Identifying the performance drivers of wastewater treatment plants through conditional order-m efficiency analysis

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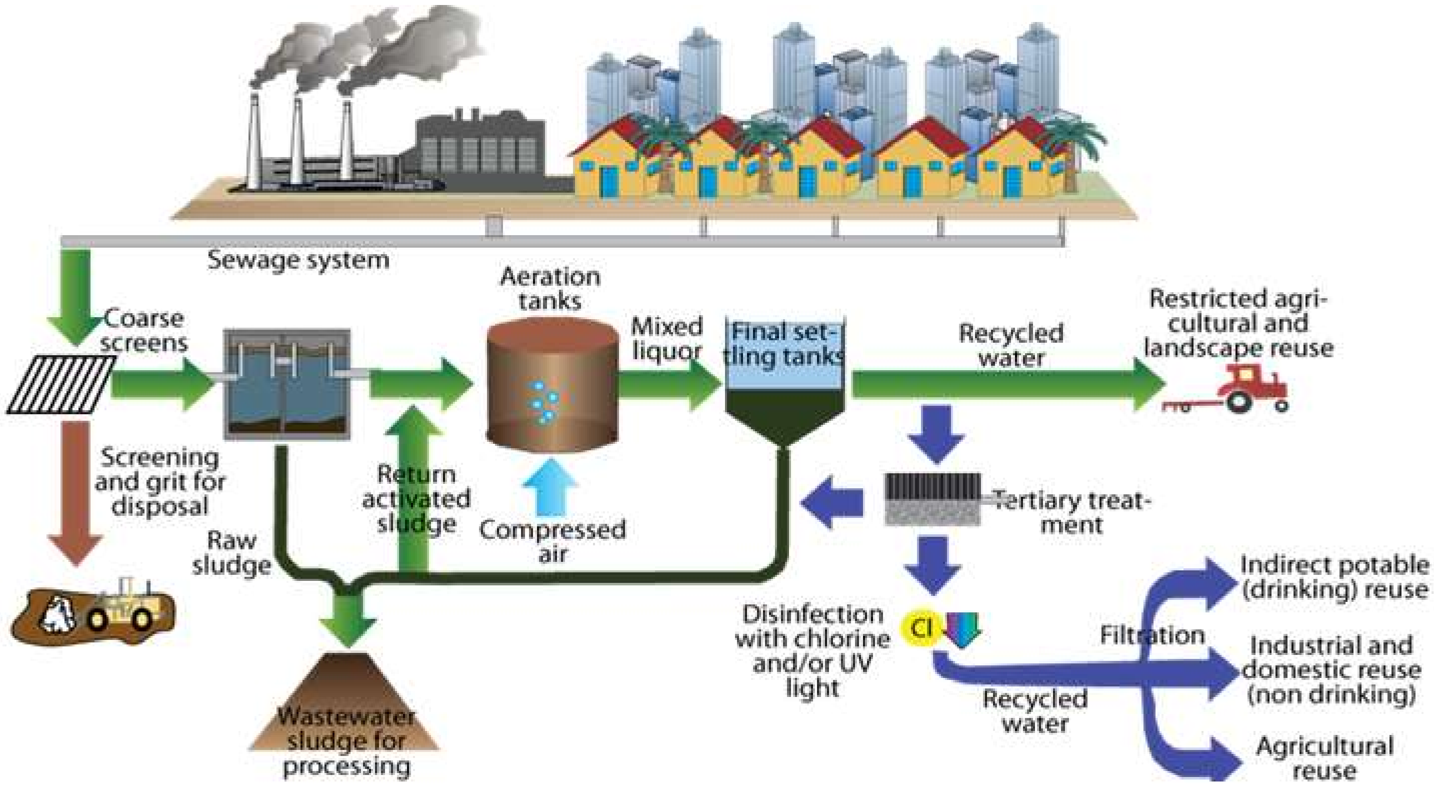
The Wastewater Treatment process



Evidences from prior studies

A number of publications have focused on analysing the managerial efficiency of water supply companies (e.g. Anwandter and Ozuna, 2007; Byrmes et al., 2008; Saal and Parker, 2009; Schaefer, 2010). However, the application of such tools in the field of wastewater treatment plants (WWTPs) has remained limited (but see Hernandez-Sancho et al. 2011; Hsiao et al., 2012).

