2017 KDI - Brookings Workshop

Estimation of Industry-level Productivity with Cross-sectional Dependence using Spatial Analysis

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Korea's Leading Think Tank KDI

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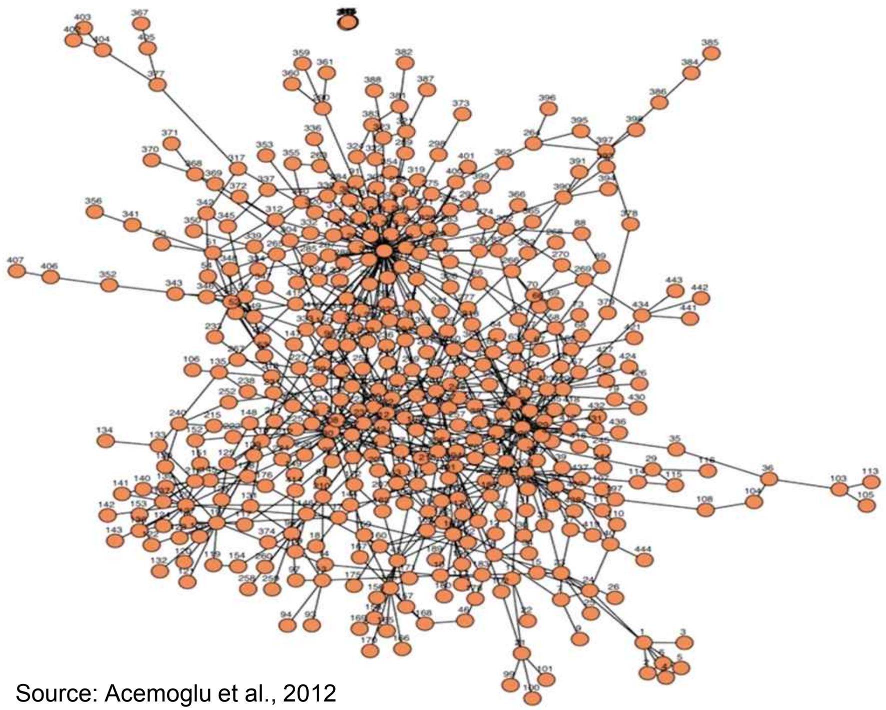
Motivation

Intersectoral network

Fig 1. Intersectoral network corresponding to the U.S. input-output matrix in 1997



Source: Acemoglu et al., 2012

How can we measure **industry-level productivity** considering interconnectivity among industries?

Measuring Productivity

- Non-econometric approach

  - Growth accounting, Index-number approach

  - Jorgenson and Griliches(1967), Diewert(1976)

  - Strong assumptions:

    Constant returns to scale, Perfect competition etc.

