Measuring Output and Estimating Cost Functions for Hospitals: Analysis of U.S. Data from 2004-2011

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Introduction

New Policy in 2010

- Affordable Care Act (ACA)
  - What are the effects on competition and productivity?

High investment on healthcare

- 16.9% of GDP spent in health (2012)
- Approximately 5% of GDP is spent solely on hospital care

Hospitals make-up such large portion of healthcare expenditures → **Hospitals are a potential source of cost savings**

Objectives

- Measuring the production synergies the service sector
  - Define and measure output in services systems is difficult
  - Hospitals are an important service system
- Control for differences across hospitals
- Flexible shape for the relationship between cost and output

U.S. Hospitals 2011

Total Number of All U.S. Registered Hospitals	**5,627**
Number of U.S. Community Hospitals	4,926
Nongovernment Not-for-Profit	*2,870*
Investor-Owned (For-Profit)	*1,053*
State and Local Government	*1,003*
Number of Federal, Psychiatric, Nonfederal Long Term Care and Other	701

http://www.aha.org/research/rc/stat-studies/fast-facts.shtml

Data

HCUP National inpatient sample

Sample of U.S. Community hospitals (~ 1,000 hospitals per year)

Clinical and non clinical information about patient

8 million records of hospital activities

International Classification of Diseases, Clinical Modification (ICD-9-CM) codes

2004 up to 2011

AHA Annual survey database

Annual Survey since 1946

Collect wide range of information

- Organizational structure, facility and service lines, inpatient and outpatient utilization, expenses, physician arrangements, staffing, etc.
- Up to 1,000 variables

Covers 6,500 health systems

Data Used in Estimation

Service Production Data

- Costs per hospital (x)

Outputs: Number of procedures per hospital

- y_1: Minor diagnostic procedures
- y_2: Major diagnostic procedures
- y_3: Minor therapeutic procedures
- y_4: Major therapeutic procedures

Contextual Variables:

- Hospital Size: hospital classification as small, medium or large.
- Ownership: classification of hospital control in private, not-for-profit and public.
- Location: whether a hospital is rural or urban.
- Region: classification of hospital according to its geographical location.
- Teaching status: whether a hospital is a teaching hospital or not.
- Percentage of inpatient surgeries over total of surgeries.
- Critical Access Hospital participation status of a hospital.

Summary Statistics

Cost and Outputs (2004 and 2011)

	2004			2011		
	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
Minor Diagnostic Procedures	3,481	945	5,782	3,415	1,093	7,996
Major Diagnostic Procedures	5,871	2,445	8,580	8,178	3,937	13,135
Minor Therapeutic Procedures	165	69	270	153	73	260
Major Therapeutic Procedures	3,900	1,630	5,633	4,336	1,841	6,731
Total Expenses ($)	116,284,908	58,066,720	179,051,070	187,453,914	96,849,686	297,936,335