Hernandez-Sancho et al., 2011: sample of 196 WWTPs located in the Valencia Region, 2003-2008. Efficiency was affected by the significant economies of scale and the type of technology in use. Energy consumption is a key factor towards improving the productivity of WWTPs;

Hernández-Sancho et al. (2011a): it applied a nonradial Data Envelopment Analysis (DEA) to a sample of Spanish WWTPs. Results showed that plant size, quantity of eliminated organic matter, and bioreactor aeration type are significant variables affecting energy efficiency of WWTPs.

Senante et al. (2014): it confirms that all inputs are affected by economies of scale. As expected from other empirical applications (Dogot et al. 2010; Zessner et al. 2010), the mean efficiency for all inputs was greater for WWTPs with higher PE than for smaller plants. Regarding individual scores, all of the plants indicated that older plants are less efficient than younger plants.

Benchmarking of WWTPs. A case study in Tuscany

- October 2014 – discussion of a benchmarking project with water local authority;
- October 2014 –A Tuscan water firms provides its interest to test a benchmarking model on its 139 WWTPs;
- November/December 2014 – definition of a grid of data, with the collaboration of a water firm and AIT staff;
- Jenuary/March 2015 – data collection
- April 2015 – statistical tests and data analysis
- June 2015 – First data presentation
- September 2016 – Publication in Utilities Policy

The grid of data – input and output variables

INPUT	OUTPUT
Cost of materials (reagents and other materials)	Kg removed of BOD5
Cost of Energy	Kg removed of COD
Staff cost	Kg removed N
Maintenance cost	Kg removed P
Depreciation and amortization	Kg sludge (wet matter)
Costs for sludge trasport and disposal	% dry matter obtained
	Kg other wastes
	Cubic meter of water treated
	% non complied controls with env. std.

- BOD5: Five days biochemical oxygen demand
- COD: chemical oxygen demand
- N and P are classified as nutrients

The main characteristics of the observed plants

Size	plants
Big (>19000 PE)	10
Medium (5000<;<19000)	15
Small (<5000)	114

Age	plants
Mature (1986-2000)	60
New (2000-2013)	10
Old (<1985)	69

Size/Sludge treatment	plants
Big (>19000 PE)	10
No	1
Yes	9
Medium (5000<;<19000)	15
No	6
Yes	9
Small (<5000)	114
No	111
Yes	3

Size/Treatment	plants
Big (>19000 PE)	10
Secondary	8
Tertiary	2
Medium (5000<;<19000)	15
Secondary	14
Tertiary	1
Small (<5000)	114
Primary	9
Secondary	104
Tertiary	1

Size/Active sludge	plants
Big (>19000 PE)	10
No	1
Yes	9
Medium (5000<;<19000)	15
No	2
Yes	13
Small (<5000)	114
No	13
Yes	92
Primary	9

