Technology Forecasting using Data Envelopment Analysis in Stata

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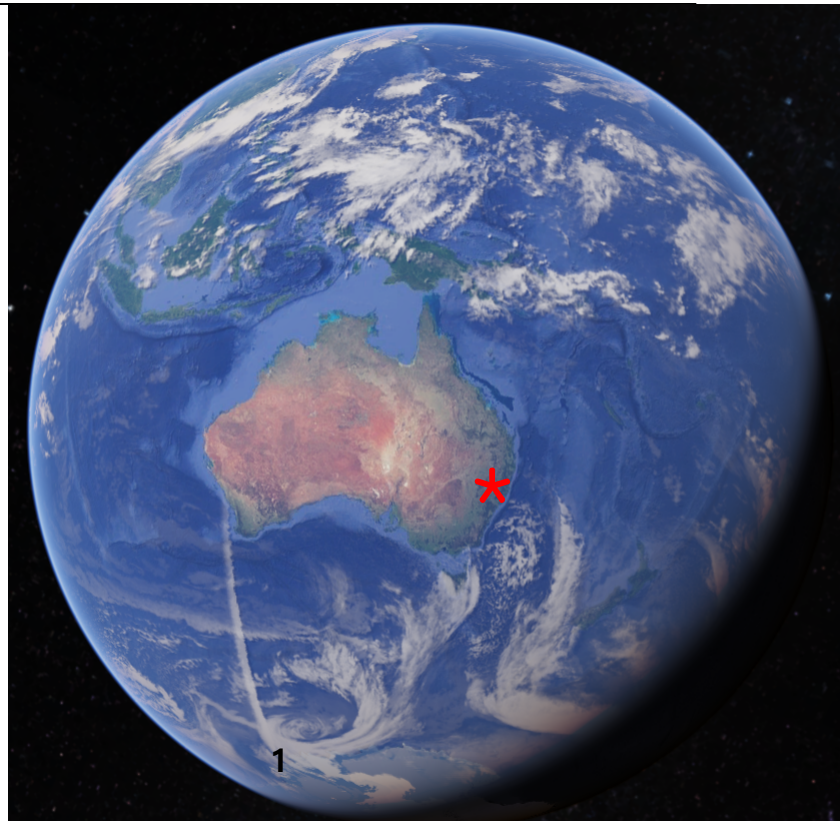

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I. Technology Forecasting using DEA

❑ Technology Forecasting

"A prediction of the future characteristics of useful machines, procedures, or techniques" (Martino, 1982, 1993; Inman, 2004)

"Prediction for Invention, Innovation or Technology Spread"(Schon, 1966)

"Probabilistic Assessment of Future Technology Transfer Processes"(Jantsch, 1967)

"Quantitative perspectives on the degree of change in technical characteristics, technical attributes, and timing associated with the use of design, production, machinery, materials and processes according to specific logic systems"(Bright, 1978)