Summary Statistics

Contextual Variables

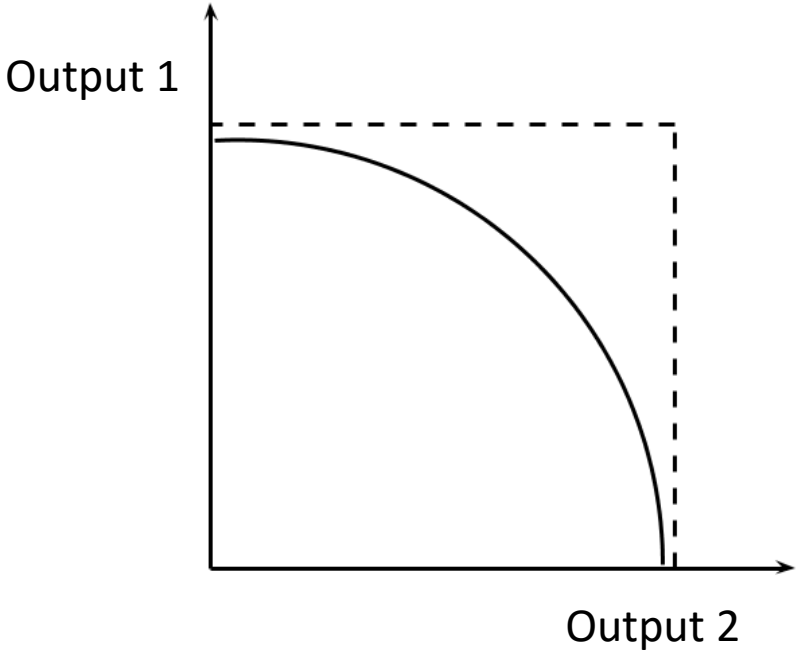
	Obs.	Critical Access Hospital (CAH)		Rural	Rural & CAH	Ownership			Size		
						Public	Not For Profit	Private	Small	Medium	Large
2004	484	114	22%	41%	19%	21%	68%	11%	38%	29%	33%
2005	528	141	27%	41%	21%	22%	67%	11%	38%	28%	34%
2006	528	127	24%	40%	18%	21%	69%	11%	42%	25%	34%
2007	523	144	28%	40%	21%	20%	68%	12%	38%	28%	33%
2008	511	130	28%	39%	20%	20%	68%	12%	38%	27%	35%
2009	458	117	24%	38%	20%	19%	72%	9%	36%	29%	34%
2010	496	136	28%	39%	22%	20%	70%	10%	40%	27%	33%
2011	482	119	24%	39%	21%	18%	71%	11%	38%	29%	33%
Average	501	128.5	26%	40%	20%	20%	69%	11%	39%	28%	34%

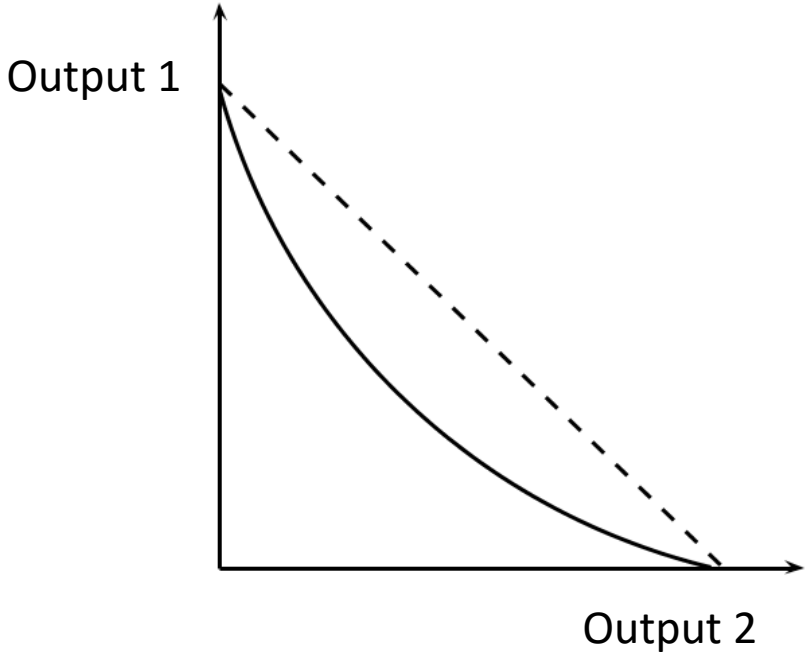
Summary Statistics

Contextual Variables

	Obs.	Region				Teaching	Ownership		
		NE	MW	S	W		Public	NFP	Private
2004	484	20%	26%	31%	23%	19%	21%	68%	11%
2005	528	20%	25%	25%	29%	15%	24%	73%	12%
2006	528	20%	27%	26%	26%	23%	23%	75%	12%
2007	523	18%	26%	28%	28%	22%	22%	73%	13%
2008	511	18%	28%	27%	28%	22%	21%	72%	12%
2009	458	21%	24%	27%	29%	23%	18%	69%	8%
2010	496	20%	23%	31%	25%	22%	20%	72%	10%
2011	482	21%	23%	30%	25%	22%	18%	71%	11%
Average	501	20%	25%	28%	27%	21%	21%	72%	11%