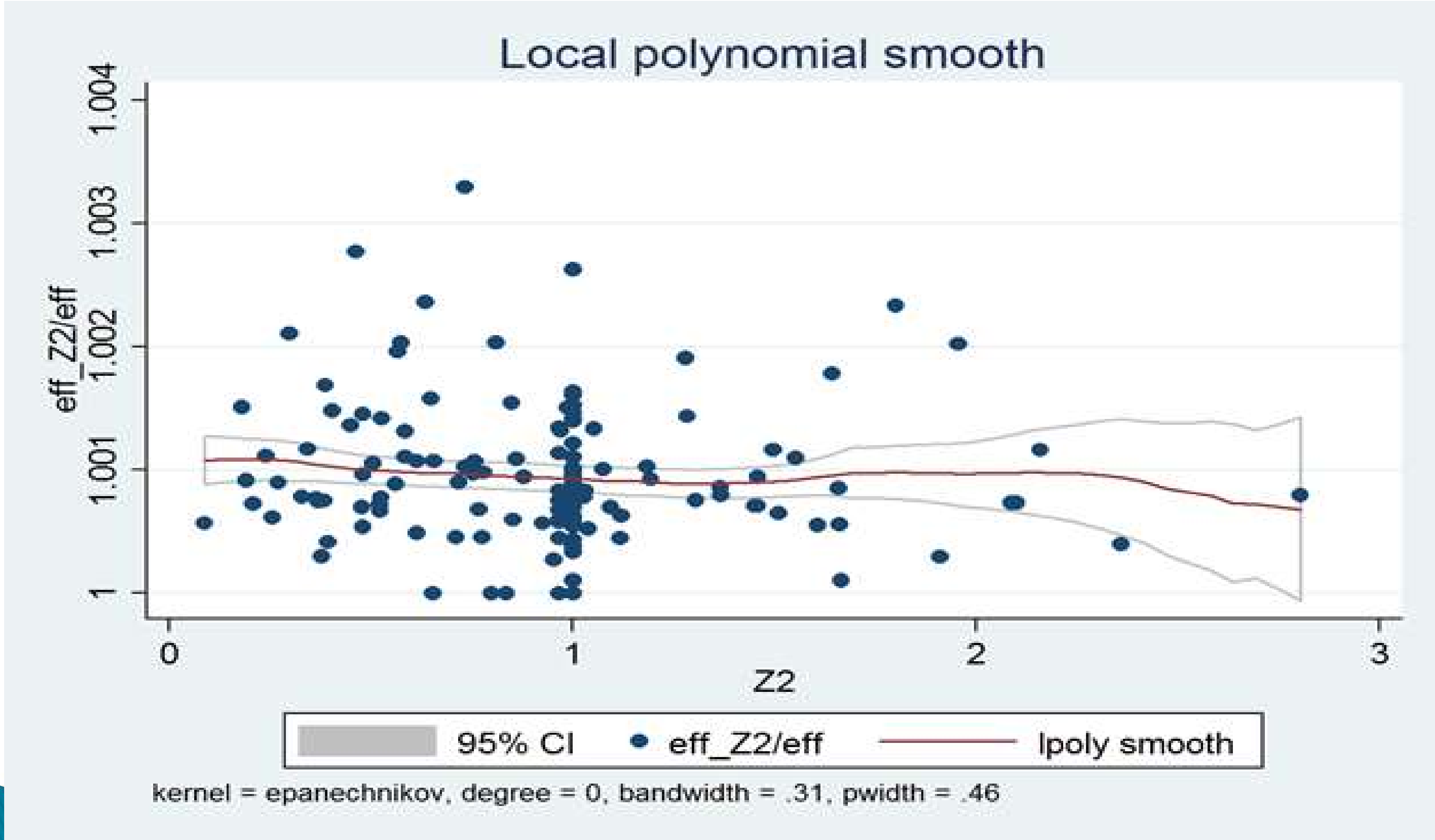
Age/Derogation	plants
Mature	60
No	59
Yes	1
New	10
No	10
Old	69
No	55
Yes	14

