# Evaluating the Efficiency Effects of Industry Consolidation

## *Evidence from US Interstate Pipeline Companies*

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INFRADAY
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# Agenda

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2. Methods
3. Empirical Results
4. Conclusion

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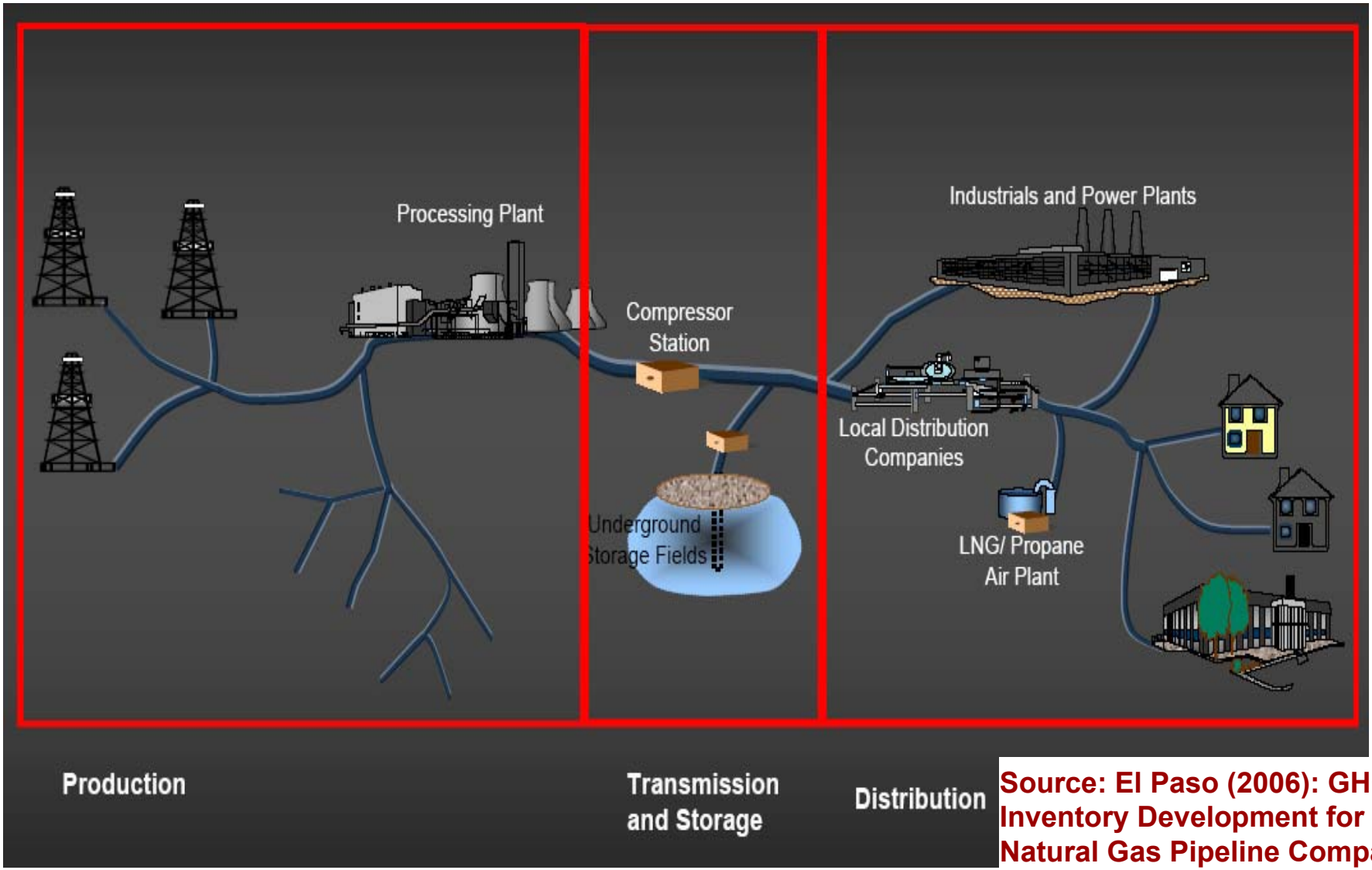
# Introduction

**There are different business strategies that prevail in the US natural gas interstate pipeline industry that become increasingly interesting**

1. **Increasing number of acquisitions per years**
2. **Formation of big holding companies**
3. **Cooperation investment in pipeline (Joint Ventures)**