  - No considerations on the interdependence

- **Econometric approach**

  - Advantages: Free of the restrictive assumption, Flexibility of models

  - Disadvantages: Possible insufficient information,

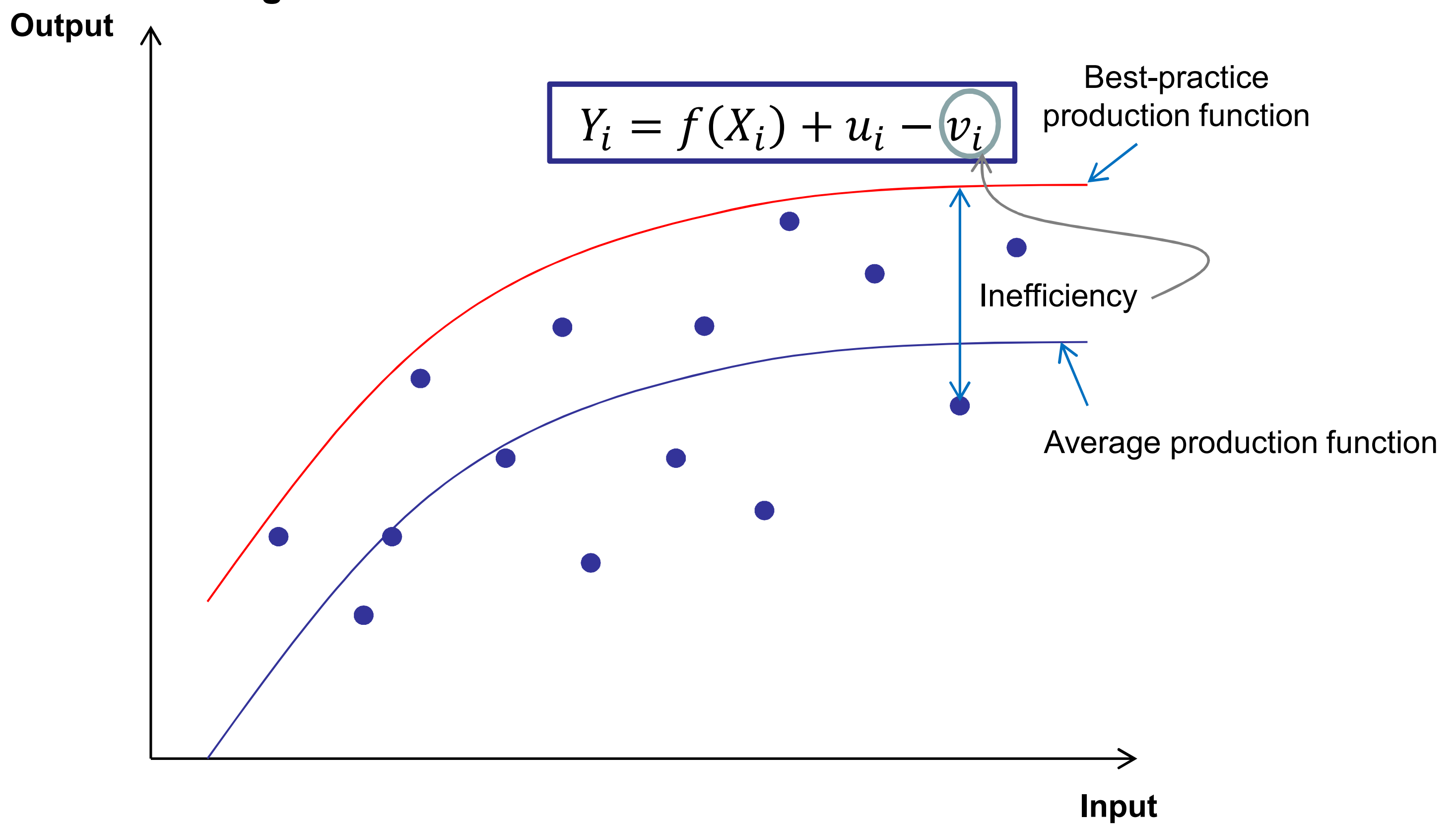
    complication of flexible models

  - Typically, error terms are assumed to be symmetric.

Methodology

Stochastic Frontier Analysis

Fig 2. Frontier function vs. Production function



I follow Cornwell, Schmidt, and Sickles (1990).

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Methodology

A Spatial Econometric Model

- Cross-sectional dependence

  - Possible presence of common shocks

  - Spatial dependence

  - **Idiosyncratic pairwise dependence**

    (with no particular pattern of common components or spatial dependence)

⇨ **Ignoring CSD causes inefficient, sometimes inconsistent, estimation.**

Methodology

SAR and SDM

- **General Nesting Spatial Model (Elhorst, 2014)**

$$Y = \boldsymbol{\rho W Y} + f(X) + \boldsymbol{W X \lambda} + \epsilon,$$
$$\epsilon = \boldsymbol{\xi W \epsilon} + \varepsilon$$

- SARCSS

$$y = \rho(W_N \otimes I_T)y + X\beta + Z\gamma + R\delta_0 + QU + V$$

- SDMCSS

$$y = \rho(W_N \otimes I_T)y + X\beta + (W_N \otimes I_T)X\lambda + Z\gamma + R\delta_0 + QU + V$$

Methodology

Marginal Effects in Spatial Models (1)

- Reduced Form Equations

$$y = (I_{NT} - \rho(W_N \otimes I_T))^{-1}(X\beta + \boldsymbol{Z}\gamma + \boldsymbol{R}\delta_0 + \varepsilon)$$

and

$$y = (I_{NT} - \rho(W_N \otimes I_T))^{-1}(X\beta + (W_N \otimes I_T)X\lambda + \boldsymbol{Z}\gamma + \boldsymbol{R}\delta_0 + \varepsilon)$$