Model 1)
Order-m conditional efficiency

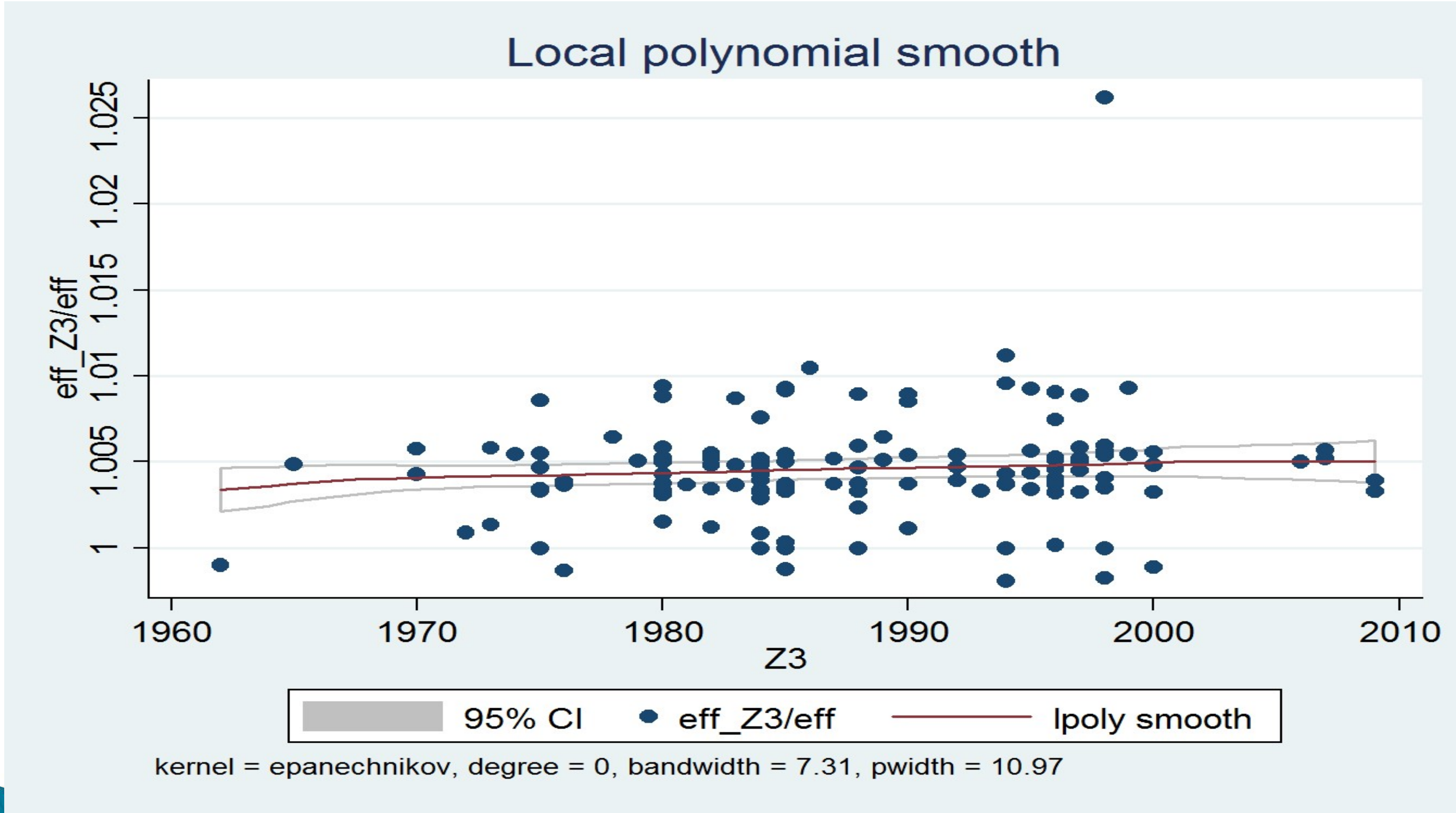
INPUT	OUTPUT
Total costs	Cubic meter of water treated

1. The "Two Stage" approach requires a restrictive separability condition between the input–output space and the space of environmental factors—that is, it assumes that these factors have no influence on the shape of the production set, which is usually unrealistic (Badin et al., 2010);
2. A new approach introduces in the production process a constraint referred to environmental variable (Daraio and Simar, 2005 and 2007);
3. $H(x,y|z)=\text{Prob}(X \leq x, Y \geq y | Z = z)$ This function measures the probability of a DMU operating with (x, y) to be dominated by DMUs operating under the same environmental conditions, z
4. Conditional and unconditional efficiency from the Z variables are obtained and their ratio is non parametrically regressed on environmental variables.