Curvature of Output Sets





Translog Cost Function

$$\ln C = \alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mi} + \frac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{mn} \ln y_{mi} \ln y_{ni}$$

$$\alpha_{mn} = \alpha_{nm}, m, n = 1,2, \dots, M$$

$$\sum_{m=1}^{M} \alpha_m = 1$$

$$\sum_{m=1}^{M} \alpha_{mn} = 0, \qquad m = 1,2, \dots, M$$

Methodology

Regression Model:

$$\boldsymbol{C_i} = f(\boldsymbol{Y_i})e^{\varepsilon_i}e^{\delta \boldsymbol{z_i}}$$

- $\boldsymbol{C_i}$ is a vector of observed costs (input)
- $\boldsymbol{Y_i} = (\boldsymbol{y_1}, \boldsymbol{y_2}, \boldsymbol{y_3}, \boldsymbol{y_4})$ is a matrix of observed number of procedures (output)
- $f(\cdot)$ represents the best attainable cost level
- $\boldsymbol{\varepsilon}$ is a symmetric random firm specific error term
- $\boldsymbol{z_i} = (\boldsymbol{z1_i}, \boldsymbol{z2_i}, \boldsymbol{z3_i}, \boldsymbol{z4_i})$ is the contextual variables matrix
- $\boldsymbol{\delta}$ is a parameter to estimate the marginal effects of the contextual variables

Methodology

We have two types of constraints,

Convexity:

$$f(\boldsymbol{Y}_i) \geq f\left(\boldsymbol{Y}_j\right) + \nabla f(\boldsymbol{Y}_j)^T\left(\boldsymbol{Y}_i - \boldsymbol{Y}_j\right) \forall i, j.$$

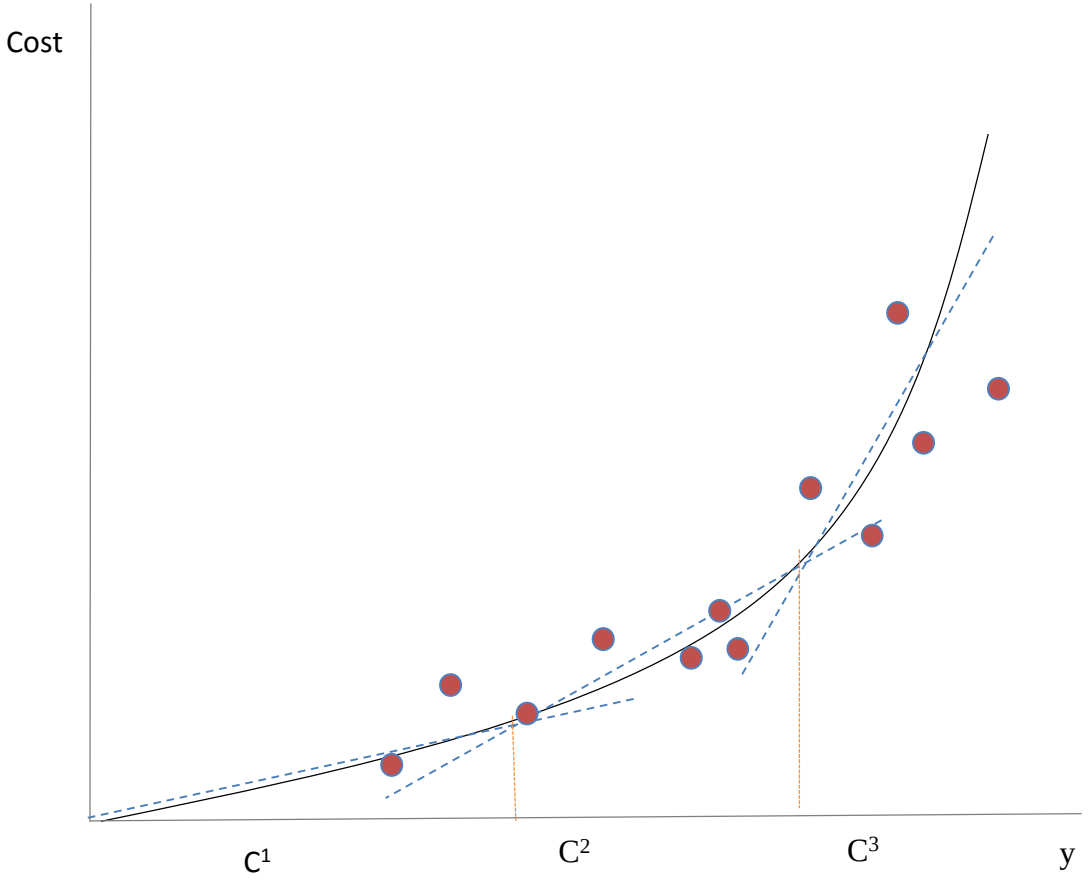
Let $f_i = f(Y_{1i}, Y_{2i}, Y_{3i}, Y_{4i})$ and $\boldsymbol{Y_i} = Y_{1i}, Y_{2i}, Y_{3i}, Y_{4i}$ for notation simplicity