- Output Elasticity at time t

$$\frac{\partial y_t}{\partial X_{k,t}} = (I_N - \rho W)^{-1}\beta_k I_N \qquad \text{(SARCSS)}$$

$$\frac{\partial y_t}{\partial X_{k,t}} = (I_N - \rho W)^{-1}(\beta_k I_N + \lambda_k W) \qquad \text{(SDMCSS)}$$

Methodology

Marginal Effects in Spatial Models (2)

SAR

$$\left[\frac{\partial Y}{\partial X_{k,1}} \cdots \frac{\partial Y}{\partial X_{k,N}}\right] = (I_N - \rho W)^{-1} \begin{bmatrix} \beta_k & 0 & \cdots & 0 \\ 0 & \beta_k & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \beta_k \end{bmatrix}$$

SDM

$$\left[\frac{\partial Y}{\partial X_{k,1}} \cdots \frac{\partial Y}{\partial X_{k,N}}\right] = (I_N - \rho W)^{-1} \begin{bmatrix} \beta_k & \lambda_k w_{12} & \cdots & \lambda_k w_{1N} \\ \lambda_k w_{21} & \beta_k & \cdots & \lambda_k w_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \lambda_k w_{N1} & \cdots & \lambda_k w_{N,N-1} & \beta_k \end{bmatrix}$$

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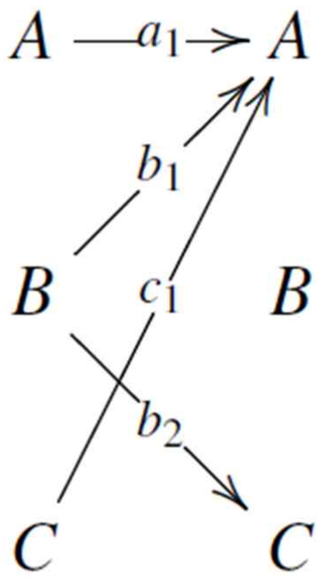
Spatial Weights Matrix

Economic Distance (1)

- Backward and Forward Linkages

Fig 3. Hypothetical supply flows of intermediate inputs



$$BL = \begin{pmatrix} a_1 + b_1 + c_1 \\ 0 \\ b_2 \end{pmatrix}$$

$$FL^T = \begin{pmatrix} a_1 \\ b_1 + b_2 \\ c_1 \end{pmatrix}$$

Spatial Weights Matrix

Economic Distance (2)

- Multiplier Product Matrix (Sonis, Hewings, and Guo; 1997)

$$M\,PM = \frac{1}{V} FL \cdot BL,$$

$$where \quad V = \sum_{j=1}^{n} BL_j = \sum_{i=1}^{n} FL_i .$$

Take Euclidean norm to make MPM symmetric:

$$m^E{}_{ij} = m^E{}_{ji} = \sqrt{m^2{}_{ij} + m^2{}_{ji}}$$

- Economic Distance between industry *i* and *j*

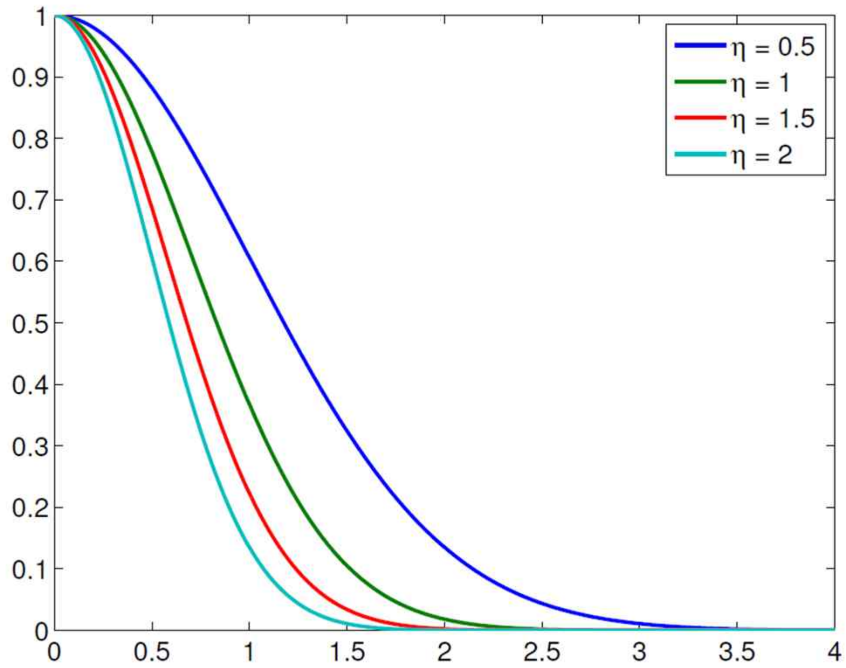
$$d_{ij} \equiv \max_{i'} m^E{}_{i'j} - m^E{}_{ij}$$

