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A Panel Based Profit Decomposition Technique to Identify the Sources of Profit Change in the English and Welsh Water and Sewerage Companies

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Motivation

- Evaluation of various profit drivers on the financial performance of the Water and Sewerage Companies (WaSCs) over the period 1991-2008 when the number of observations is small, using index numbers and DEA techniques.
- This methodology enables regulators and regulated companies to identify the sources of profit variation such as price effects, productivity effects, changes in the mix of resources, outputs and the scale of operations and aid them in evaluating both the effectiveness of the price cap scheme and the performance of the regulated companies.
- Since WaSCs have carried out substantial capital investment projects to improve drinking water quality and environmental standards, it is important to control for quality in our analysis.
- Thus, we present a profit decomposition approach which makes allowances for differences in output characteristics such as output quality between firms and across time.

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Theoretical Model

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Profit Decomposition With Adjustments for Quality in Theory

- The positive vector of output quantities $Y=\left(Y_1, Y_2, \ldots, Y_M\right)$

where M denotes the total number of outputs is separated into

a non-negative vector of output for high quality $Y_h=\left(Y_{1,h}, Y_{2,h}, \ldots, Y_{M,H}\right)$

and a non-negative vector of output for low quality $Y_l=\left(Y_{1,l}, Y_{2,l}, \ldots, Y_{M,L}\right)$

where H and L denotes the total number of outputs for high and low quality

respectively and we assume that $Y=Y_h+Y_l$

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Profit Decomposition With Adjustments for Quality in Theory

- The positive vector of output prices $P = (P_1, P_2, \dots, P_M)$

  is separated into

  a non-negative vector of output prices for high quality $P_h = (P_{1,h}, P_{2,h}, \dots, P_{M,H})$

  and a non-negative vector of output for low quality $P_l = (P_{1,l}, P_{2,l}, \dots, P_{M,L})$

  The inputs are represented by a positive input quantity vector

  $$X = (X_1, X_2, \dots, X_N)$$

  The positive vector of input prices is defined as $W = (W_1, W_2, \dots, W_N)$

  where N denotes the total number of resources

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Profit Decomposition With Adjustments for Quality

Given that $Y = Y_h + Y_l$ and P_h, P_l and following De Witte and Saal's (2010) approach, we provide an input oriented profit decomposition between two time periods t and t+1 using Bennet indicators, average prices and quantities as weights to estimate the contributions of the quantity and price effect to profit change :

$$\Pi^{t+1} - \Pi^{t} = [\overline{P}_h\left(Y_h^{t+1} - Y_h^{t}\right) + \overline{P}_l\left(Y_l^{t+1} - Y_l^{t}\right)] - \overline{W}\left(X^{t+1} - X^{t}\right) \quad quantity \;\; effect$$

$$+[\overline{Y}_h\left(P_h^{t+1} - P_h^{t}\right) + \overline{Y}_l\left(P_l^{t+1} - P_l^{t}\right)] - \overline{X}\left(W^{t+1} - W^{t}\right) \quad price \;\; effect$$