I. Technology Forecasting using DEA

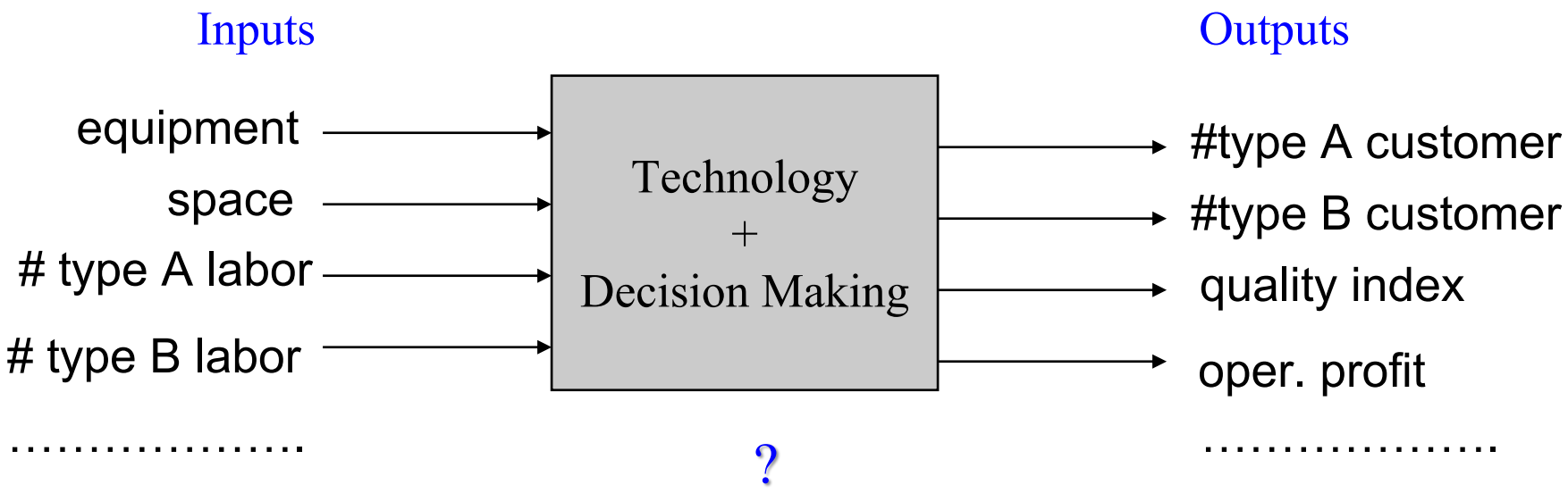
❑ Data Envelopment Analysis(DEA)

"This is a method for adjusting data to prescribed theoretical requirements such as optimal production surfaces, etc., prior to undertaking various statistical tests for purposes of public policy analysis."(Charnes A., 1978; Rhode, 1978).

I. Technology Forecasting using DEA

❑ DEA Efficiency

$$\text{Performance(Efficiency, Productivity)} = \frac{\text{Outputs}}{\text{Inputs}}$$



I. Technology Forecasting using DEA

❑ Assumption and Interpretation of DEA Efficiency Models

- Assumptions to analyze the black box
  - Economic Behaviors: No input, no output!
  - (Free) Disposability
  - Convexity
  - Frontier Search: Piece-wise Linear Method
  - Scale Economy
  - Orientation: Input-based or Output-based Analysis

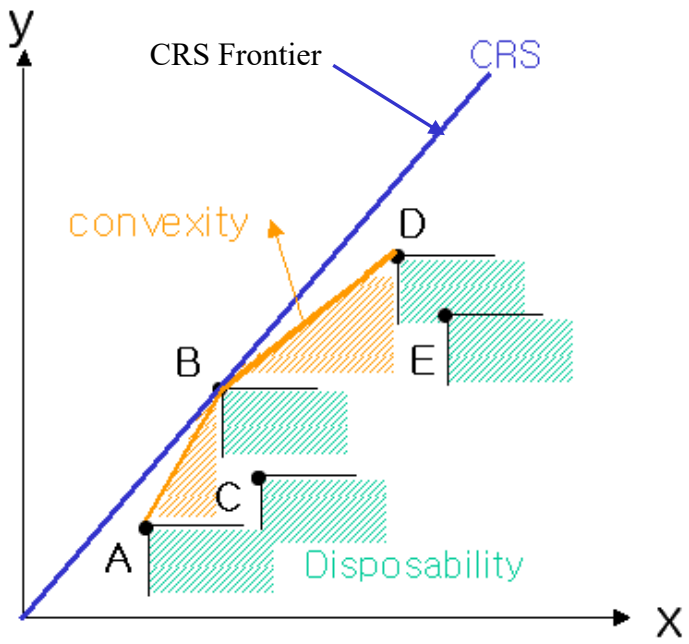
  …

- Interpretation of DEA Results
  - X-inefficiency
  - Rational Choice of Input-Output Mixes
  - Performance

