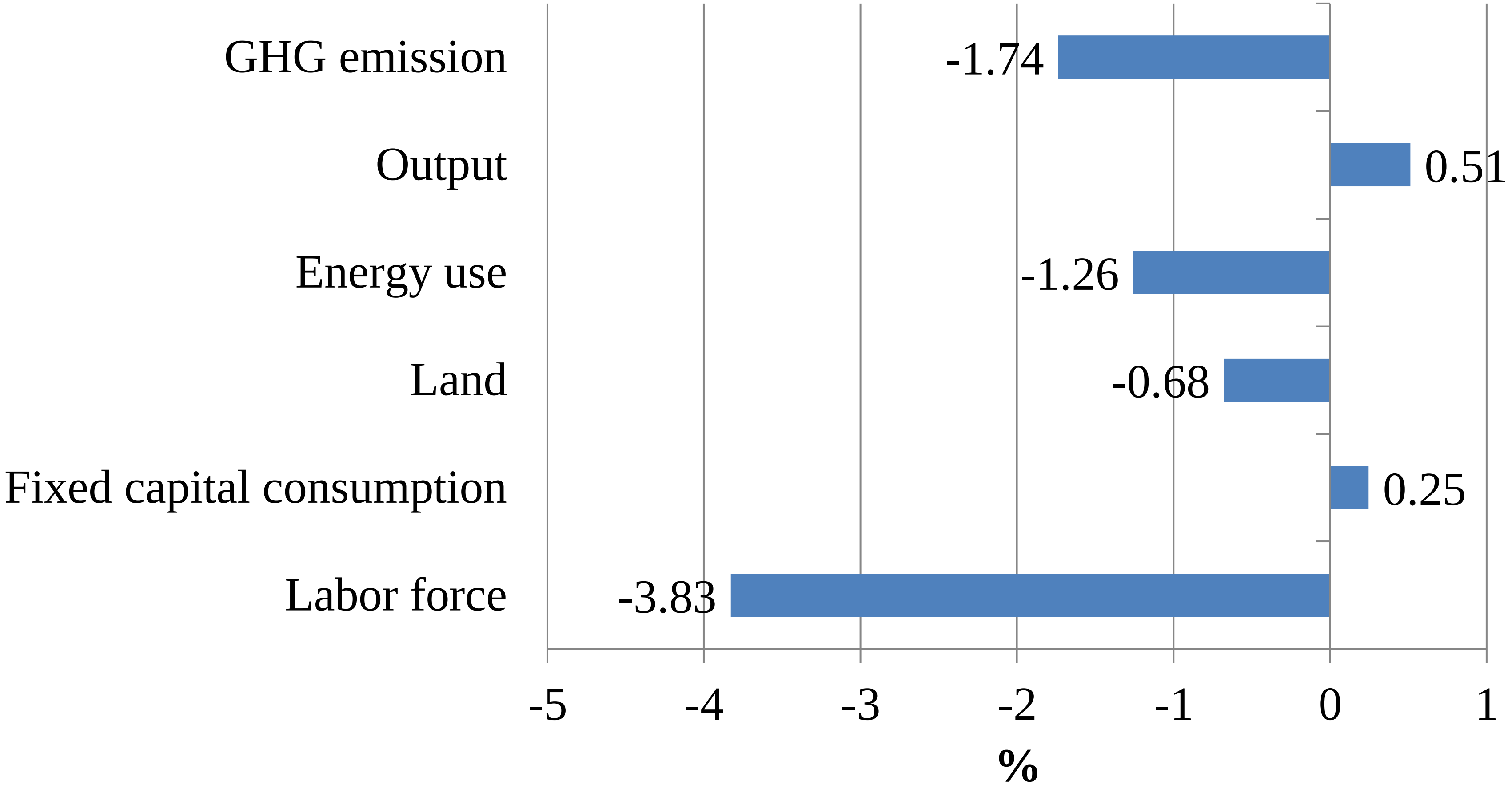
$$TP^{t,t+1}=\frac{1}{2}\begin{pmatrix}[D^{t+1}(\mathbf{x}_k^{t},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{0},\mathbf{g}_y^{t},\mathbf{g}_z^{t})-D^{t}(\mathbf{x}_k^{t},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{0},\mathbf{g}_y^{t},\mathbf{g}_z^{t})]\\ +[D^{t+1}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{0},\mathbf{g}_y^{t+1},\mathbf{g}_z^{t+1})-D^{t}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{0},\mathbf{g}_y^{t+1},\mathbf{g}_z^{t+1})]\end{pmatrix}$$

