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Productivity growth in electricity and gas networks since 1990

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Background

This paper evaluates the productivity growth of the electricity and gas networks in Great Britain (GB) since privatisation and the introduction of incentive regulation (around 1990). For the period up until 2013 networks operated under a regulatory regime known as RPI-X. Since 2013 a new regime, known as RIIO (Revenue=Incentives+Innovation+Outputs) , has been put in place. This has emphasised a wider range of outputs, around quality, for energy networks.

Available at:

https://www.ofgem.gov.uk/ofgem-publications/146010

Methodology

- The paper uses the Malmquist data envelopment analysis (DEA) method with the variable returns to scale (VRS) input oriented approach (see Fare et al., 1994; Coelli et al., 2005). We use a new dataset collected with the help of the energy regulator in Great Britain, Ofgem.

- We perform separate analyses for four network sectors: electricity distribution (ED) and gas distribution (GD) and electricity transmission (ET) and gas transmission (GT). Different models are proposed for each sector with a combination of inputs/outputs and non-quality/quality variables.

- This work builds on earlier efficiency work on electricity networks (Giannakis et al., 2005; Llorca et al., 2016) and gas networks (Price and Weyman-Jones, 1996; Rossi, 2001; and Jamasb et al., 2008).

- In each case we have a base model consisting of a number of physical outputs (including energy delivered) and two inputs (operating expenditure (opex) and capital expenditure (capex)). We report a number of other models (often estimated over shorter periods due to lack of data) which include measures of quality as additional inputs or outputs.

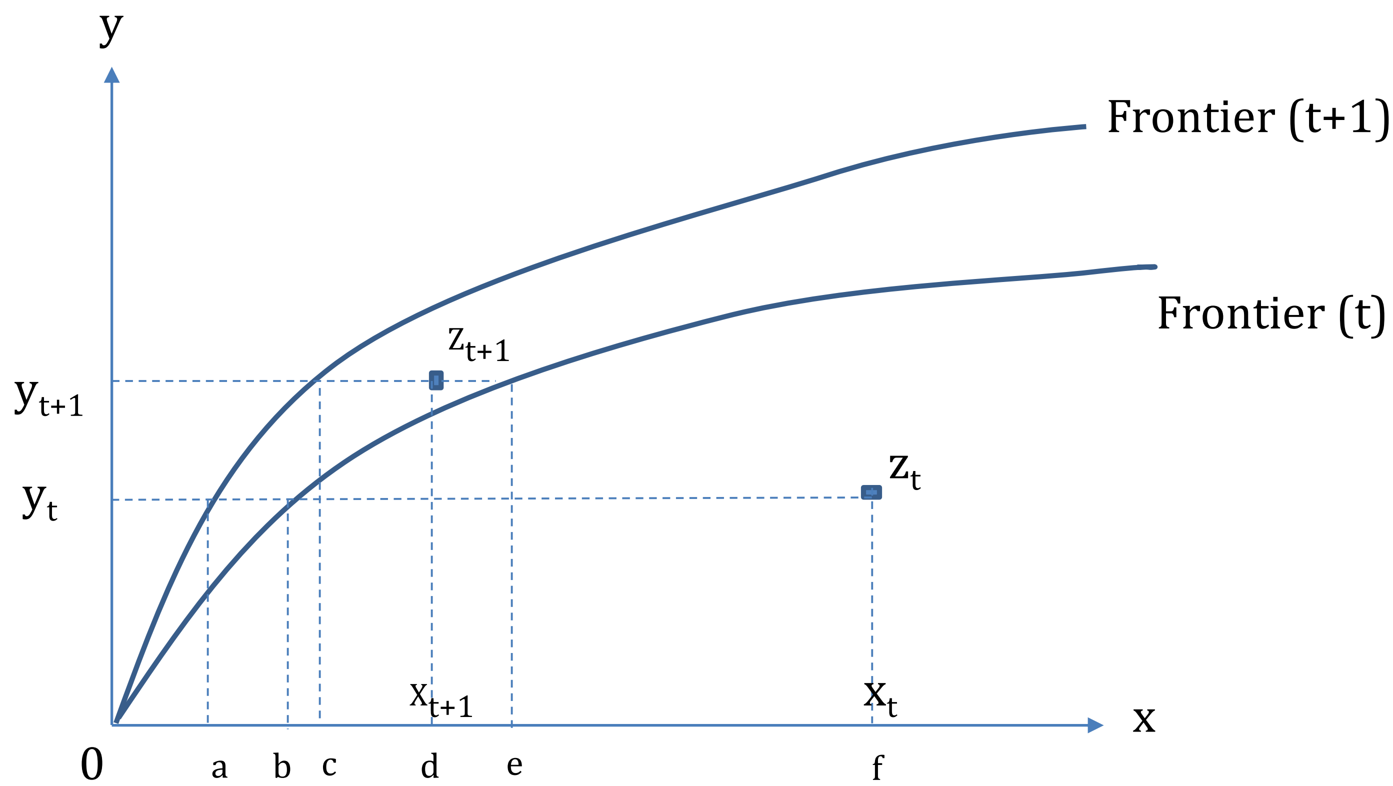
Malmquist Productivity Index (MPI)