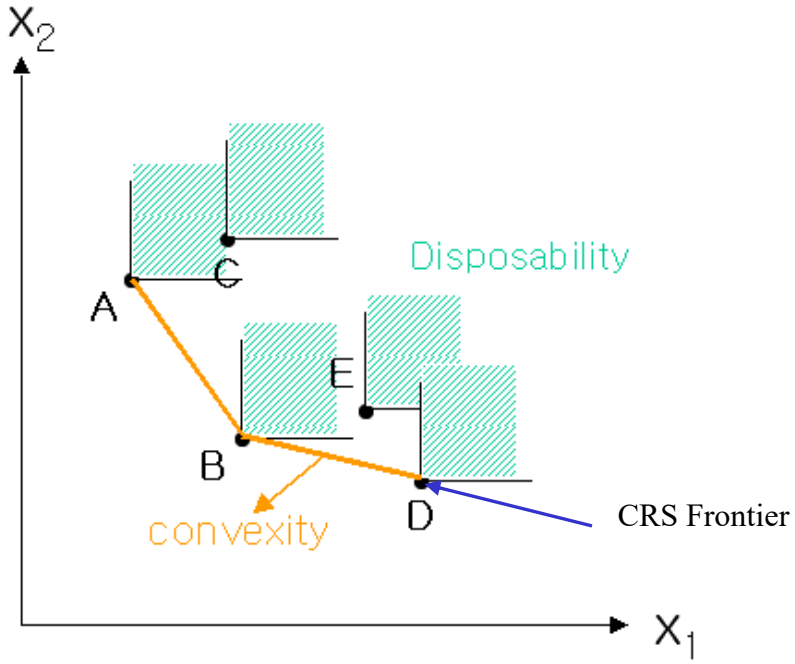
  …

I. Technology Forecasting using DEA

- DEA model development satisfying the assumptions of Disposability, Convexity, Scale Economy, and Frontier estimation.



(1) One input-one output



(2) Two inputs

I. Technology Forecasting using DEA

- DEA Production Possibility Set can be obtained from {Free Disposability, Convex, Constant Returns to Scale, piece-wise linear frontier}

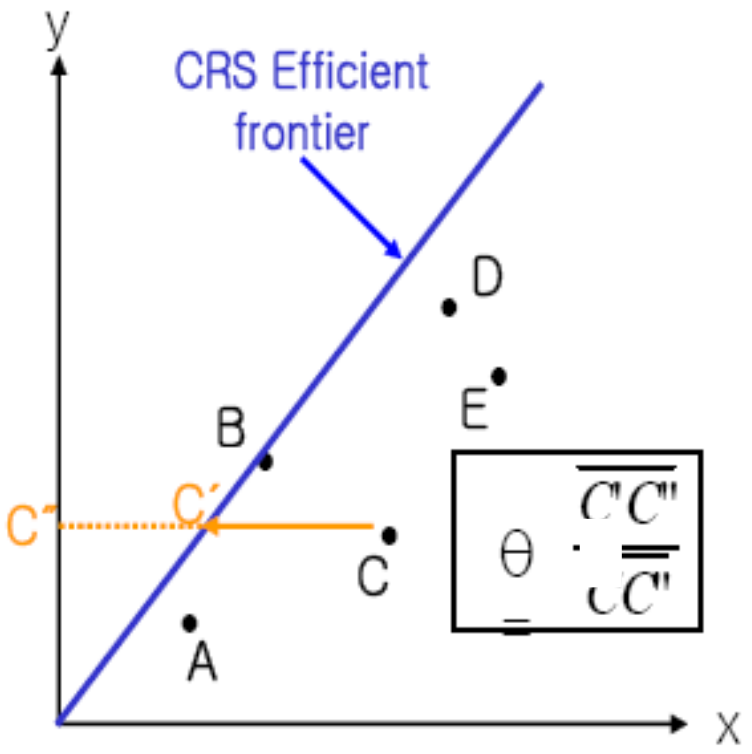
$$P(x,y \mid CRS) = \{(x,y) \mid y_m \le \sum_{j=1}^{J} z^j y_m \quad (m = 1,\ldots,M)$$