$$SEC^{t,t+1}=\frac{1}{2}\begin{pmatrix}[D^{t}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{0},\mathbf{g}_y^{t+1},\mathbf{g}_z^{t+1})-D^{t}(\mathbf{x}_k^{t},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{0},\mathbf{g}_y^{t+1},\mathbf{g}_z^{t+1})]\\ -[D^{t}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{g}_x^{t+1},\mathbf{0},\mathbf{0})-D^{t}(\mathbf{x}_k^{t},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{g}_x^{t},\mathbf{0},\mathbf{0})]\\ +[D^{t+1}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{0},\mathbf{g}_y^{t},\mathbf{g}_z^{t})-D^{t+1}(\mathbf{x}_k^{t},\mathbf{y}_k^{t},\mathbf{z}_k^{t};\mathbf{0},\mathbf{g}_y^{t},\mathbf{g}_z^{t})]\\ -[D^{t+1}(\mathbf{x}_k^{t+1},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{g}_x^{t+1},\mathbf{0},\mathbf{0})-D^{t+1}(\mathbf{x}_k^{t},\mathbf{y}_k^{t+1},\mathbf{z}_k^{t+1};\mathbf{g}_x^{t},\mathbf{0},\mathbf{0})]\end{pmatrix}$$

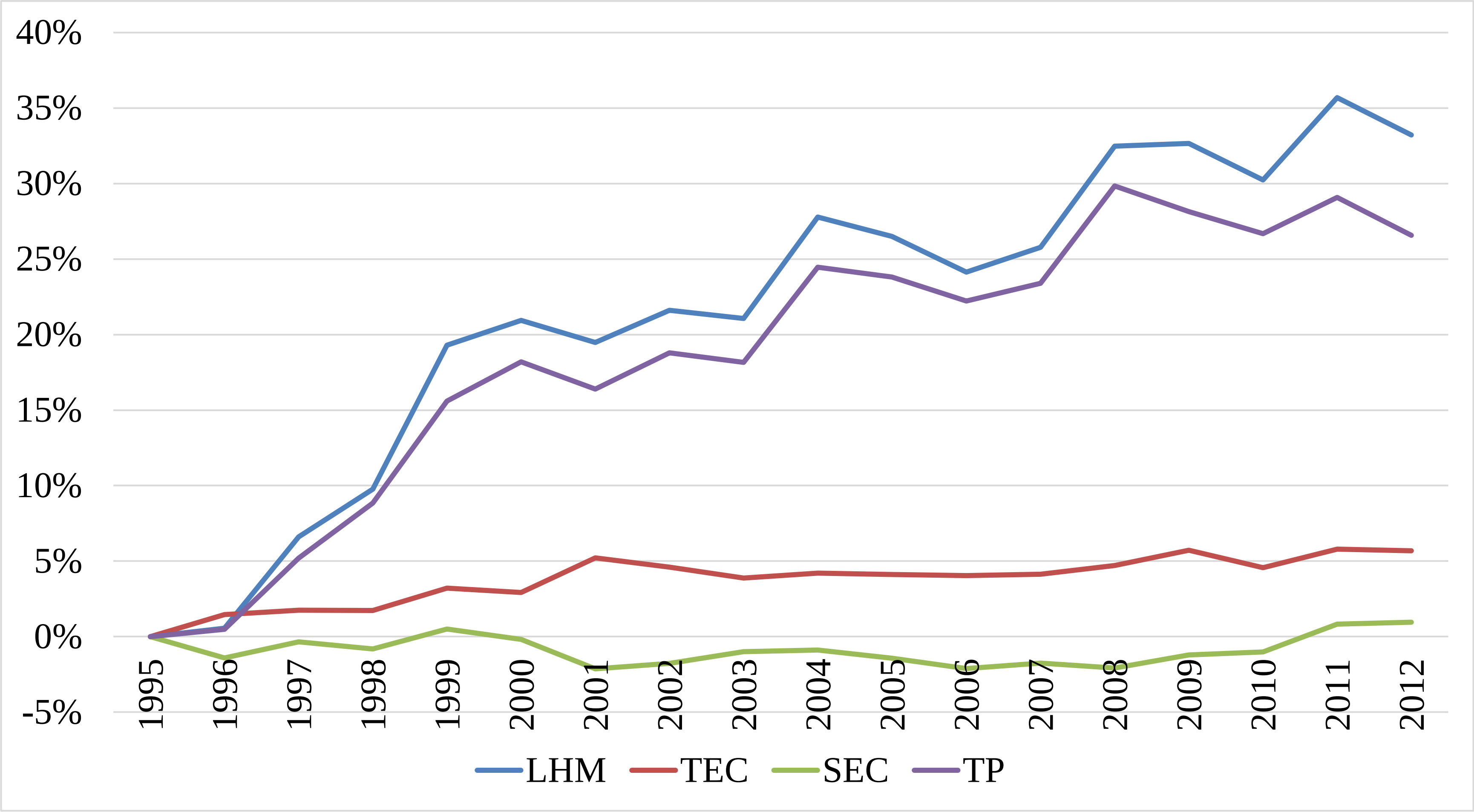
Data used

- In this paper, we seek to estimate the growth in TFP for agricultural sectors of a sample of the European counties. Besides conventional production process, we also focus on environmental pressures caused by energy-related emissions.
- The data from Eurostat (European Commission, 2017) and FAOSTAT (FAO, 2017) databases are applied.
- The technology includes
  - one desirable output (i.e. agricultural output),
  - one undesirable output (energy-related GHG emission) and
  - four inputs (labour, energy, land, and capital consumption).
- Due to data availability, we chose 17 European countries featuring rather similar production structure. These countries are Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Hungary, Latvia, Lithuania, the Netherlands, Poland, Romania, Slovakia, Slovenia, Sweden.
- The data cover years 1995-2012.