Firm Z_t moves to z_{t+1}

Need to measure change relative to both old and new frontiers.

This can be then reorganized into efficiency change and technical change.

That is what the MPI measures.



MPI = $(((0e/0d)/(0b/0f)) * ((0c/0d)/(0a/0f)))^{0.5}$

Data Issues

- Data Envelopment Analysis (DEA) Malmquist TFP, with inputs (I) and outputs (O).
- Discussion of role of quality (i.e. I: CML, CI; O: CS).
- Efficiency and productivity analysis of firm level data (ED, GD).
- Aggregate productivity analysis for sectors with few firms. Evaluation of sectors as a single firm (ET, GT).
- Presentation of results in line with Ofgem's price control review regime.
- Data provided by Ofgem with a lot effort (with few additions from EPRG).
- We did what we could with the data available!
- Evaluation of different models (combination of inputs/outputs, including quality variables).
- Quality variables: a reduction is desirable (inputs: CMI, CI, losses) but not always (output: CS).
- All figures adjusted (RPI), 2012/13 prices.

Price Control Periods

- **Electricity Distribution:**
- DPCR1: 1990/91-1994/95
- DPCR2: 1995/96-1999/2000
- DPCR3: 2000/01-2004/05
- DPCR4: 2005/06-2009/10
- DPCR5: 2010/11-2014/15
- RIIO-ED1: 2015/16-2022/23

- **Gas Distribution:**
- GDPCR1: 2008/09-2012/13
- RIIO-GD1: 2013/14-2020/21

- **Electricity Transmission:**
- TPCR3: 2000/01-2006/07
- TPCR4: 2007/08-2012/13
- RIIO-ET1: 2013/14-2000/21

- **Gas Transmission:**
- TPCR4: 2007/08-2012/13
- RIIO-GT1: 2013/14-2020/21

Electricity Distribution

- Involves 14 distribution network companies (DNOs).
- Five models with a combination of non-quality and quality variables.
- Different evaluation periods in line with data availability.
- Largest one (27 years) for M1 and M2.
- Evaluation of TFP growth for 6 price control periods (DPCR 1-5, RIIO-ED1).