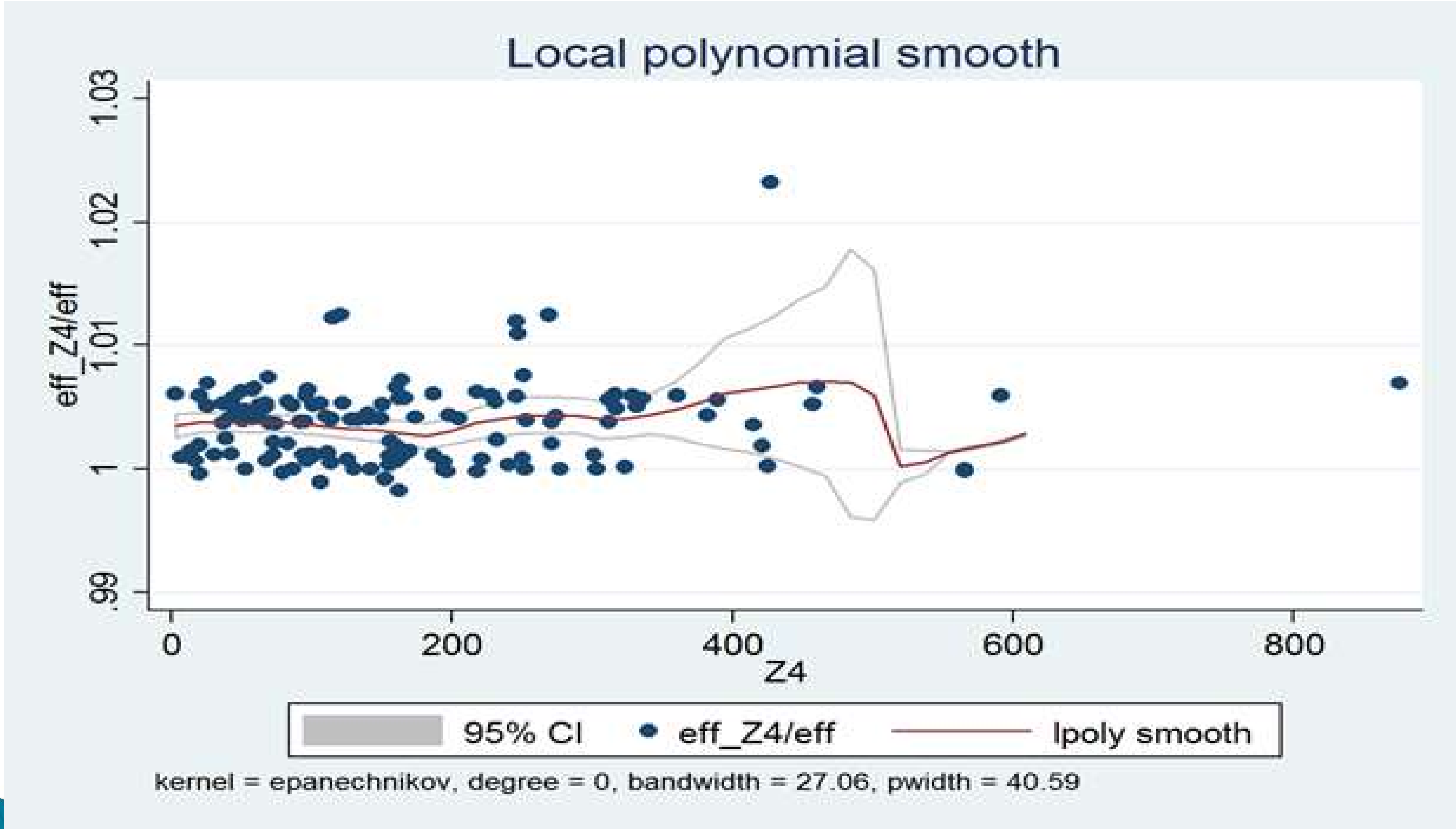
Rate of used capacity



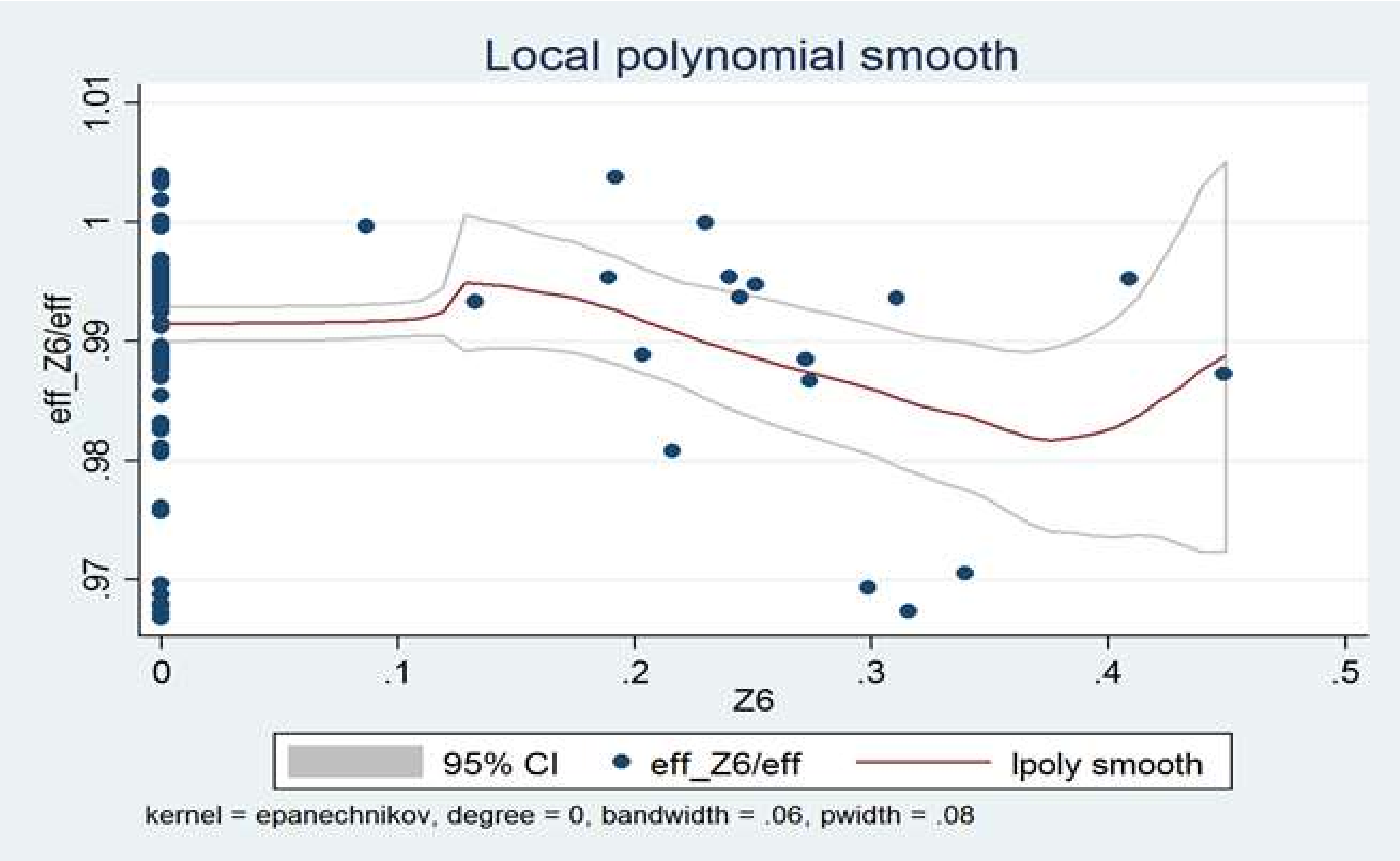
Year of construction



Average concentration of BOD5



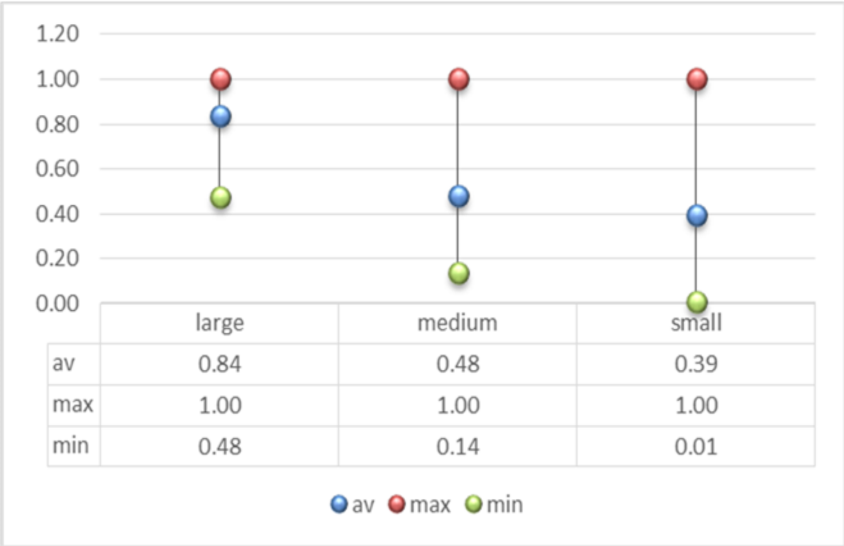
Rate of sludge disposed to farms



Model 2)
DEA Double Bootstrapped

INPUT	OUTPUT
Cost of energy	Kg of COD removed % of dry matter

127 plants	
Double boostrap DEA	Estimators
Capacity (PE)	0.000***
Rate of used capacity	0.110***
Dilution of WW	- 0.000
WW from industry	-0.284*
Year of building	- 0.001
Aeration	
- Turbines	0.006
- No Aeration	0.243
COD concentration	0.000***
Sludge to farm	0.159



key findings (1)

- Wastewater features
  - The presence of wastewater from factories determines a rising in energy costs for a longer treatment in aeration tanks.
  - The COD/BOD concentration:
    - (–) increases costs to treat a cubic meter