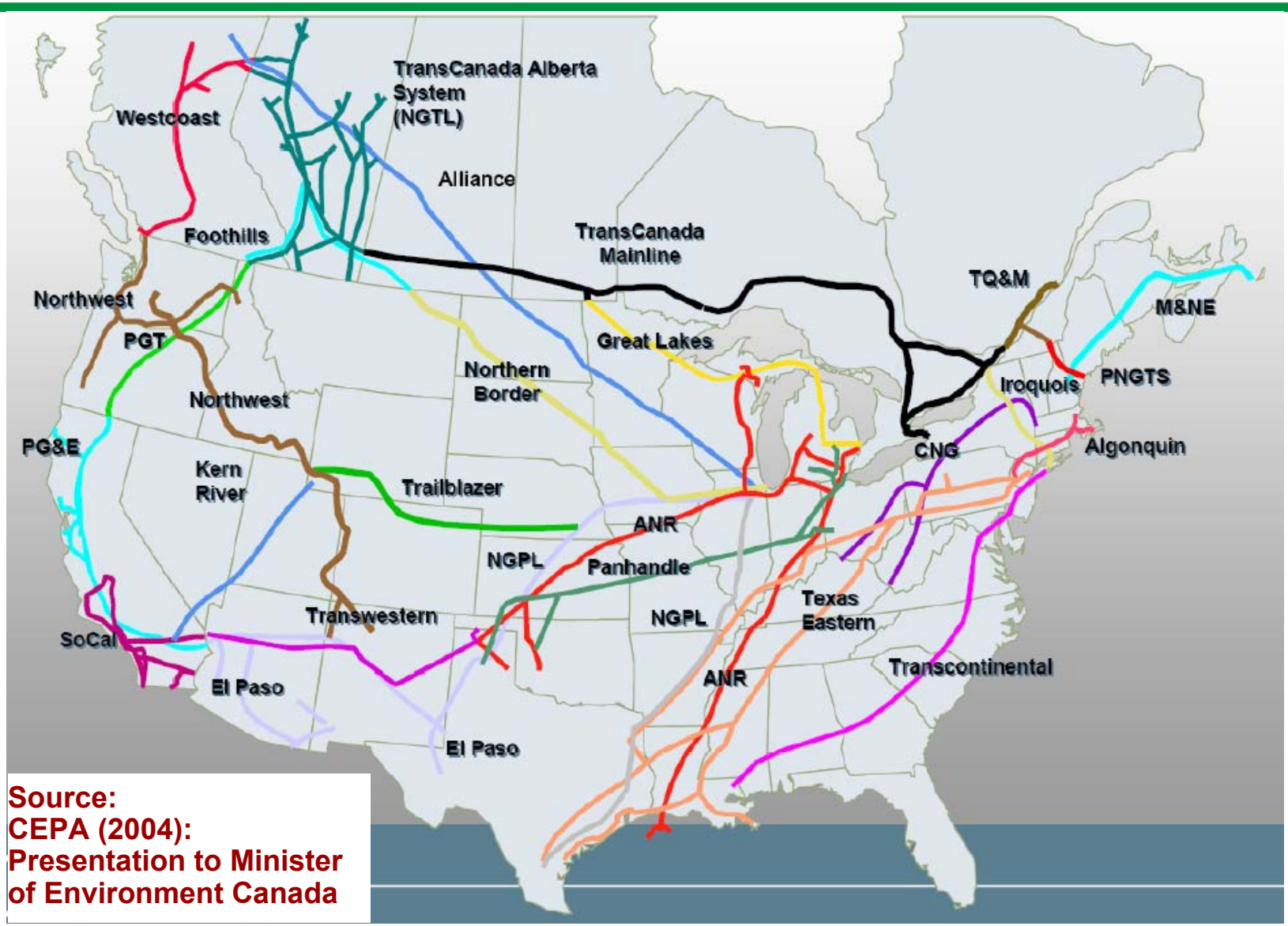
**→ Are those business strategies successful?**

# The US Natural Gas Industry




Source: El Paso (2006): GHG Inventory Development for Natural Gas Pipeline Company

# US and Canadian Natural Gas Pipelines




Source:
CEPA (2004):
Presentation to Minister of Environment Canada

# Why do Firms merge?

**Diamond and Edwards (1997) emphasized five major causes:**

1. **Economic efficiency** in form of cost savings by synergy effects;
2. **Defensive motives**
3. **Diversification**
4. **Growth and personal aggrandizement**
5. **Market power**

\+ **Supply security (gas fired electricity generation, natural gas supplier)**

**Efficiency: production function, define the relationship between the inputs and outputs. Represents the maximum output attainable from each input level, reflects current state of technology; firms operating on the frontier technically efficient.**

# State of the Literature

## Efficiency estimation of natural as transmission companies

- Sickles, Streitwieser (1992):
  - 14 US interstate Gas Transmission Companies (1977-1985), SFA, DEA, Production function
  - Findings suggested the introduction of the Natural Gas Policy Act of 1978 to affect a decline in technical efficiency
- Granderson, Linvell (1999):
  - 20 US interstate Gas TSOs (1977-1987), SFA, DEA, Cost function
  - Quite similar ranking of firms of DEA and SFA efficiency scores

## Related work on mergers only concerning electricity sector:

- Nillesen, Pollitt and Keats (2001) and Nillesen and Pollitt (2001)
- Kwoka and Pollitt (2005 and 2007): DEA and Tobit regression on panel data set (78 distributors; 1994-2001)
  → buying firms are winners / targets are losers of a merger

**→ We use parametric Stochastic Frontier Analyses (SFA) to analyze the effect of business strategies (mergers, holding, Joint venture) on technical efficiency**

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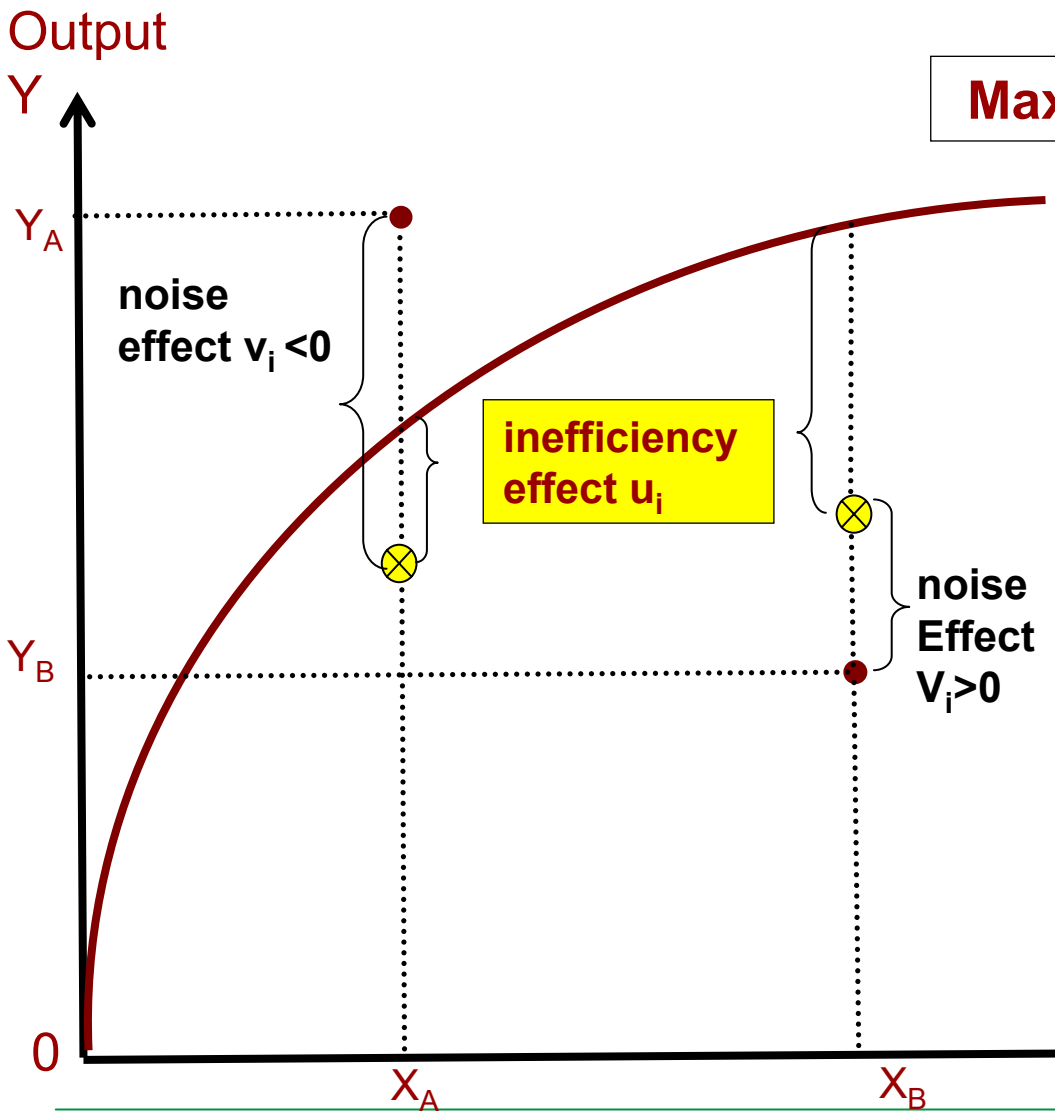
# Stochastic Frontier Analysis (SFA)