Table 1: Models for Electricity Distribution

Model	Non-quality variables						Quality variables				Periods
	opex	capex	Cust	END	NL	PD	CML	CI	Loss	CS	
Model 1	I	I	O	O	O						1990/91-2016/17
Model 2	I	I	O	O	O		I	I			1990/91-2016/17
Model 3	I	I	O	O	O		I	I	I		1990/91-2004/05, 2015/16-2016/17
Model 4	I	I	O	O	O	O	I	I			2010/11-2016/17
Model 5	I	I	O	O	O	O	I	I		O	2012/13-2016/17

I: input, O: output, Cust: # of customers, END: energy delivered, NL: network length, PD: peak demand, CML: customer minutes lost, CI: # interruptions, Loss: energy losses, CS: customer satistaction

Electricity Distribution

Results

- M2 the one with the highest average annual TFP growth among the five models(2%) and also for the whole period (+69%), followed by M1 (+34%).
- Average annual TFP growth in DPCR 3 (2000-05) is higher relative to others across the five models, followed by DPCR 4 (2010-15).
- DPCR 5 with the lowest average annual TFP growth (regress).

Table 2: TFP change by Price Control Periods Models 1-5

DPCR	TFPC-M1	TFPC-M2	TFPC-M3	TFPC-M4	TFPC-M5
1	0.5%	1.5%	2.2%		
2	1.8%	3.3%	1.9%		
3	5.2%	4.0%	4.5%		
4	3.3%	3.2%			
5	-3.6%	-1.2%		-0.7%	0.9%
RIIO-ED1	-2.5%	0.4%		0.6%	0.9%
Whole Period	1.1%	2.0%	1.9%**	-0.2%	0.9%

*M1= Model 1, M2= Model 2, M3=Model 3, M4=Model 4, M5=Model 5

** This figure does cover the whole period

Gas Distribution

- Gas distribution separated from gas transmission in 2004
- Involves 8 GD firms/regions.
- Shorter period of analysis (9 years) in comparison with ED.
- Availability of data differs depending on the type of variable.
- Consideration of two price controls only (GDPCR1, RIIO-GD1).

Table 3: Models for Gas Distribution

Model	Non-quality variables					Quality variables			Period
	opex	capex	Cust	UnitsD	NL	CML	CI	CS	
Model 1	I	I	O	O	O				2008/09-2016/17
Model 2	I	I	O	O	O	I	I		2008/09-2016/17
Model 3	I	I	O	O	O	I	I	O	2008/09-2016/17

I: input, O: output, Cust: # of customers, UnitsD: units of gas distributed, NL: network length, CML: customer minutes lost (total), CI: customer interruptions (total), CS: customer satisfaction

Gas Distribution

Results

- In M1 an average TFP growth of 1.6% p.a. is observed but it decreases when introducing CM and CI in the model (M2). A dispersion in the quality of services between GD companies may explain this.
- But adjusting for customer satisfaction increases the average rate to 1.1%p.a. (M3).
- Average annual TFP growth in GDPCR1 is higher than RIIO-GD1 (M1), but lower when considering quality variables (M2, M3).
- Looking at the whole period, M1 has the highest TFP growth (13.5%) while M2 the lowest (5.5%).