Monotonicity:

$$\nabla f(\boldsymbol{Y}_i) > \boldsymbol{0} \; \forall i$$

Methodology

Collection of Maximums Hyperplanes



Methodology

Multivariate Regression Function:

$$\hat{f}(\boldsymbol{Y}) = \max_{k \in \{1,\ldots,K\}} \alpha_k + \beta_k^T \boldsymbol{Y}$$

α_k is intercept for each hyperplane k
β_k is slope for each hyperplane k

Convex Nonparametric Least Squares with z-variables

Johnson & Kuosmanen (2011), *JPA*

- Model

$$C_i = f(\mathbf{y}_i)\exp(\mathbf{z}_i'\boldsymbol{\delta} + \varepsilon_i)$$

- Semi-nonparametric least squares

$$\min_{\alpha,\boldsymbol{\beta},\phi,\boldsymbol{\delta},\varepsilon} \sum_{i=1}^{n} \varepsilon_i^2$$

$$\ln C_i = \ln \phi_i + \mathbf{z}_i'\boldsymbol{\delta} + \varepsilon_i \quad \forall i \qquad \text{(regression equation)}$$

$$\phi_i = \alpha_i + \boldsymbol{\beta}_i'\mathbf{y}_i \quad \forall i \qquad \text{(supporting hyperplane)}$$

$$\alpha_i + \boldsymbol{\beta}_i'\mathbf{y}_i \geq \alpha_h + \boldsymbol{\beta}_h'\mathbf{y}_i \quad \forall h,i \qquad \text{(concavity)}$$

$$\boldsymbol{\beta}_i \geq \mathbf{0} \quad \forall i \qquad \text{(monotonicity)}$$