**Maximum Production Function**

$$Y_{SFA} = \beta X \pm v_i - u_i$$

$v_i \sim iidN(0,\sigma_v^2)$ $\quad u_i \sim iidN^+(\mu,\sigma_u^2)$

Deviations are either due to noise ($v_i$) or due to inefficiency ($u_i$)

Estimation by using ML estimation

1) Obs. (●) are controlled for random noise

# Model Specification

**Carrington, Coelli and Groom (2002) discussed physical vs. monetary data models in form of capital measures in the gas industry**

- Physical (Pipeline Length):
  - + Easily to get
  - - Cannot capture the total capital equipment
  - - Difficult to account for differences, e.g. age, quality and composition (sizes or materials used)
- Monetary measures (Transmission Assets):
  - + Account for the total equipment
  - - Difficulties with different accounting standards

**Discussion can also be related to the correct output measue (gas delivered vs. total revenues)**

**Companies in the sample use similar accounting methods/standards**

**→ We specify Monetary data models due to their advantages**

# Models Used

| | | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|---|
| OUTPUT | Total Revenues | X | X | X | X |
| INPUTS | OPEX | X | X | X | X |
| | Transmission Assets | X | X | X | X |
| STRUCTURE | Compr. Station's intensity | X | X | X | X |
| | Offshore pipeline | X | X | X | X |
| | Time trend | X | X | X | X |
| STRATEGIES | Merger dummies: Time path | X | | | |
| | Merger dummies: Time periods | | X | | |
| | Holdings: different companies | | | X | |
| | Holding dummy | | | | X |
| | Joint Venture | | | X | X |
| | Time trend | X | X | X | X |

# Functional Form

**Applying SFA on Cobb-Douglas production function within a TE Effects Model (Battese/Coelli 1995)**

$$\ln REVENUES_{it} = \beta_0 + \beta_{OPEX} \ln OPEX_{it} + \beta_{ASSETS} \ln ASSETS_{it} + \beta_{CS\_INTENSITY} CS\_INTENSITY_{it} + \beta_{OFFSHORE} OFFSHORE_i + \beta_t TIME + u_{it} - v_{it}$$

**A Firms' Inefficiency is explained in a simultaneous step**

$$\mu_{it} = \delta_0 + \delta_t t + \sum_m \delta_m d_{m_{it}}$$

# Data

## Data come from US federal energy regulator FERC – Form 2/2a data

- 47 interstate natural gas pipelines over 10 years (1996-2005)
  - Balanced panel with 470 obs.
  - Heterogeneous sample but covers ca 86% of interstate pipeline network and 93% of pipeline capacity in 2005
- 46 mergers and 13 holding companies are analyzed
  - Holdings companies incorporated cover cover about 65% and 70% of total pipeline network and capacity, respectively
  - FERC is accounting data for each pipeline operator separately whether merged or not

| Explanation | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| Total Deliveries (Mio. Dth = 1bn cf)) | 949 | 1,130 | 759 | 5,950 |
| Total Revenues (mio. $) | 203 | 200 | 0.06 | 907 |
| Pipeline Length (Miles) | 3,905 | 4,077 | 25 | 16,666 |
| Total Transmission Assets (mio. $) | 1,180 | 1,220 | 10,7 | 6,000 |
| Compressor Station's Share of Total Transmission Assets | 0.21 | 0.08 | 0.00 | 0.43 |
| Peak Delivery (Mio. Dth per day) | 3.01 | 3.01 | 0.073 | 14.9 |
| OPEX (tsd $) | 60,700 | 73,400 | 2,163 | 393,000 |

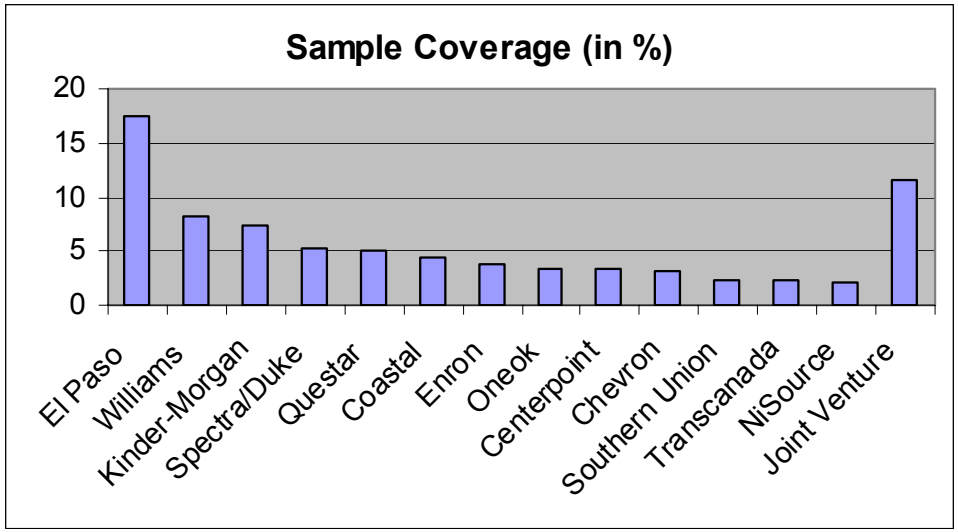
# Timing of Mergers and Cooperative Structure