Fig. 2: Average Annual TFP change (%) – All models GD

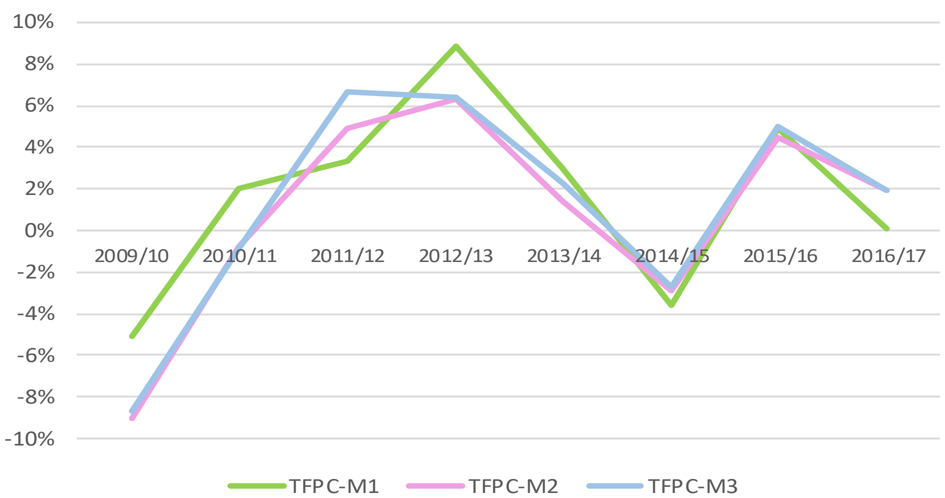
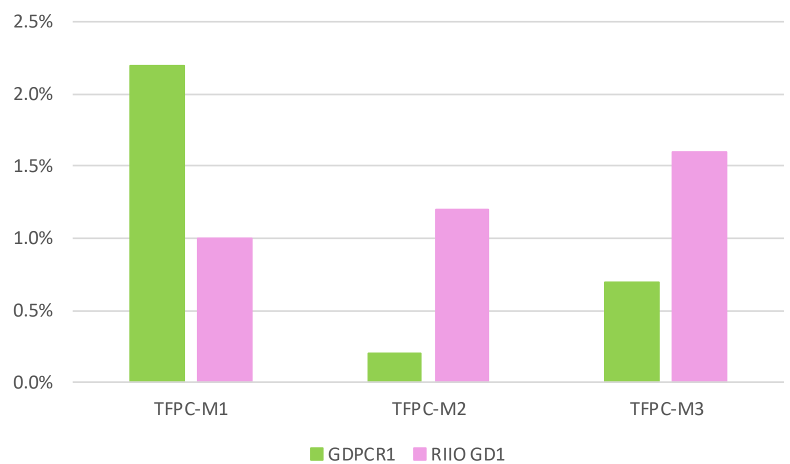


Fig. 3: GDPCR Average Annual TFP change (%) – All models GD



Electricity Transmission

- Involves 3 ET firms. Firms are not comparable in size, NGET much larger than other 2 firms.
- Therefore we followed a single combined firm approach (firms cannot be assessed against other firms).
- Same number of periods across models (17 years).

Table 4: Models for Electricity Transmission

Model	Non-quality variables					Quality variables		Periods
	opex	capex	ET	NL	MaxD	ENS	SNA	
Model 1	I	I	O	O				2000/01-2016/17
Model 2	I	I	O	O		I		2000/01-2016/17
Model 3	I	I	O	O	O	I	I	2000/01-2016/17

I: input, O:output, ET: energy transmitted, NL: network length, MaxD: Max. demand, ENS: energy not supplied, SNA: system non-availability

Electricity Transmission

Results

- Average negative TFP growth of 2.2% p.a. over the whole sample period (M1).
- But an increase in observed when considering quality variables, around 6.6% p.a.
- In terms of price control periods, average TFP growth in TPCR4 is positive in comparison with the others but the opposite is observed when quality variables are added.
- Looking at the whole period, M1 has the lowest TFP growth (-30%) but the introduction of quality variables produces an important increase (over 100%) in both M2 and M3.