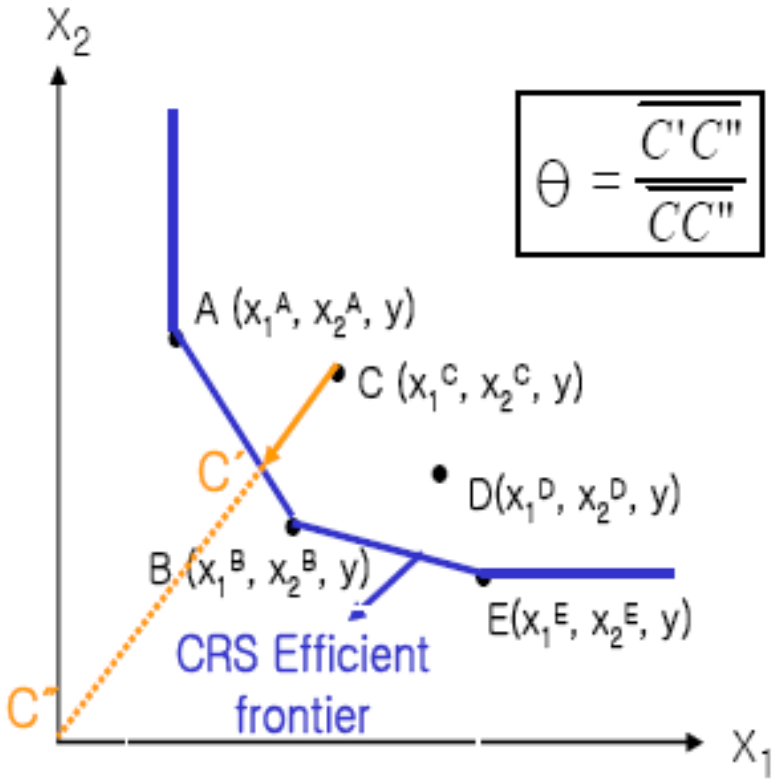
$$x_n \ge \sum_{j=1}^{J} z^j x_n^j \quad (n = 1,\ldots,N)$$

$$z^j \ge 0 \quad (j = 1,\ldots,J)\}$$

I. Technology Forecasting using DEA

- Define the Input-oriented-DEA Efficiency score as the Input ratio of observation to ideal input required to produce the same output.





I. Technology Forecasting using DEA

- Input-based CRS DEA

$$\theta^{*} = Min\ \theta_{k}$$

$$s.t.$$

$$y_{mk} \leq \sum_{j=1}^{J} z_{j} y_{mj} \quad (m = 1, \ldots, M)$$

$$\theta_{k} x_{nk} \geq \sum_{j=1}^{J} z_{j} x_{nj} \quad (n = 1, \ldots, N)$$

$$z_{j} \geq 0 \quad (j = 1, \ldots, J)$$

I. Technology Forecasting using DEA

- Input-based Variable-returns-to-scale(VRS) DEA

$$\theta^* = Min\ \theta_k$$

$$s.t.$$

$$y_{mk} \le \sum_{j=1}^{J} z_j y_{mj} \quad (m = 1,\ldots,M)$$

$$\theta_k x_{nk} \ge \sum_{j=1}^{J} z_j x_{nj} \quad (n = 1,\ldots,N)$$

$$\sum_{j=1}^{J} z_j = 1$$

$$z_j \ge 0 \quad (j = 1,\ldots,J)$$

I. Technology Forecasting using DEA

- Basic DEA Models: CCR, BCC

Orientation	Constant Return to Scale(CCR)	Variable Returns to Scale(BCC)
Input Oriented	$\text{Min } \theta$ $\text{s.t. } \theta xA - X\lambda \geq 0$ $Y\lambda - yA \geq 0$ $\lambda \geq 0$	$\text{Min } \theta$ $\text{s.t. } \theta xA - X\lambda \geq 0$ $Y\lambda - yA \geq 0$ $e\lambda = 1$ $\lambda \geq 0$
Output Oriented	$\text{Max } \eta$ $\text{s.t. } xA - X\mu \geq 0$ $\eta yA - y\mu \leq 0$ $\mu \geq 0$	$\text{Max } \eta$ $\text{s.t. } xA - X\mu \geq 0$ $\eta yA - y\mu \leq 0$ $e\lambda = 1$ $\mu \geq 0$