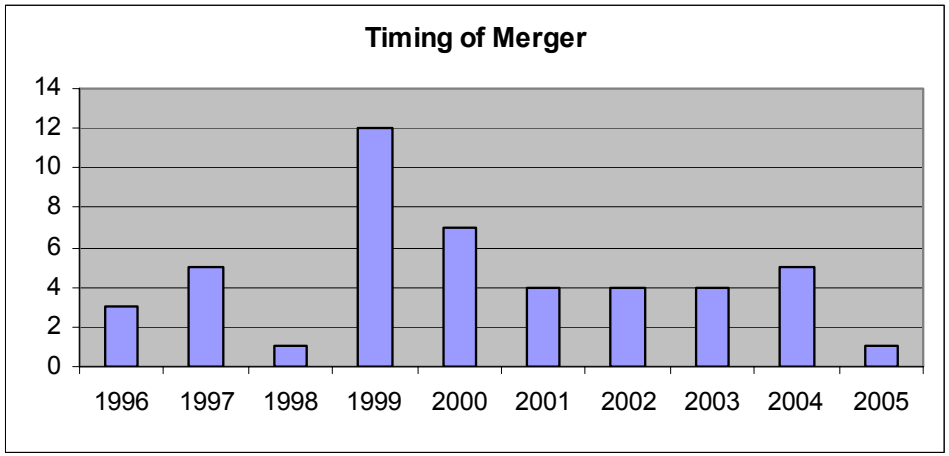
Data come from SEC (Securities and Exchange Commission) and various firms' websites

46 mergers and 13 holding companies are analyzed

Holdings companies incorporated cover about 65% and 70% of total pipeline network and capacity, respectively

70% of all observations are related to holding structures



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# Estimation of the Production Function

**Inputs are significant and have the correct sign**

**All models show similar results**

- Assets have highest revenue elasticity, as expected
- The higher the share of compressor station assets on total assets, the higher is the revenue
- Revenue reduction by 3-4% each year
- Offshore pipelines have significantly lower revenues
  - Might be due to small distance pipelines

**→ well specified production function**

| Coefficient | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| constant | 0.10<br>(0.21) | 0.04<br>(0.25) | 0.38<br>(0.26) | 0.12<br>(0.24) |
| ln*OPEX* | 0.13***<br>(0.02) | 0.13***<br>(0.02) | 0.12***<br>(0.02) | 0.12***<br>(0.02) |
| ln*ASSETS* | 0.82***<br>(0.02) | 0.82***<br>(0.02) | 0.81***<br>(0.02) | 0.82***<br>(0.02) |
| CS_intensity | 0.61***<br>(0.18) | 0.59**<br>(0.20) | 0.36*<br>(0.20) | 0.43**<br>(0.19) |
| OFFSHORE | -0.63***<br>(0.05) | -0.65***<br>(0.05) | -0.80***<br>(0.05) | -0.73***<br>(0.05) |
| TIME | -0.03***<br>(0.00) | -0.04***<br>(0.00) | -0.03***<br>(0.01) | -0.04***<br>(0.00) |
| $\sigma^2$ | 2.46***<br>(0.84) | 3.33***<br>(1.40) | 0.43***<br>(0.06) | 3.33***<br>(1.11) |
| Log Likelihood | -73.12 | -315.58 | -48.19 | -78.37 |
| Significance 1%-, 5%-, 10%-level: ***,**,*; SE in parentheses. | | | | |

# Results from Merger Analysis

| | Model 1 | | Model 1 |
|---|---|---|---|
| **Constant** | **-10.27***(3.60)** | ***TIME*** | **-0.13* (0.07)** |
| **PRE-MERGER** | | **POST-MERGER** | |
| 9 years before | 4.75*** (1.61) | 1 year after | 2.58*** (0.85) |
| 8 years before | -2.45* (1.43) | 2 year after | 2.24*** (0.73) |
| 7 years before | -0.77 (0.58) | 3 years after | 2.75*** (0.94) |
| 6 years before | 4.82*** (1.50) | 4 years after | 3.92*** (1.29) |
| 5 years before | 1.89** (0.76) | 5 years after | 3.15*** (1.02) |
| 4 years before | 2.77*** (0.86) | 6 years after | 3.65*** (1.23) |
| 3 years before | 3.72*** (1.13) | 7 years after | 1.74* (0.96) |
| 2 years before | 3.06*** (0.99) | 8 years after | 1.69* (0.95) |
| 1 year before | 2.68*** (0.82) | 9 years after | 4.13*** (1.34) |

| | Model 2 | | Model 2 |
|---|---|---|---|
| **Constant** | **-14.43** (6.23)** | ***TIME*** | **-0.05 (0.03)** |
| **pre-merger** | **5.18** (2.05)** | **post-merger** | **3.92*** (1.50)** |