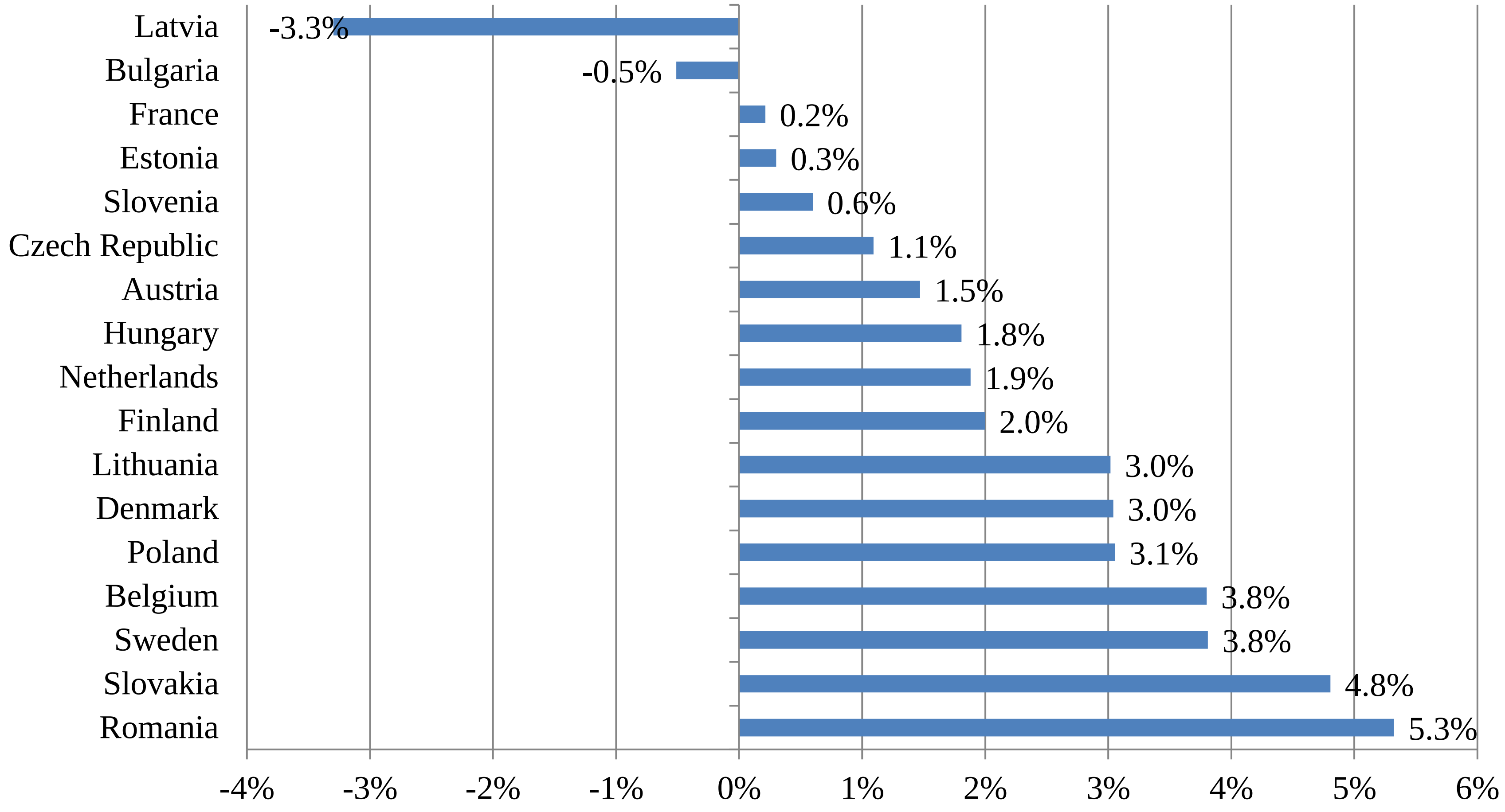
Dynamics in inputs/outputs, 1995-2012



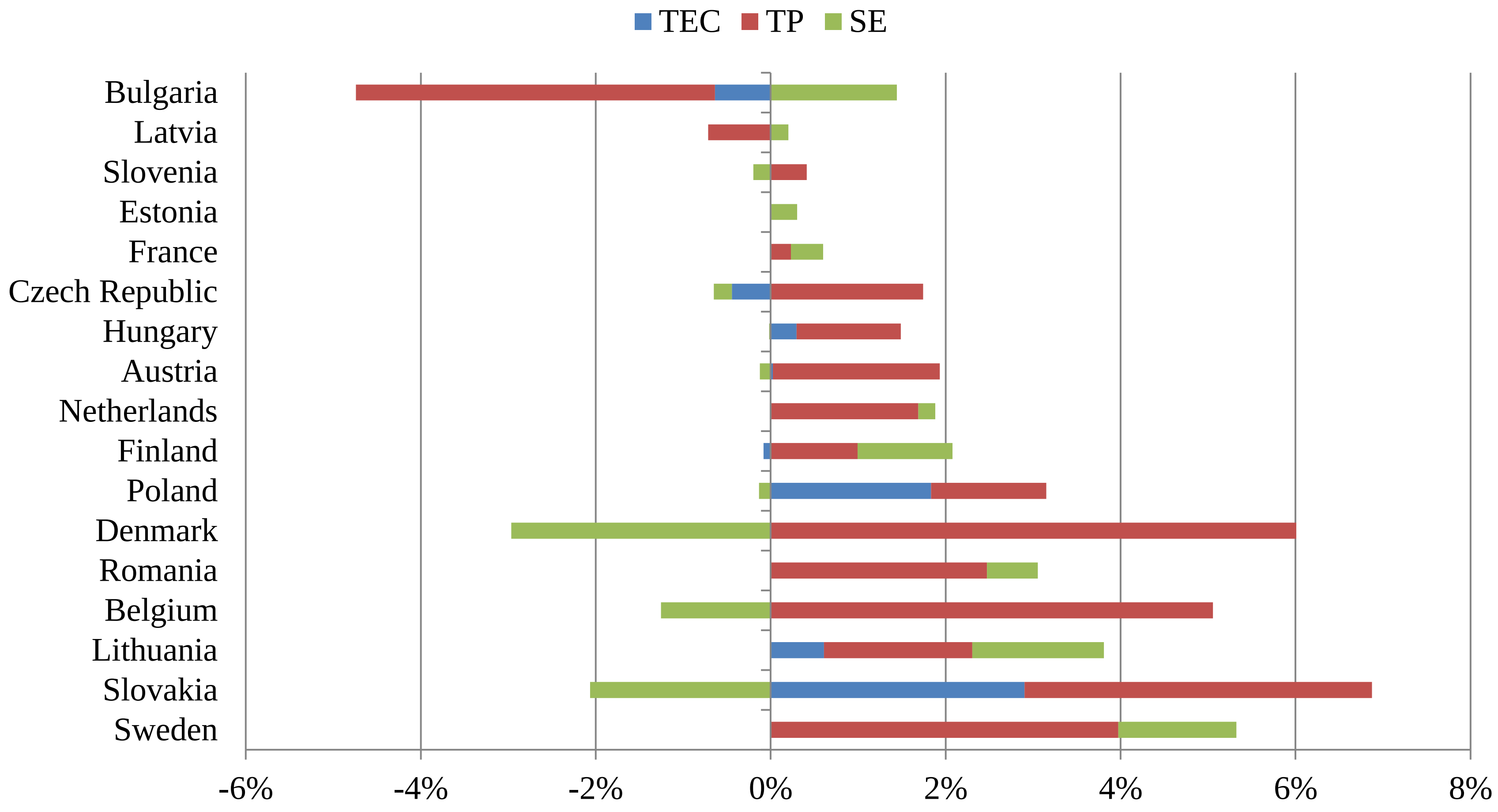
LHM indicator based on the modified BP approach (average values for the sample), 1995-2012