I. Technology Forecasting using DEA

❑ Characteristics of DEA

- No assumption about Input-Output Function
- No limits to the number of inputs and outputs
- Not required to weight restrictions
- Provide reference sets for benchmarking
- Provide useful information for input-output mix decision
- n times computations for n DMUs

I. Technology Forecasting using DEA

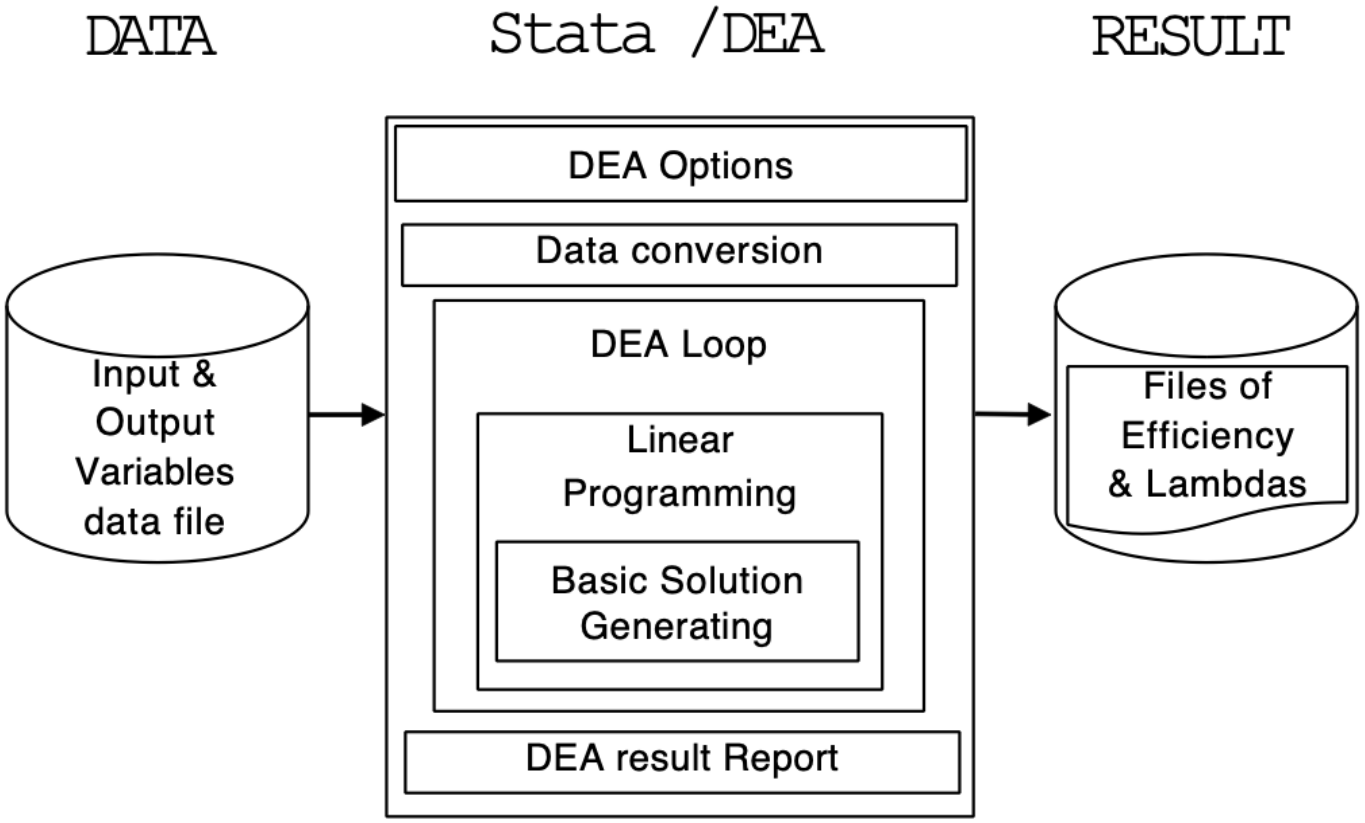
❑ User Written Stata/DEA Description

- Various DEA models (CCR, BCC, SBM, FDH, Super-efficiency, Additive, Malmquist Index, etc.)
- The data flow in the Stata/DEA program
  - the input and output variables data sets required
  - the DEA options define the model
  - the "Stata/DEA" program consists of "basic" and "lp" subroutine
  - the result data sets available for print or further analysis

- User written programs are available from https://sourceforge.net/p/deas/code/HEAD/tree/trunk/
- Also, we can calculate the efficiency score applying Stata 16 new Mata class "LinerProgram()".

I. Technology Forecasting using DEA

- Diagram of Data flow in Stata/DEA program



I. Technology Forecasting using DEA

❑ Technology Forecasting using Data Envelopment Analysis(TFDEA)

- Technology Forecasting Process
  - ✓ Step 1 : Measure Technology Rate-of-Change (ROC) using DEA efficiency score.
  - ✓ Step 2 : Predict the emergence time of new technology (product) by using measured technology ROC

* TFDEA model based on Anderson et al. (2001), Inman et al.(2006)

I. Technology Forecasting using DEA

- Step 1: Measure Technology Rate-of-Change (ROC) using DEA efficiency score
  - ✓ Obtain Production possibility set according to time of release(t_k)