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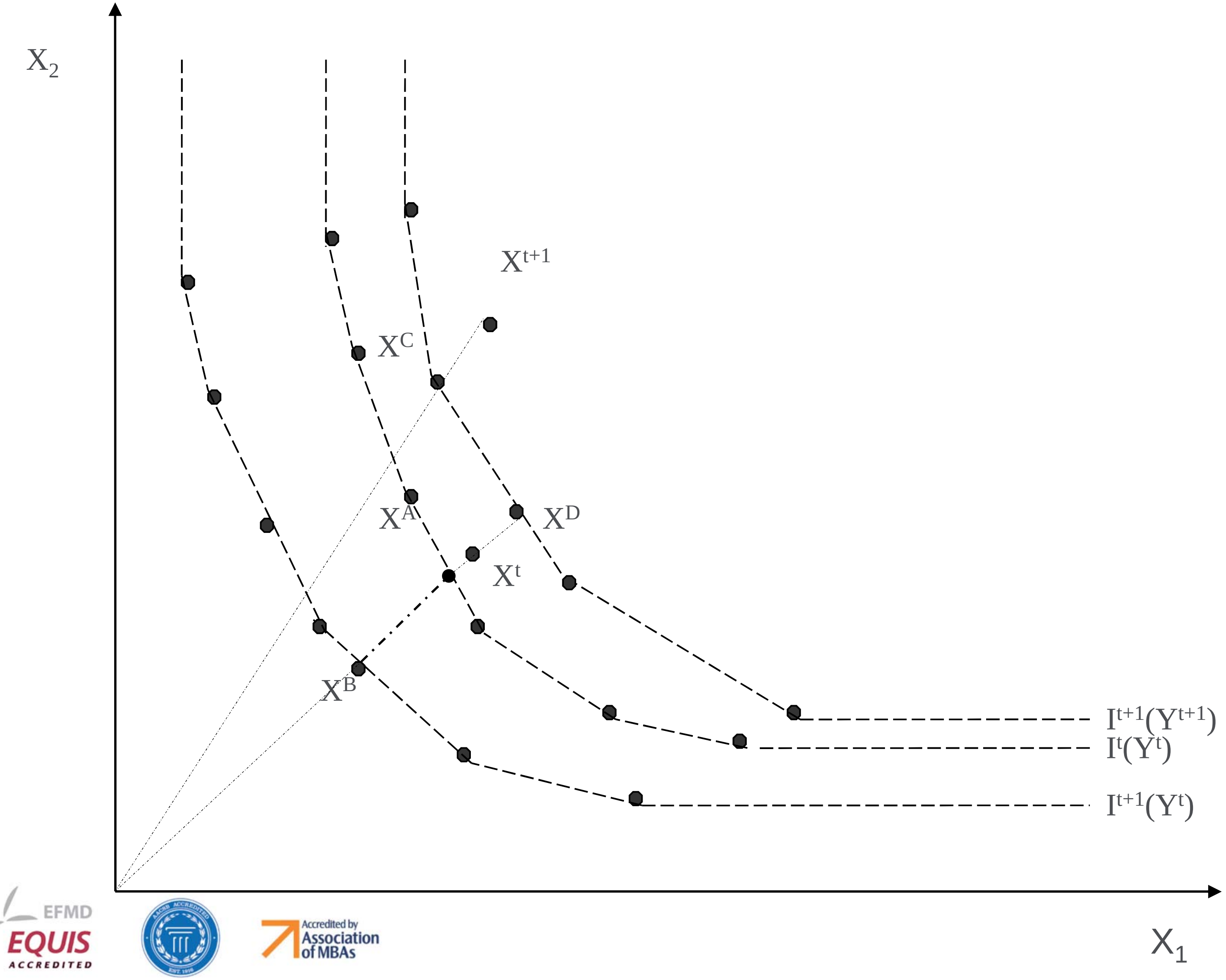
Decomposition of the Quantity Effect

The decomposition of the quantity effect makes use of the observed quantities X^t to X^{t+1} and of the unobserved quantities $\left(X^A, X^B, X^C, X^D, Y^E\right)$

$$[\overline{P_h}\left(Y_h^{t+1} - Y_h^t\right) + \overline{P_l}\left(Y_l^{t+1} - Y_l^t\right)] - \overline{W}\left(X^{t+1} - X^t\right) \quad quantity \quad effect$$

$$= \left[\overline{W}\left(X^t - X^B\right) - \overline{W}\left(X^{t+1} - X^C\right)\right] \quad productivi \;\; ty \quad effect$$

$$+ \left[[\overline{P_h}\left(Y_h^{t+1} - Y_h^t\right) + \overline{P_l}\left(Y_l^{t+1} - Y_l^t\right)] - \overline{W}\left(X^C - X^B\right)\right] \quad activity \quad effect$$


X2
X1
Xt+1
XC
XA
XD
Xt
XB
It+1(Yt+1)
It(Yt)
It+1(Yt)

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Decomposition of the Productivity Effect