Fig. 4: Average Annual TFP change (%) – All models ET

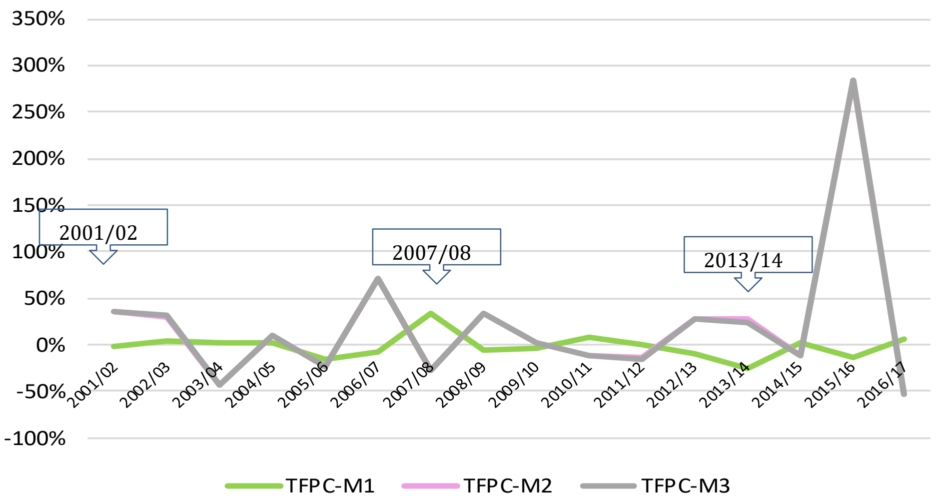


Table 5: TFP change (%) by Price Control Periods – All models ET

TPCR	TFPC-M1	TFPC-M2	TFPC-M3
TPCR3	-2.7%	6.4%	6.5%
TPCR4	3.1%	-0.6%	-0.6%
RIIO-ET1	-9.1%	18.6%	18.1%
Whole Period	-2.2%	6.6%	6.5%

*M1= Model 1, M2= Model 2, M3=Model3

Gas Transmission

- Involves 1 firm (NGG) and 2 models only.
- GT network as a sole decision making unit (DMU) in DEA.
- Same number of periods across models (10 years), 2010/11 omitted due to missing data.

Table 6: Models for Gas Transmission

Model	Non-quality variables					Quality variable	Periods
	opex	capex	GT	NL	GD	GS	
Model 1	I	I	O	O	O		2006/07-2016/17
Model 2	I	I	O	O	O	I	2006/07-2016/17

I: input, O: output, GT: gas transmitted at system entry points, NL: network length, GD: gas NTS demand, GS: gas shrinkage

Gas Transmission

Results

- A downward trend in productivity growth is observed over time.
- Similar to ET, the addition of quality variables improves productivity (from 5.6% to 7.6% p.a). This emphasise the importance of quality of service provision for transmission networks characterized by declining or flat energy demand.
- Looking at the whole period we observe a TFP change of 72% in M1 and over 100% when quality variables are included in M2.