  - ✓ Calculate the specified DEA model Efficiency Scores($\emptyset_i^{t_f}$)
  - ✓ Identify Decision Making Unit(DMU) that are initially identified as the efficient DMU(called State of Art, SOA) but obsolete over time
  - ✓ Measure the above said DMUs' technology rate of changes($\gamma_i^{t_f}$) and annual average technology rate of change($\bar{\gamma}$)

I. Technology Forecasting using DEA

❖ Algorithm of Technology Rate of Change measure

① The targets to be analyzed are selected from all observations (DMUs), and the production possibility set is formed by increasing the DMUs according to the release time from the initial release(t_k) to the prediction baseline(t_f).

② Calculate the efficiency score($\emptyset_i^{t_f}$) of the DMU using the specified DEA model using the constructed production possibility set.

③ Based on the efficiency calculated based on the current time(t_f), the effective time(t_{eff}) to be placed in the production frontier for each DMU is calculated using the following equation.

$$t_{eff} = \sum_{j=1}^{n} \lambda_j t_j \,/\, \sum_{j=1}^{n} \lambda_j \;\; \forall j = 1, \ldots, n;\; (0 \le \lambda_j \le 1)$$

❖ Algorithm of Technology Rate of Change measure

④ Among the DMUs, the DMU, which was efficient at the time of its first release($\emptyset_i^{t_k} \leq 1$) but was changed inefficient over time($\emptyset_i^{t_f} > 1$), is selected and the rate of change of technology($\gamma_i^{t_f}$) is calculated using the following equation.

$$\boldsymbol{\gamma_i^{t_f} = (\emptyset_i^{t_f})^{1/(t_{eff} - t_k)} \; \forall i = 1, \ldots, n}$$

⑤ The annual technology change rate is calculated by arithmetically calculating the technology change rate($\bar{\gamma}$) of each DMU.