    - (+) decreases energy costs to remove a kg of COD

This implies that with high diluted wastewater inflows <u>cost per cubic meter</u> decreases, BUT <u>energy costs</u> per kg COD removed increases (less energy for pumps).

key findings (2)

- WWTPs features of WWTPs
  - Plant capacity, rate of used production capacity improve all type of efficiency measured
  - Water inflows far beyond the maximum production capacity decrease efficiency (WI/PC>1.5)
  - The age of the plants positively affect efficiency
  - The type of aeration do not affect efficiency: maybe, diffusers require higher costs, but allow to achieve higher removal rate of COD.

Practical implications

1. REGULATION: In Italy tariff for household are based on cubic meter of water consumed, but the BOD/COD concentration really affects water utility costs. Companies should be repaid by the tariff model according to a measure of the average pollutants concentration of the water treated (*operational condition*)

2. PLANT DESIGN: new plant should be large enough to get scale economies but at the same time they should be projected according to the expected amount of wastewater inflow in order to reduce the unused capacity

3. SLUDGE DISPOSAL: Maximize the sludge disposed in agriculture site. Today in our region this opportunity was limited, and cost per ton of sludge achieve 160 €/ton.

References

- Guerrini et al., (2016), Identifying the performance drivers of wastewater treatment plants through conditional order-m efficiency analysis, *Utilities Policy,* 42, 20-31

- Guerrini et. al. (2016), A performance measurement tool leading wastewater treatment plants toward economic efficiency and sustainability, *Sustainability*