Results

Cost Drivers

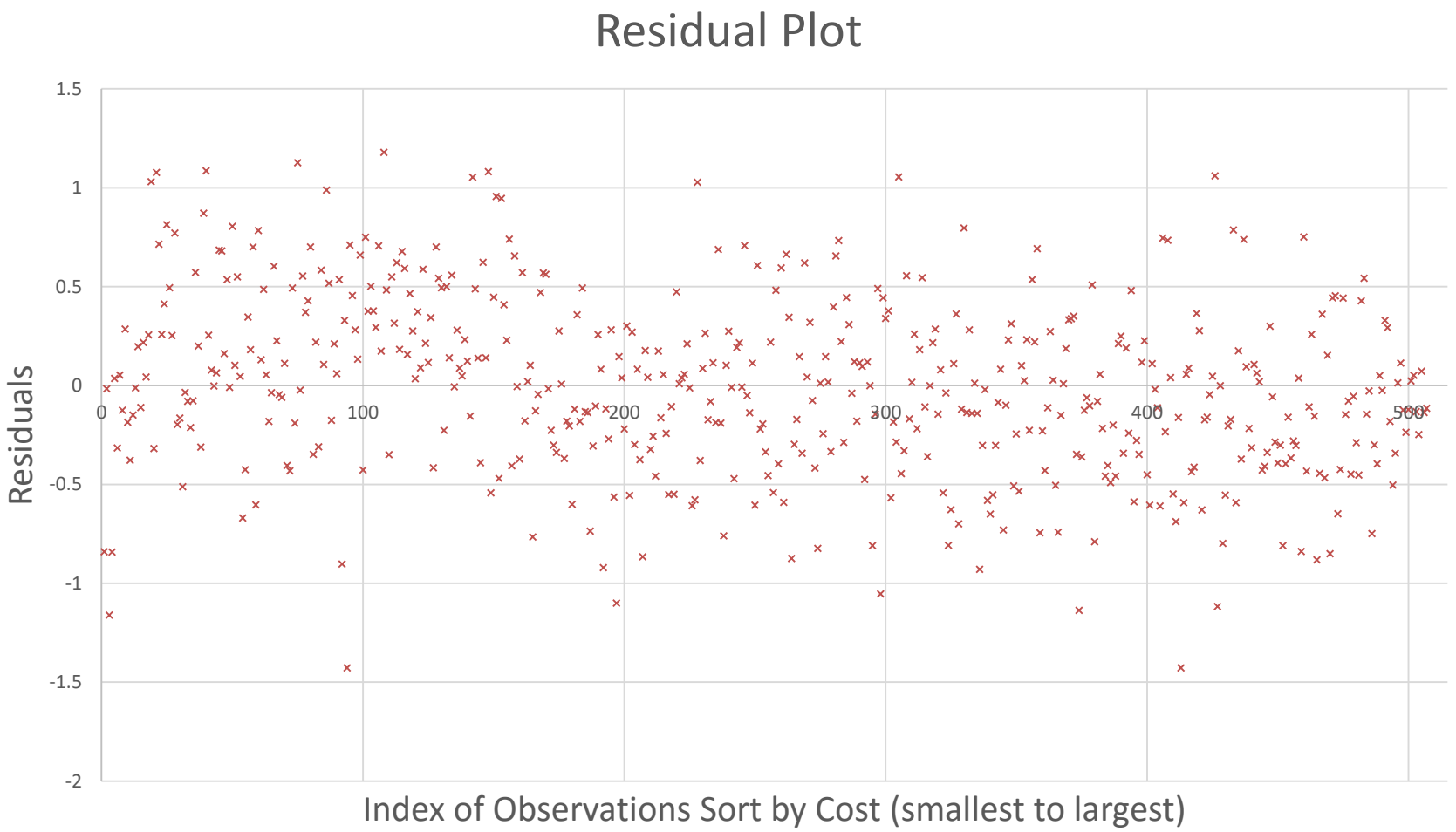
Base case:

Small
Northeast
Non Teaching
Public

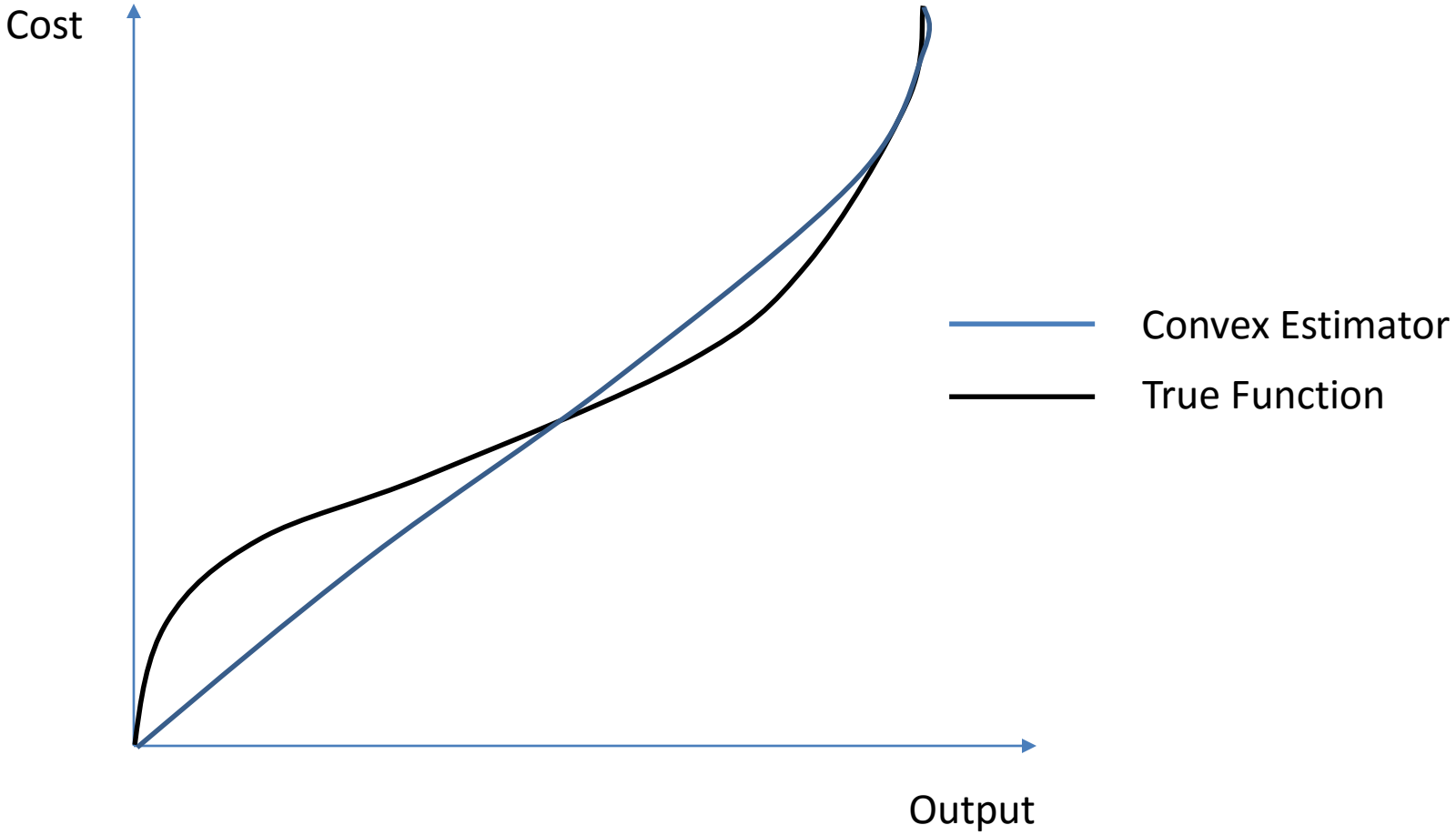
	2004	2005	2006	2007	2008	2009	2010	2011
Hospital size (large - small)	0.08	0.13*	1.46*	0.06	0.18*	0.10	0.09	0.12*
Hospital size (medium - small)	0.07	0.12*	0.75*	0.04	0.09*	0.03	0.05	0.09*
Region (West - Northeast)	-0.26*	-0.26*	-0.25*	-0.32*	-0.21*	-0.21*	-0.12*	-0.17*
Region (South - Northeast)	-0.17*	-0.26*	-0.35*	-0.32*	-0.23*	-0.28*	-0.22*	-0.22*
Region (Midwest - Northeast)	-0.12*	-0.21*	-0.39*	-0.31*	-0.08*	-0.10*	-0.10*	-0.02*
Teaching Status (0 - no / 1 -yes)	0.17	0.12	-1.19*	-0.22*	0.07	0.10*	0.05	0.07
Ownership (Private - Public)	-0.08	-0.20*	0.33*	-0.16*	-0.08	-0.19*	-0.26*	-0.23*
Ownership (Not for profit - Public)	-0.02	0.04	0.06	-0.03	0.04	0.02	0.05	0.03