**Inefficiency is decreasing over time remarkably**

**Model 1 shows almost always significant positive values fro the time path dummies**

**→ Overall effect cannot be evaluated**

**Model 2 shows decreasing but still positive values**

**→ Acquired pipelines are less efficient than non-acquired firms, but after acquisition the effect reduced**

# Results from Cooperation Analysis

| | Model 3 | | Model 3 |
|---|---|---|---|
| **Constant** | **-1.04*** (0.30)** | **Joint Venture** | **0.68*** (0.22)** |
| *TIME* | -0.02 (0.03) | | |
| **El Paso** | **-0.34* (0.21)** | Oneok | -0.11 (0.63) |
| **Williams** | **-3.12*** (0.98)** | **Centerpoint** | **0.75*** (0.27)** |
| **Kinder-Morgan** | **0.59*** (0.16)** | **Chevron** | **-3.96*** (1.31)** |
| Spectra/Duke | -0.60 (0.77) | South. Union | 0.43 (0.51) |
| **Questar** | **1.24*** (0.21)** | Transcanada | -0.37 (0.87) |
| Coastal | 0.09 (0.36) | NiSource | 0.13 (0.19) |
| **Enron** | **-2.07** (1.00)** | | |

| | Model 4 | | Model 4 |
|---|---|---|---|
| **Constant** | **-12.90***(4.38)** | **Joint Venture** | **0.88*** (0.28)** |
| ***TIME*** | **-0.23*** (0.08)** | **Holding** | **7.79*** (2.36)** |

**Inefficiency is decreasing over time remarkably**

**A Joint Venture appears to rive down the efficieny (e.g. multiple interests)**

**Model 3 shows heterogeneous picture of inefficiency of holding companies**

→ **Williams and Chevron are very efficient (due to Oil experience?)**

**Model 4 shows average evidence for a large efficiency drop by being part f a holding/parent company**

# Efficiency Estimates

| Statistics | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| Mean | 0.78 | 0.80 | 0.78 | 0.79 |
| Median | 0.84 | 0.86 | 0.83 | 0.85 |
| Minimum | 0.04 | 0.04 | 0.04 | 0.04 |
| Maximum | 0.93 | 0.94 | 0.93 | 0.93 |
| 95th Percentile | 0.97 | 0.97 | 0.96 | 0.96 |

Sample of 470 obs.

Very similar efficiency results across all models

Low variance but also some very bad performer

Average technical efficiency of about 80%

High correlation of over 90%

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# Conclusion

**Presenting a fresh approach for analyzing business strategies with respect to technical efficiency**

- Estimate technical efficiency of interstate natural gas pipeline companies from the US for 1996-2005
- Applied a robust one-stage SFA (Battese, Coelli 1995) with a Cobb-Douglas production function

**Pipeline acquisitions lead to an increase in efficiency but non-merging firms still perform better**

**Joint ventures have lower efficiency than pipelines fully owned by one company**

**Holding structures on average lead to lower efficiency, but firms with experience in the oil pipeline industry perform better**

**→ We cannot find evidence for successful business strategies of acquisitions, joint ventures or holding structures**

**Further work:**

- Controlling for unobserved heterogeneity, scope effects gas&power and gas&oil

# Thank you for your attention.
# Comments and questions are welcome.

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# Literature (selected)


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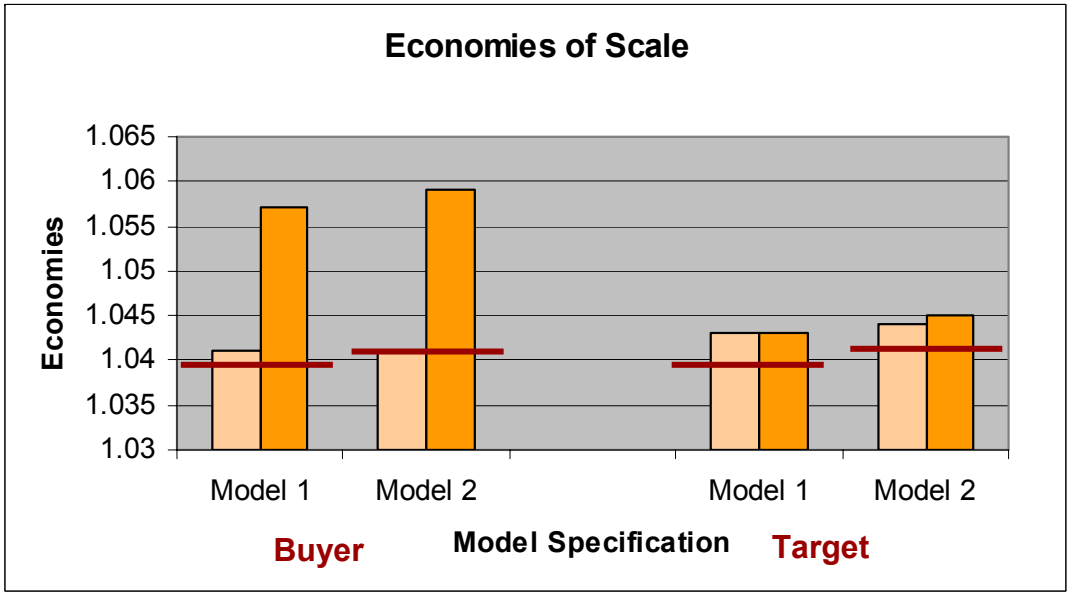
# Is the Efficiency Shift due to Economies of Scale?

**Measuring economies of scale by the inverse of the sum of cost elasticities of outputs:**

$$\varepsilon_c = \left[ \sum_{m=1}^{M} \frac{\partial \ln c(y,w)}{\partial \ln y_m} \right]^{-1}$$