Spatial Weights Matrix

Weights

- Exponential Distance Decay Function (Brunsdon et al. 1996)

$$w_{ij} = \exp(-\eta d^2_{ij})$$



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Data

- Data

(1) World KLEMS Database

- Quality-adjusted variables
- Period: 1947 - 2010
- 31 industries (NACE)

(1) World Input-Output Database

- Period: 1995 - 2011
- little variation across time, so averaged over time
- 31 industries (NACE)

An Empirical Application

Industry Classification

Index	Industry	ISIC Rev. 3
	TOTAL MANUFACTURING	
1	Textiles, Textile, Leather and Footwear	17t19
2	Wood and Products of Wood and Cork	20
3	Pulp, Paper: Paper: Printing and Publishing	21t22
4	Coke, Refined Petroleum and Nuclear Fuel	23
5	Rubber and Plastics	25
6	Other Non-Metallic Mineral	26
7	Machinery, Nec	29
8	Electrical and Optical Equipment	30t33
9	Transport Equipment	34t35
10	Manufacturing, Nec; Recycling	36t37
11	ELECTRICITY, GAS AND WATER SUPPLY	E
12	CONSTRUCTION	F
	WHOLESALE AND RETAIL TRADE	G
13	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	50
14	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	51
15	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	52
16	HOTELS AND RESTAURANTS	H
	TRANSPORT AND STORAGE AND COMMUNICATION	I
17	Transport and Storage	60t63
18	Post and Telecommunications	64
	REAL ESTATE, RENTING AND BUSINESS ACTIVITIES	K
19	Real Estate Activities	70
20	PUBLIC ADMIN AND DEFENCE; COMPULSORY SOCIAL SECURITY	L
21	EDUCATION	M
22	HEALTH AND SOCIAL WORK	N
23	OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICES	O

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Parameter Estimates

GLS	Non-spatial		SARCSS		SDMCSS	
	Coef.	std.err	Coef.	std.err	Coef.	std.err
$log(K)$	0.146***	0.022	0.107***	0.021	0.096***	0.023
$log(L)$	0.446***	0.024	0.388***	0.023	0.405***	0.024
$log(I)$	0.278***	0.014	0.261***	0.013	0.267***	0.013
$Intercept$	-0.369	0.125	-0.067	0.131	-0.052	0.142
$Time$	0.014***	0.002	0.001***	0.003	0.001***	0.003
$Time^2$	0.000***	0.000	0.000***	0.000	0.000***	0.000
σ_v^2	0.005***	0.000	0.004***	0.000	0.004***	0.000
Spatial Parameters						
$W \cdot log(Y)(\rho)$	-	-	0.374***	0.024	0.492***	0.044
$W \cdot log(K)(\lambda_1)$	-	-	-	-	0.047***	0.035
$W \cdot log(L)(\lambda_2)$	-	-	-	-	-0.131***	0.053
$W \cdot log(I)(\lambda_3)$	-	-	-	-	-0.097***	0.040
η	-	-	1.505		1.158	
R^2	0.681		0.722		0.717	
$AdjustedR^2$	0.664		0.707		0.701	
$loglikelihood$	1,851.505		1,929.299		1,937.191	

Note: *, **, *** denote that we reject the null hypotheses of constant returns to scale at the 5%, 1%, and 0.1% levels, respectively.