The unobserved quantities $\left(X^{A}, X^{B}, X^{C}\right)$ can be estimated by means of input distance functions:

$$X^{A} = X^{t} * D_{I}^{t}\left(Y_{h}^{t}, Y_{l}^{t}, X^{t}\right) \quad X^{B} = X^{t} * D_{I}^{t+1}\left(Y_{h}^{t}, Y_{l}^{t}, X^{t}\right) \quad X^{C} = X^{t+1} * D_{I}^{t+1}(Y_{h}^{t+1}, Y_{l}^{t+1}, X^{t+1})$$

$$\overline{W}\left[\left(X^{t} - X^{B}\right) - \left(X^{t+1} - X^{C}\right)\right] \quad productivity\ effect$$

$$= \overline{W}\left[\left(X^{A} - X^{B}\right)\right] \quad technical\ change$$

$$+ \overline{W}\left[\left(X^{t} - X^{A}\right) - \left(X^{t+1} - X^{C}\right)\right] \quad efficiency\ change$$

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Decomposition of the Activity Effect

The unobserved quantities $\left(X^{D}, Y^{E}\right)$ can be estimated by means of input and output distance functions:

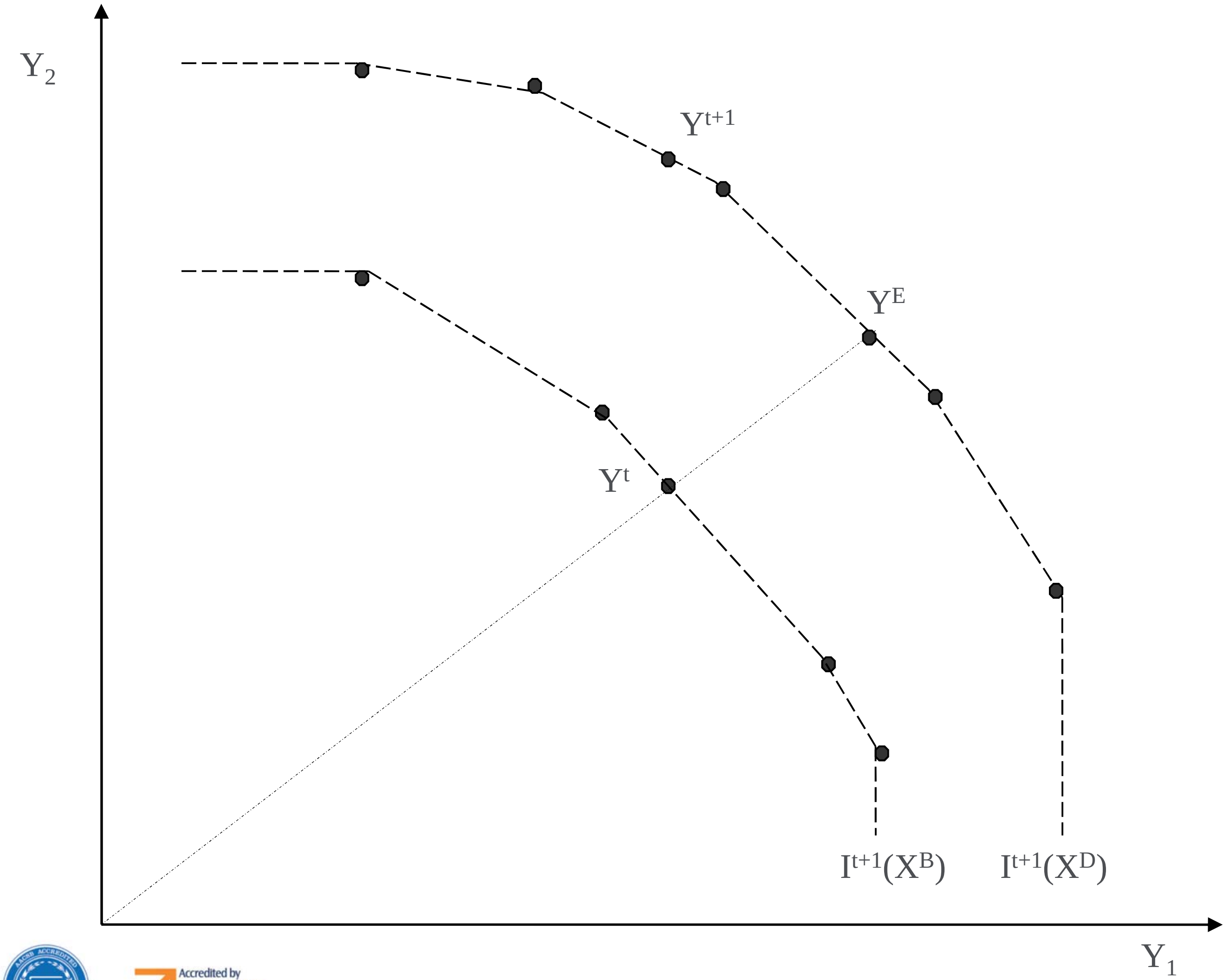
$$X^{D} = X^{t} * D_{I}^{t+1}\left(Y_{h}^{t+1}, Y_{l}^{t+1}, X^{t}\right) \qquad Y^{E} = (Y_{h}^{t} + Y_{l}^{t}) * D_{O}^{t+1}\left(\left(X^{t} * D_{I}^{t+1}\left(Y_{h}^{t+1}, Y_{l}^{t+1} X^{t}\right), Y_{h}^{t}, Y_{l}^{t}\right)\right)$$