**ES do (not) exist, if ε > (<) 1**




**Merging parties have higher ES than the average/non-merging parties**

**Merging parties increase their SE after merging**

**But: Buyer have higher increase in scale efficiency than the target**

**→Efficiency gains might be due to scale effects**

**→Efficiency losses have its sources in technical and/or allocative efficiency**

# Results: Explaining Efficiency

**Table 4: Estimation Results of Efficiency Function**

| Coefficient | Model 1 | | Coefficient | Model 2 | |
|---|---|---|---|---|---|
| $\delta$ | *Estimate* | *t-statistic* | $\delta$ | *Estimate* | *t-statistic* |
| constant $\delta_0$ | -0.86*** | -4.49 | constant $\delta_0$ | -1.81*** | -3.09 |
| $t$ | 0.07*** | 3.50 | $t$ | 0.13*** | 3.99 |
| Multiple buyer | -0.03 | -0.04 | Multiple buyer | -0.56 | -1.17 |
| Multiple target | -1.87*** | -2.63 | Multiple target | -3.10** | -2.52 |
| Buyer: 7 years before | 0.49* | 1.72 | | | |
| Buyer: 6 years before | 0.31 | 1.18 | | | |
| Buyer: 5 years before | 0.27 | 1.48 | | | |
| Buyer: 4 years before | 0.37*** | 2.83 | | | |
| Buyer: 3 years before | -0.26 | -1.31 | | | |
| Buyer: 2 years before | -0.20 | -1.24 | | | |
| Buyer: 1 year before | -0.37** | -2.12 | Buyer: before first merger | -0.15* | -1.74 |
| Buyer: 1 year after | -0.06 | -0.58 | Buyer: since first merger | -0.78*** | -3.02 |
| Buyer: 2 year after | -0.35 | -1.36 | | | |
| Buyer: 3 years after | -1.38*** | -3.44 | | | |
| Buyer: 4 years after | -0.70 | -1.39 | | | |
| Buyer: 5 years after | -0.92 | -0.94 | | | |
| Buyer: 6 years after | 0.31 | 0.42 | | | |
| Target: 7 years before | 0.19 | 0.20 | | | |
| Target: 6 years before | -1.49** | -2.24 | | | |
| Target: 5 years before | -1.58*** | -4.95 | | | |
| Target: 4 years before | -0.43 | -1.43 | | | |
| Target: 3 years before | 0.06 | 0.38 | | | |
| Target: 2 years before | -0.21 | -1.48 | | | |
| Target: 1 year before | 0.08 | 0.88 | Target: before first merger | -0.26** | -2.54 |
| Target: 1 year after | 0.19** | 2.36 | Target: since first merger | 0.42*** | 3.16 |
| Target: 2 years after | 0.28*** | 2.64 | | | |
| Target: 3 years after | 0.45*** | 2.97 | | | |
| Target: 4 years after | 0.49*** | 3.80 | | | |

Significance on 10%-, 5%-, and 1%-level: *, **, ***; t-statistics in parentheses.

# Parametric Approach of Efficiency Analysis

## Applying Stochastic Frontier Analysis (SFA)

- Use of one-stage procedure to estimate inefficiency and its sources simultaneously (Technical Efficiency Effects Model by Battese/Coelli, 1995)
  - Random Effects Model á la Pitt and Lee (1981) --> heterogeneity is treated as inefficiency
- Using translog cost function for a panel data set with mean correction
- 2 outputs: electricity delivered, customer numbers
- 2 inputs prices: cost of capital and labor
- Network density (customer number per unit of assets)
  - Distributors which are operating in densely settled area have cost advantages
- Software FRONTIER 4.1

## Accounting for mergers

- Three groups of firms: buying firms, acquired firms, non-merging firms
- Dummies for timing of mergers

# Results: Cost function

| Coefficient | Model 1 | Model 1a (without ND) | Coefficient | Model 2 | Model 2a (without ND) |
|---|---|---|---|---|---|
| $\beta$ | | | $\beta$ | | |
| constant $\beta_0$ | 0.02 | -0.12*** | constant $\beta_0$ | 0.01 | -0.14*** |
| | (1.25) | (-4.62) | | (0.93) | (-5.41) |
| t | -0.01*** | 0.00 | t | -0.01*** | -0.01 |
| | (-4.18) | (-0.58) | | (-3.75) | (-1.47) |
| $Y_E$ | -0.03* | 0.13*** | $Y_E$ | -0.02 | 0.15*** |
| | (-1.80) | (6.15) | | (-1.25) | (7.36) |
| $Y_{NC}$ | 0.97*** | 0.83*** | $Y_{NC}$ | 0.96*** | 0.81*** |
| | (62.21) | (37.21) | | (61.37) | (36.75) |
| $W_K$ | 0.79*** | 0.72*** | $W_K$ | 0.80*** | 0.72*** |
| | (43.67) | (31.12) | | (48.71) | (31.49) |
| $Y_E Y_E$ | 0.09*** | -0.46*** | $Y_E Y_E$ | 0.09*** | -0.44*** |
| | (3.18) | (18.64) | | (2.94) | (-18.88) |
| $Y_{NC} Y_{NC}$ | 0.12*** | -0.58*** | $Y_{NC} Y_{NC}$ | 0.11*** | -0.56*** |
| | (3.30) | (19.88) | | (2.96) | (-20.11) |
| $W_K W_K$ | -0.20*** | -0.19*** | $W_K W_K$ | -0.20*** | -0.19*** |
| | (-11.83) | (-7.91) | | (-11.79) | (-8.12) |
| $Y_E Y_{NC}$ | -0.11*** | 0.51*** | $Y_E Y_{NC}$ | -0.11*** | 0.49*** |
| | (-3.65) | (22.05) | | (-3.32) | (22.53) |
| $Y_E W_K$ | -0.03 | -0.23*** | $Y_E W_K$ | -0.03 | -0.20*** |
| | (-1.15) | (-5.35) | | (-1.18) | (-4.88) |
| $Y_{NC} W_K$ | 0.06** | 0.27*** | $Y_{NC} W_K$ | 0.06** | 0.25*** |
| | (1.99) | (5.83) | | (1.99) | (5.42) |
| ND | -0.68*** | | ND | -0.68*** | |
| | (-27.90) | | | (-27.32) | |
| NDND | -0.26*** | | NDND | -0.22*** | |
| | (-4.46) | | | (-3.81) | |
| $Y_E$ND | -0.02 | | $Y_E$ND | 0.00 | |
| | (-0.65) | | | (-0.09) | |
| $Y_{NC}$ND | -0.03 | | $Y_{NC}$ND | -0.05 | |
| | (-0.91) | | | (-1.58) | |
| $W_K$ND | 0.06 | | $W_K$ND | 0.03 | |
| | (1.12) | | | (0.68) | |