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Direct, Indirect, and Total Elasticity

		Direct		Indirect		Total	
		Elasticity	asy. t-stat	Elasticity	asy. t-stat	Elasticity	asy. t-stat
SARCSSW	Capital	0.104***	4.617	0.064***	4.113	0.168***	4.594
	Labor	0.393***	16.570	0.242***	7.597	0.635***	14.278
	Intermediate	0.257***	18.244	0.158***	7.238	0.415***	13.874
SARCSSG	Capital	0.108***	6.168	0.063***	9.142	0.171***	7.319
	Labor	0.393***	16.980	0.230***	9.242	0.623***	15.686
	Intermediate	0.264***	20.269	0.154***	9.404	0.418***	17.501
SDMCSSW	Capital	0.095***	3.975	0.187**	2.102	0.281***	3.143
	Labor	0.409***	15.820	0.136	1.563	0.545***	6.110
	Intermediate	0.262***	18.698	0.069	1.011	0.331***	4.724
SDMCSSG	Capital	0.100***	4.433	0.179***	3.649	0.279***	6.097
	Labor	0.408***	17.095	0.131	1.503	0.539***	6.038
	Intermediate	0.269***	19.883	0.068	1.034	0.337***	4.899

Note: *, **, *** denote that we reject the null hypotheses of constant returns to scale at the 5%, 1%, and 0.1% levels, respectively.

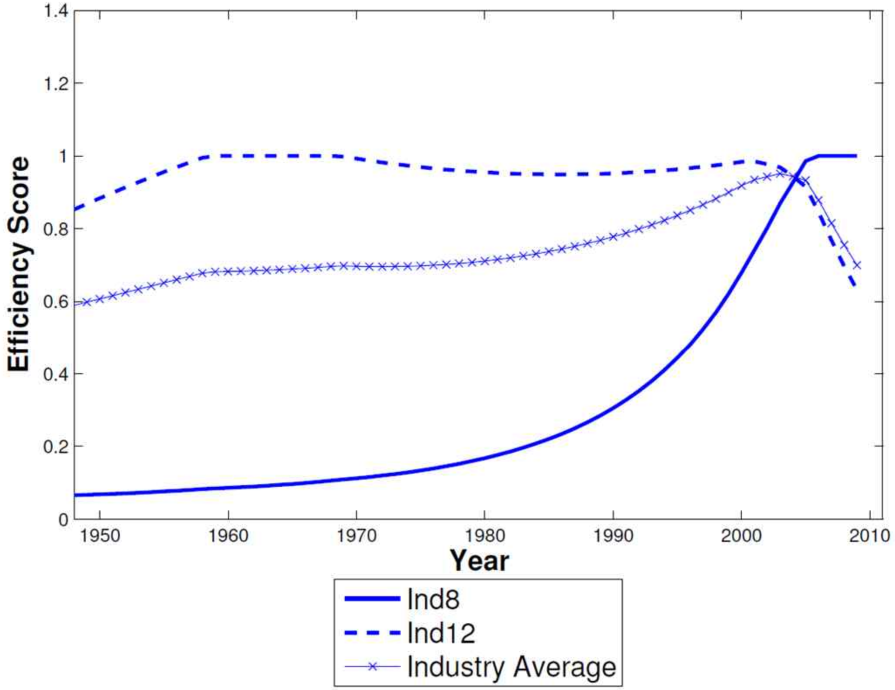
An Empirical Application

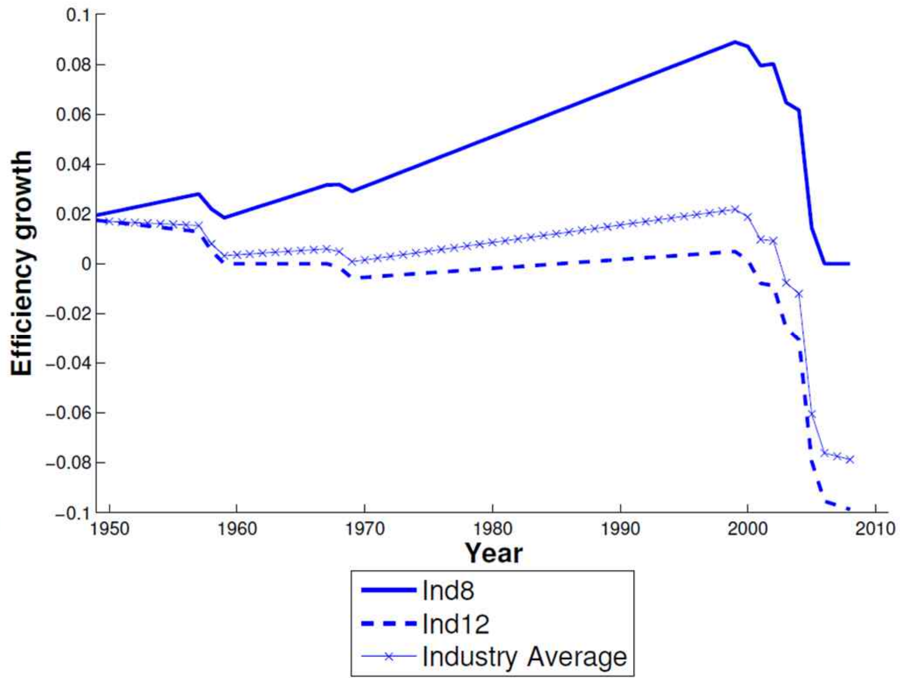
Efficiency Scores (1)