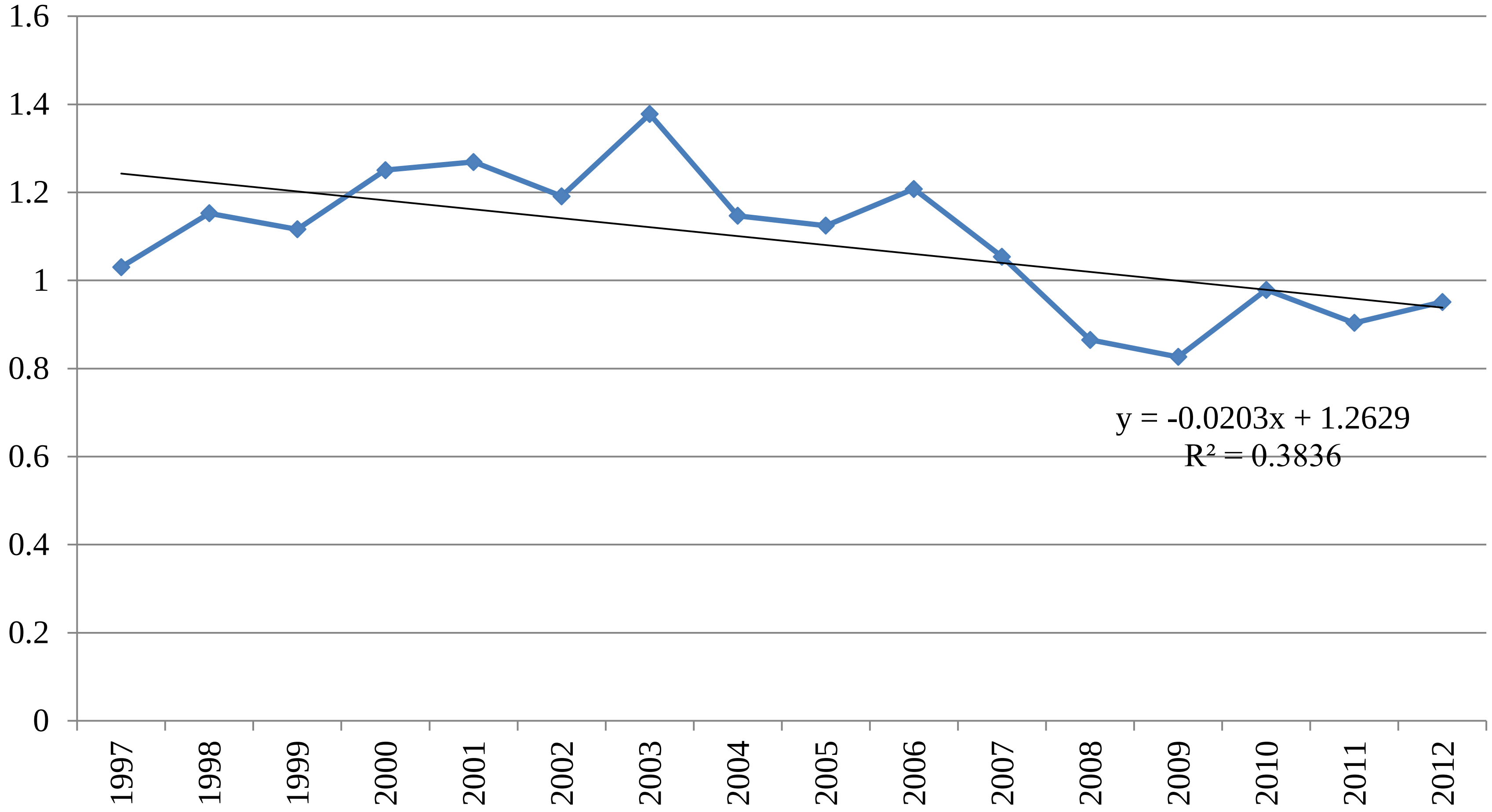
Annual stochastic growth rates in TFP for selected countries, 1995-2012