$$[\overline{P}_{h}\left(Y_{h}^{t+1} - Y_{h}^{t}\right) + \overline{P}_{l}\left(Y_{l}^{t+1} - Y_{l}^{t}\right)] - \overline{W}\left(X^{C} - X^{B}\right) \quad activity \;\; effect$$

$$= \overline{W}\left(X^{D} - X^{C}\right) \qquad resource \;\; mix \;\; effect$$

$$-[\overline{P}_{h}\left(Y_{h}^{E} - Y_{h}^{t+1}\right) + \overline{P}_{l}\left(Y_{l}^{E} - Y_{l}^{t+1}\right)] \qquad product\,mix\,effect$$

$$+\overline{W}\left(X^{B} - X^{D}\right) - [\overline{P}_{h}\left(Y_{h}^{t} - Y_{h}^{E}\right) + \overline{P}_{l}\left(Y_{l}^{t} - Y_{l}^{E}\right)] \quad scale\,effect$$


Y2
Yt+1
YE
Yt
It+1(XB)
It+1(XD)
Y1

$Y = (Y_1, Y_2, \ldots, Y_M)$

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Profit Decomposition With Adjustments for Quality in Practice

- The above modifications in the profit decomposition with adjustments for quality can be readily implemented if data for multiple output quality levels is available.
- In the UK water industry, all customers of a given water firm effectively pay the same price for water services regardless of output quality, as regulated water prices do not differentiate between quality of output.
- Total turnover for water and sewerage services is not disaggregated by quality of service.
- Thus, we do not in practice have different prices for high and low quality water and sewerage output types, even though we can observe quantity data reflecting differences in output quality. We proceed with the assumption that consumers pay the same price for high and low quality outputs.
- $$P = P_h = P_l$$

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Profit Decomposition With Adjustments for Quality in Practice

Given that $Y = Y_h + Y_l$ and $P = P_h = P_l$ the decomposition of profits into a quantity and price effect will now become:

$$\Pi^{t+1} - \Pi^{t} = \overline{P}[\left(Y_h^{\,t+1} - Y_h^{\,t}\right) + \left(Y_l^{\,t+1} - Y_l^{\,t}\right)] - \overline{W}\left(X^{t+1} - X^{t}\right) \quad \textit{quantity effect}$$

$$+[\overline{Y}_h + \overline{Y}_l]\left(P^{t+1} - P^{t}\right) - \overline{X}\left(W^{t+1} - W^{t}\right) \quad \textit{price effect}$$

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Decomposition of the Quantity Effect