# Results: Explaining Efficiency I

| Coefficient | Model 1 | Model 1a ( without ND) | Coefficient | Model 2 | Model 2a (without ND) |
|---|---|---|---|---|---|
| $\delta$ | | | $\delta$ | | |
| constant $\delta_0$ | -0.69*** | -0.51** | constant $\delta_0$ | -0.71*** | -0.19** |
| | (3.43) | (-2.42) | | (-3.91) | (-2.04) |
| t | 0.06*** | 0.08*** | t | 0.05*** | 0.06*** |
| | (3.34) | (4.74) | | (3.66) | (4.49) |
| More than once a buyer | -0.88 | -0.87 | | | |
| | (-1.09) | (-1.06) | | | |
| More than once a seller | -1.63** | -3.08* | | | |
| | (-2.02) | (-1.69) | | | |
| Buyer: 7 years before | 0.46 | 0.80*** | Buyer: before first merger | 0.00 | 0.08* |
| | (1.14) | (3.02) | | (-0.05) | (1.66) |
| Buyer: 6 years before | 0.32* | 0.23 | Buyer: before second merger | 0.52*** | -0.48* |
| | (1.74) | (1.35) | | (3.00) | (-1.82) |
| Buyer: 5 years before | 0.34** | 0.46*** | Buyer: since first merger | -0.51*** | -0.03 |
| | (2.21) | (3.31) | | (-5.13) | (-0.63) |
| Buyer: 4 years before | 0.32** | 0.31*** | Buyer: since second merger | 0.29 | -0.18 |
| | (2.43) | (2.57) | | (1.01) | (-0.87) |
| Buyer: 3 years before | -0.26 | -0.03 | | | |
| | (-1.06) | (-0.24) | | | |
| Buyer: 2 years before | -0.15 | -0.02 | | | |
| | (-0.98) | (-0.16) | | | |
| Buyer: 1 years before | -0.29 | -0.11 | | | |
| | (-1.28) | (-1.04) | | | |
| Buyer: 1 year after | -0.80*** | 0.03 | | | |
| | (-2.63) | (0.36) | | | |
| Buyer: 2 year after | -0.58 | -0.12 | | | |
| | (-1.53) | (-0.69) | | | |
| Buyer: 3 years after | -0.99* | -0.93** | | | |
| | (-1.70) | (-2.17) | | | |
| Buyer: 4 years after | -0.61 | -0.94** | | | |
| | (-0.79 | (-1.96) | | | |
| Buyer: 5 years after | 0.12 | 0.41 | | | |
| | (0.12) | (0.40) | | | |
| Buyer: 6 years after | 1.23 | 0.97 | | | |
| | (1.30) | (1.04) | | | |

# Results: Explaining Efficiency II

| Coefficient | Model 1 | Model 1a ( without ND) | Coefficient | Model 2 | Model 2a (without ND) |
|---|---|---|---|---|---|
| $\delta$ | | | $\delta$ | | |
| Seller: 7 years before | 0.51 | 0.13 | Seller: before first merger | 0.03 | 0.03 |
| | (1.15) | (0.19) | | (0.46) | (0.52) |
| Seller: 6 years before | -0.36 | -1.09 | Seller: before second merger | -1.43*** | -2.27*** |
| | (-0.53) | (-1.67) | | (-12.77) | (-2.42) |
| Seller: 5 years before | -1.09 | 0.00 | Seller: before second merger | 1.44*** | 1.20 |
| | (-1.38) | (0.02) | | (6.65) | (1.57) |
| Seller: 4 years before | -0.29 | -0.15 | Seller: since first merger | 0.29*** | 0.15*** |
| | (-0.68) | (-0.66) | | (4.57) | (3.04) |
| Seller: 3 years before | 0.08 | -0.12 | Seller: since second merger | -1.86*** | -2.05** |
| | (0.55) | (-0.88) | | (-3.00) | (-2.27) |
| Seller: 2 years before | -0.13 | -0.20 | Seller: since third merger | -0.07 | 0.73 |
| | (-0.70) | (-1.30) | | (-0.07) | (0.67) |
| Seller: 1 year before | 0.13 | 0.03 | | | |
| | (1.15) | (0.29) | | | |
| Seller: 1 year after | 0.09 | -0.01 | | | |
| | (0.67) | (-0.07) | | | |
| Seller: 2 year after | 0.27** | 0.21** | | | |
| | (2.43) | (2.07) | | | |
| Seller: 3 year after | 0.07 | 0.21 | | | |
| | (0.32) | (1.47) | | | |
| Seller: 4 year after | 0.35* | 0.24 | | | |
| | (1.91) | (1.52) | | | |
| $\sigma^2$ | 0.08*** | 0.13*** | $\sigma^2$ | 0.09*** | 0.09*** |
| | (5.45) | (5.02) | | (6.06) | (9.88) |
| $\gamma = \sigma^2_u/\sigma^2$ | 0.91*** | 0.88*** | $\gamma = \sigma^2_u/\sigma^2$ | 0.92*** | 0.88*** |
| | (46.15) | (36.64) | | (59.46) | (40.94) |
| Log Likelihood | 539.54 | 126.22 | Log Likelihood | 537.09 | 132.27 |

Significance on 10%-, 5%-, and 1%-level: *, **, ***; t-statistics in parentheses.