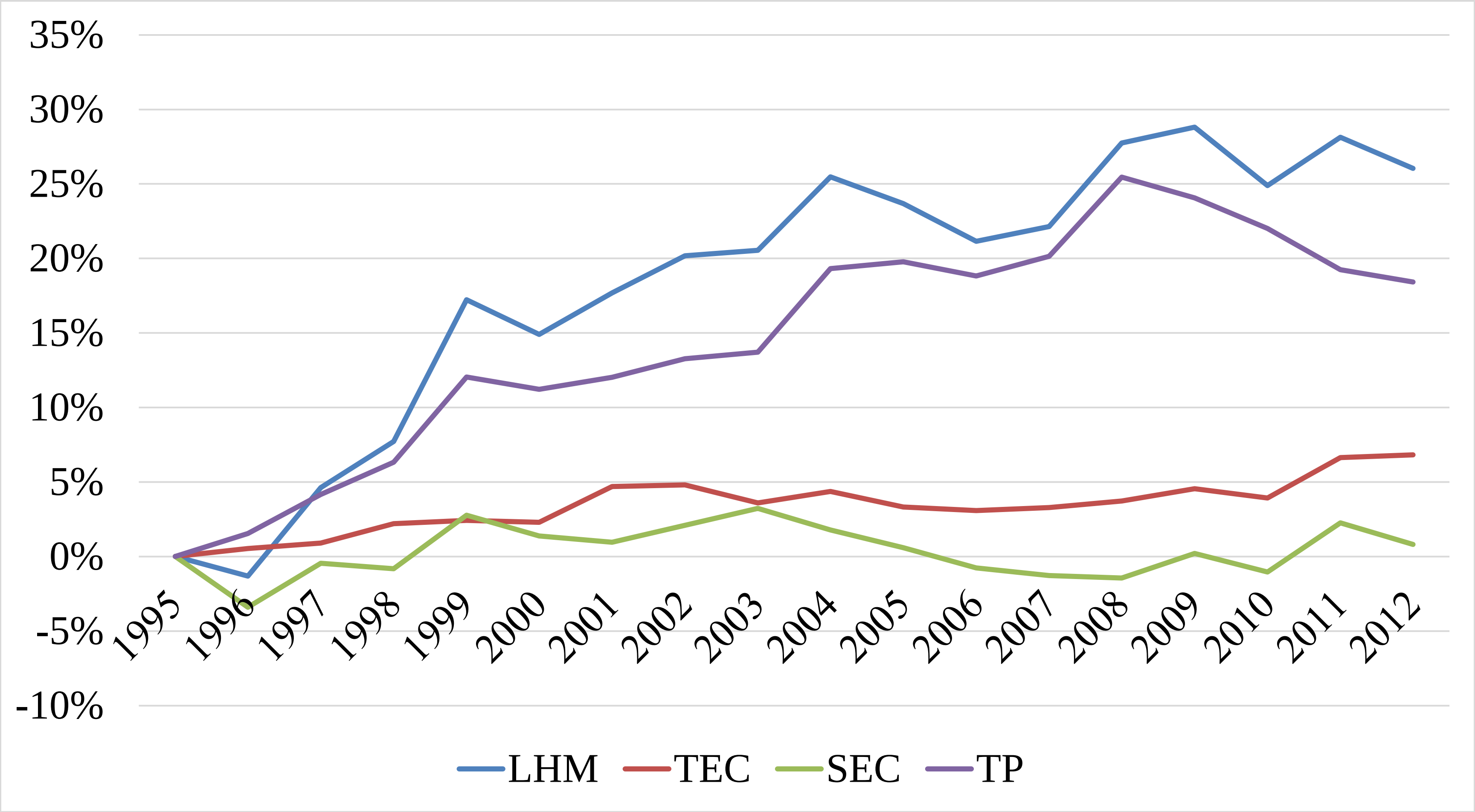
Decomposition of the average growth rates of TFP for selected countries, 1995-2012