2007/08

2013/14

Fig. 5: Average Annual TFP change (%) – All models GT

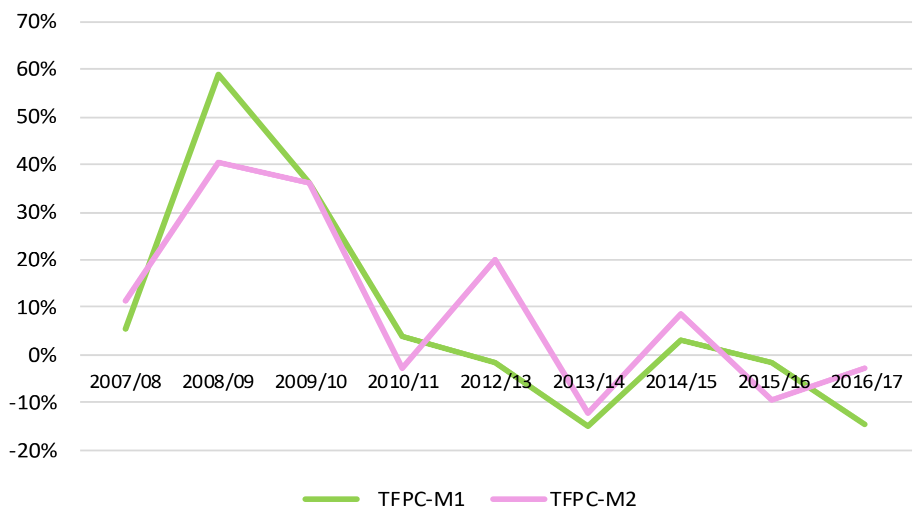


Table 7: TFP change by Price Control Periods (%) – All models GT

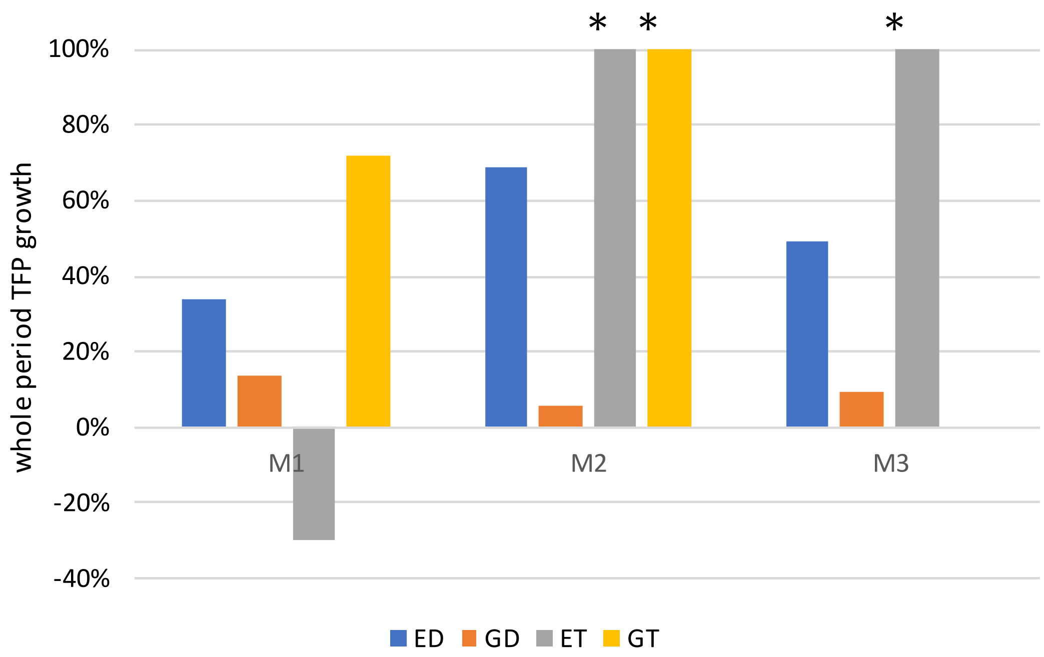
TPCR	TFPC-M1	TFPC-M2
TPCR4	15.1%	16.5%
RIIO-GT1	-7.2%	-4.4%
Whole Period	5.6%	7.6%

*M1= Model 1, M2= Model 2

Comparing sectoral performance

A Comparison among the four sectors (M1, M2, M3)

Fig. 6: TFP growth across models (whole period), all sectors M1-M3



(*) For M2: ET=176%, GT=109%, for M3: ET=174%. For M3 (ED): whole period includes only up to 2004/05.

Conclusions

- In general, ED performs better than GD and GT better than ET.
- The differences between the sectors can be viewed as being a function of the asset replacement cycle, i.e. low replacement Capex (GT) with high one (ET).
- Overall, energy network sectors perform better than the reported performance for the whole market economy in the UK (TFP = 0.63% p.a. 1990-2016).

- Addition of most of the quality measures has improved measured productivity.
- A downward trend on productivity is observed after 2005 (especially for ED), in line with the global financial crisis…
- But others factors can also being behind this trend (e.g. investments that facilitate energy transition, decrease in gas demand due to large increase in energy efficiency, addition of renewables, others).
- Particular attention should be paid by Ofgem to measure specific variables (e.g. CS, stakeholder engagement, those that help to meet environmental targets), and valuation of the inputs and outputs of network innovation projects.

- Data issues: missing data and collection of data for short periods (time-limited incentives), difficult access (old data). ET and GD in particular might benefit from inclusion of 1990s.
- Better synergy is required between Ofgem and national institutions (i.e. ONS) for data collection and publication.