The decomposition of the quantity effect makes use of the observed quantities X^{t} to X^{t+1} and of the unobserved quantities $\left(X^{A'}, X^{B'}, X^{C'}, X^{D'}, Y^{E'}\right)$

$$\overline{P}[\left(Y_h^{t+1} - Y_h^{t}\right) + \left(Y_l^{t+1} - Y_l^{t}\right)] - \overline{W}\left(X^{t+1} - X^{t}\right) \qquad \textit{quantity effect}$$

$$= \left[\overline{W}\left(X^{t} - X^{B'}\right) - \overline{W}\left(X^{t+1} - X^{C'}\right)\right] \qquad \textit{productivity effect}$$

$$+ \left[\overline{P}[\left(Y_h^{t+1} - Y_h^{t}\right) + \left(Y_l^{t+1} - Y_l^{t}\right)] - \overline{W}\left(X^{C'} - X^{B'}\right)\right] \qquad \textit{activity effect}$$

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Decomposition of the Activity Effect

The unobserved quantities $\left(X^{D'}, Y^{E'}\right)$ can be estimated by means of input and output distance functions:

$$X^{D'} = X^{t} * D_{I}^{t+1}\left(Y_{h}^{t+1}, Y_{l}^{t+1}, X^{t}\right) \quad Y^{E'} = (Y_{h}^{t} + Y_{l}^{t}) * D_{O}^{t+1}\left(\left(X^{t} * D_{I}^{t+1}\left(Y_{h}^{t+1}, Y_{l}^{t+1} X^{t}\right), Y_{h}^{t}, Y_{l}^{t}\right)\right)$$

$$\overline{P}[\left(Y_{h}^{t+1} - Y_{h}^{t}\right) + \left(Y_{l}^{t+1} - Y_{l}^{t}\right)] - \overline{W}\left(X^{C'} - X^{B'}\right) \quad activity \quad effect$$

$$= \overline{W}\left(X^{D'} - X^{C'}\right) \quad resource \ \ mix \ effect$$

$$- \overline{P}[\left(Y_{h}^{E'} - Y_{h}^{t+1}\right) + \left(Y_{l}^{E'} - Y_{l}^{t+1}\right)] \quad product \ \ mix \ effect$$

$$+ \overline{W}\left(X^{B'} - X^{D'}\right) - \overline{P}[\left(Y_{h}^{t} - Y_{h}^{E'}\right) + \left(Y_{l}^{t} - Y_{l}^{E'}\right)] \quad scale \ \ effect$$

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Data

Outputs: water connected properties and sewerage connected properties

Inputs: labour (FTE), capital (MEA), other costs = operating costs- labour costs

Output price: turnover divided by output index

Labour price: labour costs divided by the average number of full-time equivalent employees

Capital Cost : sum of opportunity cost of regulatory capital stock and capital depreciation of the MEA asset values

Capital Price = Capital Cost/MEA capital stocks

Other costs price: UK price index for materials and fuel purchased in purification and distribution of water

Other costs usage: deflated other costs

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High and Low Quality of Water Output

High drinking water quality, $Q_{w,h}$ is defined as the average percentage of each WaSC's water supply zones that are compliant with six water quality parameters. Low drinking water quality $Q_{w,l}$ is defined as the average percentage of each WaSC's water supply zones that are not compliant with these six water quality parameters.

The water output for high quality, $Y_{w,h}$ is calculated as the product of the water connected properties and high drinking water quality $Y_{w,h} = Y_w Q_{w,h}$

The water output for low quality, $Y_{w,l}$ is defined as the product of the water connected properties and low drinking water quality,

$$Y_{w,l} = Y_w Q_{w,l} = Y_w(1 - Q_{w,h})$$

Note that the sum of water output for high and low quality is equal to the water output, $Y = Y_{w,h} + Y_{w,l}$

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High and Low Quality of Sewerage Output

High sewerage treatment quality, $Q_{s,h}$ is defined as the percentage of connected population receiving at least secondary or high sewerage treatment. Low drinking water quality $Q_{s,l}$ is defined as the percentage of connected population receiving zero or primary sewerage treatment.