# Components of Efficiency

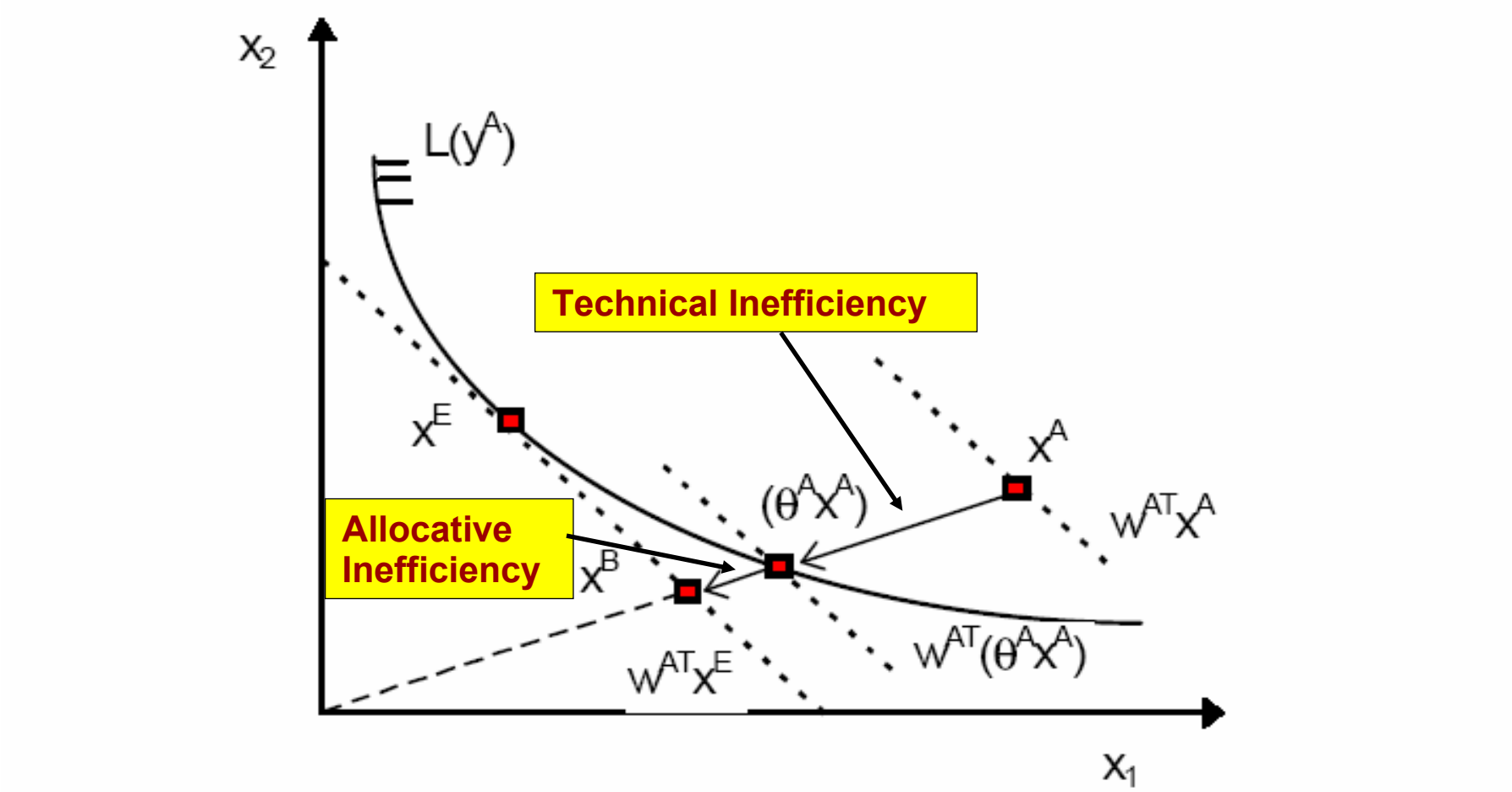



Figure 2.20 The Measurement and Decomposition of Cost Efficiency (N=2)

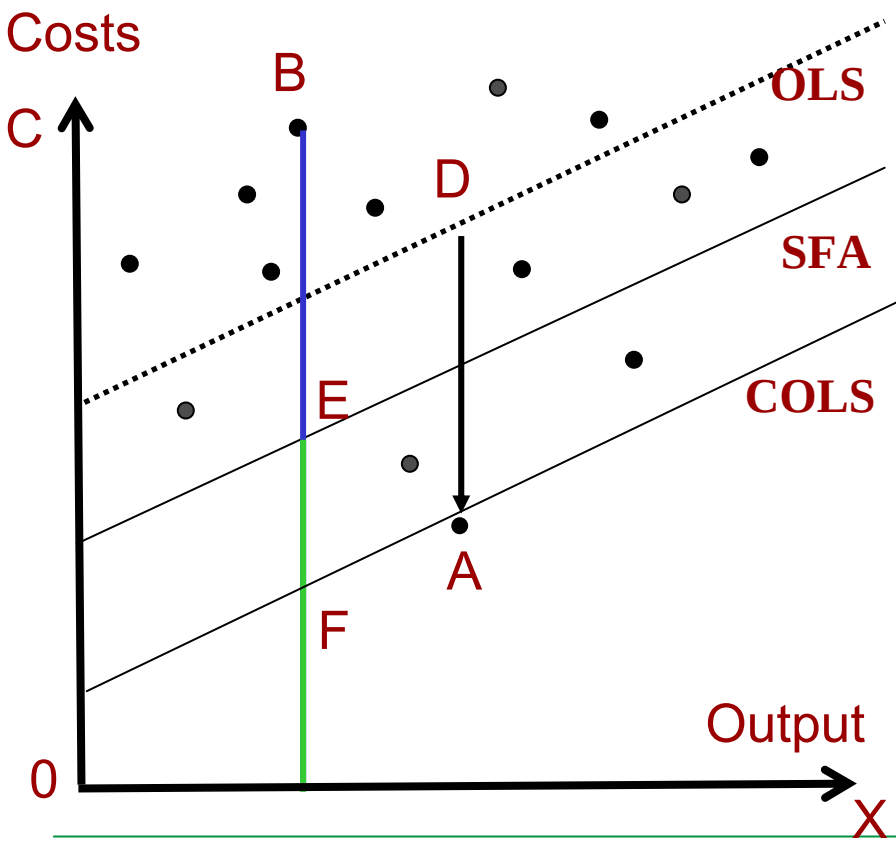
**Source: Stefanou (2006): Lecture notes, Wageningen Summer School**

# Parametric Methods

(Pollitt (2001), 6)

**Parametric: functional form** $\hat{C} = f(x_1, \ldots, x_n)$

**Easiest form linear:** $\hat{C} = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n$




OLS: $C_{OLS} = \beta x + \beta_{OLS} \pm v_i$

SFA: $C_{SFA} = \beta x + \beta_{SFA} \pm v_i + u_i$

COLS: $C_{COLS} = \beta x + (\beta_{OLS} - v^{max}) + u_i$

**C Costs**

**X Output, Input price**

**V stochastic error (White noise)**

**U Inefficiency**

**Efficiency of firm $B_{SFA}$ = EF/BF**