(*) significant at the 5%

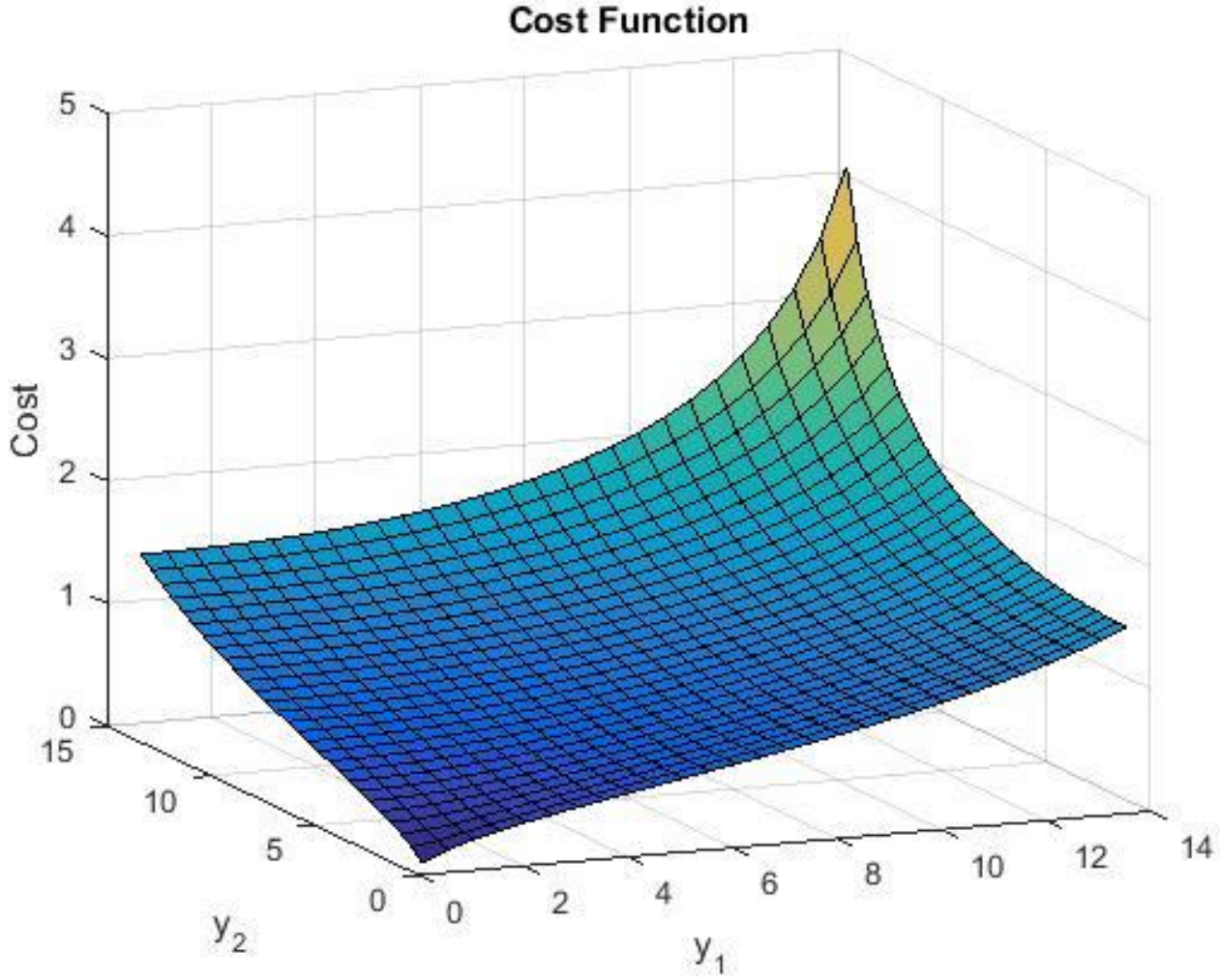
Non-convex?


Residual Plot
Residuals
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
100
200
300
400
500
Index of Observations Sort by Cost (smallest to largest)

Regular Ultra Passum Law (S-shape)



Regular Ultra Passum Restricted Estimator



Conclusions

- Evidence for production synergies
- More costly hospitals are:
  - Teaching hospitals
  - Larger
  - Located in northeast region
  - Public Owned
- Identify alternative axiomatic specification to better estimate cost function

- Future research
  - Cost function of hospitals are subjected to Regular Ultra Passum Law

Thank you for your attention

For further information please visit

https://www.andyjohnson.guru