I. Technology Forecasting using DEA

- Step 2: Predict the emergence time of new technology (product) by using measured technology ROC
  - ✓ Forecast of technology development trend based on current technology level
    - Measure the super-efficiency ($\emptyset_i^{SE,t_f}$) of the target DMU using DEA and the super-efficiency model
    - Prediction of technology emergence by applying effective time (t_{eff}) and average rate of change of technology($\bar{\gamma}$) to nonlinear growth function (exponential function)

I. Technology Forecasting using DEA

※ DEA Super-efficiency model

- Measure efficiency based on production changes obtained by constructing a set of production possibilities, excluding specific DMUs to be analyzed.
- If the DMU of interest is placed in a production frontier, the super-efficiency model score is measured to be greater than 1($\emptyset_i^{SE,t_f} > 1$).

I. Technology Forecasting using DEA

✓ Prediction of product emergence

- Product emergence time($t_{i,expected}$) is defined as the ratio of super-efficiency($\emptyset_i^{SE,t_f}$) and average technology change rate($\bar{\gamma}$) based on the effective time(t_{eff}).

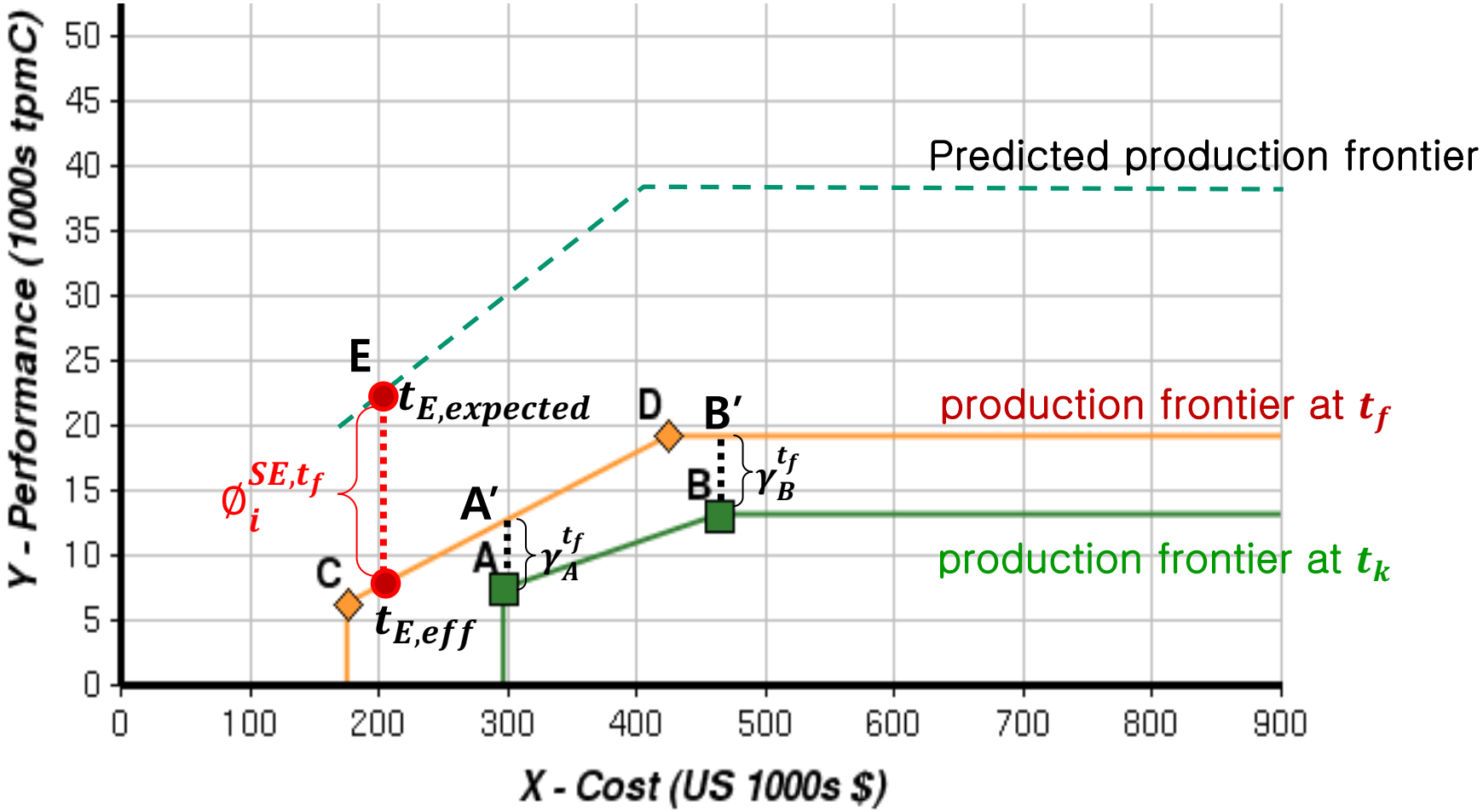
$$t_{i,expected} = t_{eff} + \ln\left(1/\emptyset_i^{SE,t_f}\right) / \ln(\bar{\gamma})$$