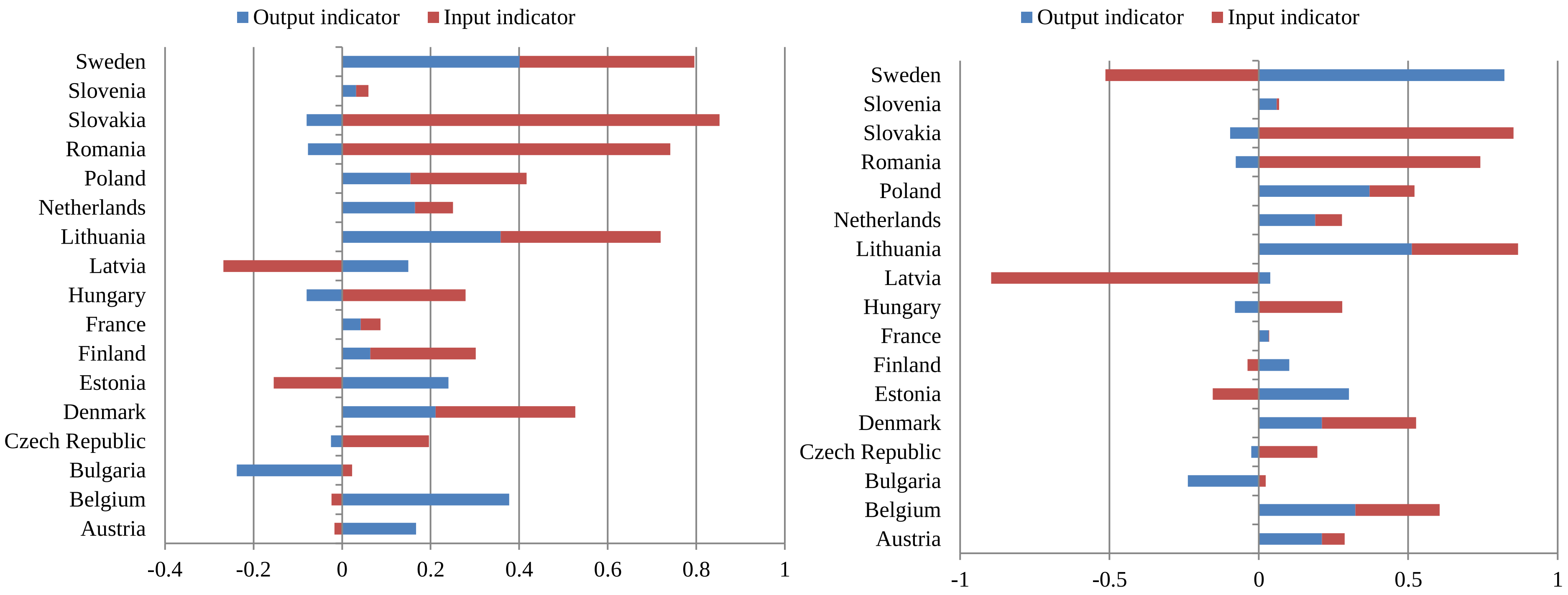
Cefficient of variation for the cumulative TFP, 1995-2012



Decomposition of the LHM indicator based on the old BP approach



Contributions of input and output indicators to the LHM indicator



a - New BP model

b - Old BP model

Conclusions

- The proposed by-production model utilizes the generalized directional distance function. Therefore, the simultaneous expansion of desirable outputs and contraction of the undesirable ones is facilitated when constructing the measures of the environmental total factor productivity. The Luenberger-Hicks-Moorsteen indicator was adapted for the proposed BP model and decomposed into the components of technical efficiency change, scale efficiency change, and technical progress.
- The proposed approach was applied to measure the environmental total factor productivity change in agricultural sectors of the selected European countries. The results indicated that a positive change in the environmental total factor productivity was observed during 1995-2012. The major driving force was technical progress. Also, the results suggested that there had been convergence among the countries analyzed in terms of the total factor productivity change. Methodologically, we showed that the proposed by-production model rendered lower estimates of the total factor productivity if opposed to the conventional BP model. Furthermore, the input indicator was affected to a higher extent (if compared to the output indicator).
- The proposed modification of the by-production model can be applied either in a self-standing manner (for measurement of efficiency and shadow prices) or integrated into the measurement of the total factor productivity. Indeed, other indices and indicators of the total factor productivity can be applied along with the proposed models.

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