- A possible extension of this study is to include a valuation of quality improvements in terms of willingness to pay.

Malmquist Productivity Index

- The productivity index is built by measuring the radial distance of the observed inputs and outputs in two different periods (t and s for instance) relative to a reference technology. Different indices can be computed depending on the distance technology selected (input or output oriented). Following Caves et al. (1982), the index can be expressed as the geometric average of two indices associated to the period s (Mi^s) and period t (Mi^t) technologies, see *Eq. 8*.
- $Mi(y^t, x^t, y^s, x^s) = [Mi^s(y^t, x^t, y^s, x^s) * Mi^t(y^t, x^t, y^s, x^s)]^{1/2}$ *Eq. 8*
- *Eq. 8* represents the Malmquist productivity index under the input-oriented method (i). The estimation of the index (Mi) requires the computation of four different distance functions, See *Eq. 9*.
- $Mi(y^t, x^t, y^s, x^s) = \left[\frac{Di^s(y^t, x^t)}{Di^s(y^s, x^s)} * \frac{Di^t(y^t, x^t)}{Di^t(y^s, x^s)}\right]^{1/2}$ *Eq. 9*
- Following Färe et al. (1992, p.90), the Malmquist productivity index from *Eq. 9* can be represented by the following equation:
- $Mi(y^t, x^t, y^s, x^s) = \frac{Di^t(y^t, x^t)}{Di^s(y^s, x^s)} \left[\frac{Di^s(y^t, x^t)}{Di^t(y^t, x^t)} * \frac{Di^s(y^s, x^s)}{Di^t(y^s, x^s)}\right]^{1/2}$ *Eq. 10*
- The first component of *Eq.10* measures efficiency change (EC) while the second one technical change (TC) based on the input oriented method. From this we note that $TFP\ growth = EC * TC$. EC captures the change in relative efficiency between period s and t, also known as the catching up term. TC captures the shift in technology between the two periods. The index varies from 0 to infinity between period s and t. A positive growth happens for values greater than 1. The components of the Malmquist productivity index can be estimated using DEA.

Malmquist Productivity Index

- An enhanced decomposition proposed by Färe et al. (1994) suggests that EC can be represented by two components, pure efficiency change (PEC) and scale efficiency change (SEC). The VRS distance function is introduced under this approach. Then *Eq. 10* for and input-oriented would be as follows:
- $Mi(y^t, x^t, y^s, x^s) = \frac{Div^t(y^t,x^t)}{Div^s(y^s,x^s)} \left[\frac{SE^t(y^t,x^t)}{SE^s(y^s,x^s)}\right] \left[\frac{Dic^s(y^t,x^t)}{Dic^t(y^t,x^t)} * \frac{Dic^s(y^s,x^s)}{Dic^t(y^s,x^s)}\right]^{1/2}$ *Eq.11*
- With *v*: VRS, *c*: CRS.
- The first component of Equation 11 represents PEC, the second SEC and the last remains the same than Equation 10. Then $TFPgrowth = PEC * SEC * TC$. PEC is calculated under VRS. TC is calculated under CRS. SEC represents a residual scale component that represents changes in the deviation between CRS and VRS technologies, see Färe et al. (1994, pp. 74-75). Different nomenclatures are used for defining the periods: *(s, t), (t, t+1), (0,1).*
- The first component can be estimated via DEA, based on the methodology explained in footnote 1. For the second one, which involves cross-time efficiency (period s and t), a modification of the methodology is required as follows: $min_{\theta,\lambda}\, \theta,\ st: -y_i(t) + Y(s)\lambda \geq 0,\ \theta x_i(t) - X(s)\lambda \geq 0, \lambda \geq 0$; (Giannakis et. 2005, p. 2262).
- SEC captures the contribution of scale economies to productivity growth.