	non-spatial CSS				SAR				SDM				KLEMS	
	Within		GLS		Within		GLS		Within		GLS		Growth Accounting	
	Eff. Score	Rank	Eff. Score	Rank	Eff. Score	Rank	Eff. Score	Rank	Eff. Score	Rank	Eff. Score	Rank	Avg. TFP	Rank
Ind01	0.664	14	0.664	15	0.755	11	0.748	11	0.736	11	0.731	11	0.491	21
Ind02	0.789	8	0.793	7	0.801	7	0.803	7	0.787	7	0.790	7	1.098	7
Ind03	0.855	4	0.858	4	0.870	4	0.871	3	0.853	4	0.856	4	1.234	3
Ind04	0.596	19	0.597	19	0.637	18	0.635	18	0.628	18	0.626	18	0.342	22
Ind05	0.636	17	0.638	17	0.639	17	0.640	17	0.638	16	0.639	16	0.778	14
Ind06	0.692	12	0.693	12	0.736	12	0.734	12	0.730	12	0.728	12	0.781	13
Ind07	0.693	11	0.697	11	0.715	13	0.717	13	0.705	13	0.707	13	1.046	8
Ind08	0.293	23	0.294	23	0.293	23	0.294	23	0.290	23	0.291	23	0.211	23
Ind09	0.662	15	0.665	14	0.681	15	0.682	15	0.672	15	0.673	15	0.812	12
Ind10	0.583	20	0.585	20	0.598	20	0.598	20	0.592	20	0.592	20	0.545	19
Ind11	0.842	5	0.843	5	0.881	2	0.878	2	0.876	3	0.873	3	1.357	2
Ind12	0.973	1	0.973	1	0.974	1	0.974	1	0.972	1	0.973	1	1.503	1
Ind13	0.651	16	0.651	16	0.646	16	0.647	16	0.636	17	0.637	17	0.629	17
Ind14	0.501	21	0.503	21	0.488	22	0.490	22	0.485	22	0.487	22	0.532	20
Ind15	0.619	18	0.621	18	0.609	19	0.611	19	0.602	19	0.605	19	0.63	16
Ind16	0.792	6	0.792	8	0.781	9	0.782	9	0.786	8	0.786	9	1.126	6
Ind17	0.675	13	0.674	13	0.691	14	0.690	14	0.691	14	0.690	14	0.714	15
Ind18	0.496	22	0.499	22	0.491	21	0.494	21	0.486	21	0.489	21	0.591	18
Ind19	0.783	9	0.787	9	0.765	10	0.768	10	0.775	10	0.777	10	0.892	11
Ind20	0.759	10	0.763	10	0.814	6	0.813	6	0.810	6	0.809	6	0.951	10
Ind21	0.791	7	0.794	6	0.781	8	0.784	8	0.785	9	0.787	8	1.002	9
Ind22	0.864	3	0.868	3	0.839	5	0.843	5	0.845	5	0.848	5	1.205	5
Ind23	0.884	2	0.883	2	0.871	3	0.870	4	0.878	2	0.877	2	1.223	4
Average	0.700		0.702		0.711		0.712		0.707		0.707		0.856	

An Empirical Application
Efficiency Scores (2)

- The least efficient industry: Electrical and Optical Equipment (Ind8)
- The most efficient industry: Construction (Ind12)





Concluding remarks

- This paper proposes a method for choosing an appropriate weights matrix when there is no particular pattern of dependence.
- A unified measure characterizing the linkage between a pair of industries is constructed.
- The total output elasticities of factor inputs are estimated larger than the estimated elasticities from non-spatial specification.
- The U.S. economy has increasing returns to scale for the last six decades when only spatially weighted dependent variable is included in the model.
- However, the returns to scale is not significantly increasing if we additionally assume that the factor inputs also show cross-sectional dependence.