The sewerage output for high quality, $Y_{s,h}$ is calculated as the product of the sewerage connected properties and high sewerage treatment quality $Y_{s,h} = Y_s Q_{s,h}$

The sewerage output for low quality, $Y_{s,l}$ is defined as the product of the sewerage connected properties and low sewerage treatment quality,

$$Y_{s,l} = Y_s Q_{s,l} = Y_s(1 - Q_{s,h})$$

Note that the sum of sewerage output for high and low quality is equal to the sewerage output,

$$Y = Y_{s,h} + Y_{s,l}$$

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	1994-2008	1994-2000	2000-2005	2005-2008
Profit change	-1,112.6	440.6	-1,526.8	-26.4
Quantity effect	1,335.7	538.8	676.4	120.5
Output effect	1,080.4	482.6	413.7	184.1
High Quality Output Effect	2,067.1	902.3	1,015.5	149.3
Low Quality Output Effect	-986.6	-419.8	-601.7	34.9
Input effect	255.3	56.2	262.6	-63.6
Productivity	1,089.5	563.5	457.4	68.6
Technical Change	989.4	556.1	321.6	111.8
Efficiency Change	100.0	7.4	135.8	-43.2
Activity effect	246.2	-24.7	219.0	52.0
Resource Mix	1,176.1	275.6	520.8	379.7
Product Mix	30.4	-60.9	81.8	9.5
Scale Effect	-960.3	-239.5	-383.5	-337.3
Price Effect	-2,448.3	-98.1	-2,203.2	-146.9
Output Price Effect	287.7	299.2	-830.0	818.6
Input Price Effect	-2,736.00	-397.33	-1,373.14	-965.53

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Summary of the Results

- The results suggested that the major impact on the negative profit change was attributed to the negative price effect, which outstripped the positive quantity effect.
- The positive quantity effect was attributed to substantial increases in outputs (high quality of output) and a small but positive input effect.
- The major determinants on the quantity effect and finally on profit change came from technical change whose magnitude reduced during the years 2005-2008, the resource mix effect, a shift to a more cost efficient allocation of resources by substituting labour with capital and the negative scale effect.
- Efficiency change and product mix effect were found to have a small but positive impact on profit changes.

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Summary and Conclusions

- Applied an input oriented profit decomposition approach to evaluate the sources of profit change for WaSCs over time when the number of observations was extremely limited.
- By making allowances for differences in the quality of output, we decompose the output effect into high and low quality output, using the same prices as weights. It captures the general growth and movement to higher quality outputs that occurred over the period but not the mix between high and low quality of output.
- The differentiation of output quantities by quality does allow an alternative estimation of the aggregate quantity effect.
- Major impact on profit changes came from improvements in the cost efficient allocation of resources by substituting labour with capital and from technical change. Efficiency change was weak.
- Price effect and scale effect negatively contributed to profit changes. Negative scale effect suggests that further mergers in the industry will reduce productivity more.
- Future Work: The estimation of cost of quality and cost decompositions to avoid difficulties created by the non availability of quality differentiated output prices.

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Profit change	-1,112.6	440.6	-1,526.8	-26.4
Quantity effect	1,335.7	538.8	676.4	120.5
Output effect	1,080.4	482.6	413.7	184.1
Input effect	255.3	56.2	262.6	-63.6
Productivity	1,155.9	589.7	506.0	60.2
Technical Change	1,041.5	609.3	348.6	83.6
Efficiency Change	114.4	-19.6	157.4	-23.4
Activity effect	179.8	-50.9	170.4	60.3
Resource Mix	939.2	147.5	355.7	436.0
Product Mix	-2.1	47.1	-90.5	41.3
Scale Effect	-757.2	-245.5	-94.8	-417.0
Price Effect	-2,448.3	-98.1	-2,203.2	-146.9
Output Price Effect	287.7	299.2	-830.0	818.6
Input Price Effect	-2,736.00	-397.33	-1,373.14	-965.53

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