- Effective time means position at current production frontier
- The ratio of super-efficiency and rate of technological change refers to the time it takes for a production change to reach its technical level

※ super-efficiency : A measure of how far the product is from its current(t_f) production frontier as a function of production distance
※ average technology change rate : Measures the rate of increase of technology over the unit time based on product efficiency

I. Technology Forecasting using DEA

- Illustration of Product emergence time($t_{i,expected}$)



Source: Jung & Lee(2014)

I. Technology Forecasting using DEA

- Illustration of technology rate of change

No.	DMU	FFD()			
1	P-80/F-80A	1944	1.296	1977.84	1.007
2	FH-1	1945	1.315	1972.14	1.010
3	F-84B	1946	1.282	1987.00	1.009
4	FJ-1	1946	1.323	1964.28	1.007
5	F6U	1946	1.227	1973.05	1.011
6	F9F-2	1947	1.262	1969.76	1.006
7	F-86A	1947	1.233	1982.39	1.009
8	F2H-1	1947	1.227	1977.28	1.007
9	F-80B	1947	1.291	1987.00	1.007
10	F-84C	1947	1.306	1981.35	1.008
…	…	…	…	…	…
51	F/A-18A	1978	1.021	1987.00	1.009
52	F-15C	1979	1.006	1977.51	1.002
Average technology rate of change()					1.0052

<A country made Aircraft>

No.	DMU	FFD()			
1	Mig-9	1946	1.316	1977.00	1.007
2	Yak-15	1946	1.326	1986.80	1.009
3	MiG-9M	1947	1.270	1981.84	1.006
4	Mig-15	1947	1.239	1986.28	1.006
5	Yak-17	1947	1.394	1986.03	1.008
6	Yak-23	1947	1.231	1977.00	1.007
7	La-15	1948	1.268	1977.00	1.008
8	Mig-15bis	1949	1.205	1977.00	1.006
9	Mig-17	1950	1.203	1986.75	1.005
10	Mig-17P	1952	1.225	1975.00	1.006
…	…	…	…	…	…
34	Su-27S	1977	1.006	1987.65	1.001
35	Su-33	1987	1.012	1987.22	1.009
Average technology rate of change()					1.0049

<B country made Aircraft>

* FFD (First Flight Date)

Source: Jung & Lee(2014)

I. Technology Forecasting using DEA

- Illustration of TFDEA results

DMU	FFD()			Country
F-14D	1991	1.002	1984.55	A
F/A-18E	1995	1.000	1987.00	
F-22A	1997	0.900	1987.00	
F-35A	2007	0.900	1987.00	
T-50 PAK FA	2009	0.900	1988.00	B

✓ From the previous page, A country (1.0052) shows higher rate of technological change than B country (1.0049).

- But, notice that fighters with super-efficiencies less than 1 are more advanced.
- Accurate measurement limits if improvements exist that are not included in the selected parameters.

II. Data and Analysis in Stata

★Motivation to choose the data: replication and extension of data set used in Shagun Srivastava & Madhvendra Misra(2016).

II. Data and Analysis in Stata

Data Gathering

Step 1: Gather PHP links leading to each companies.

II. Data and Analysis in Stata

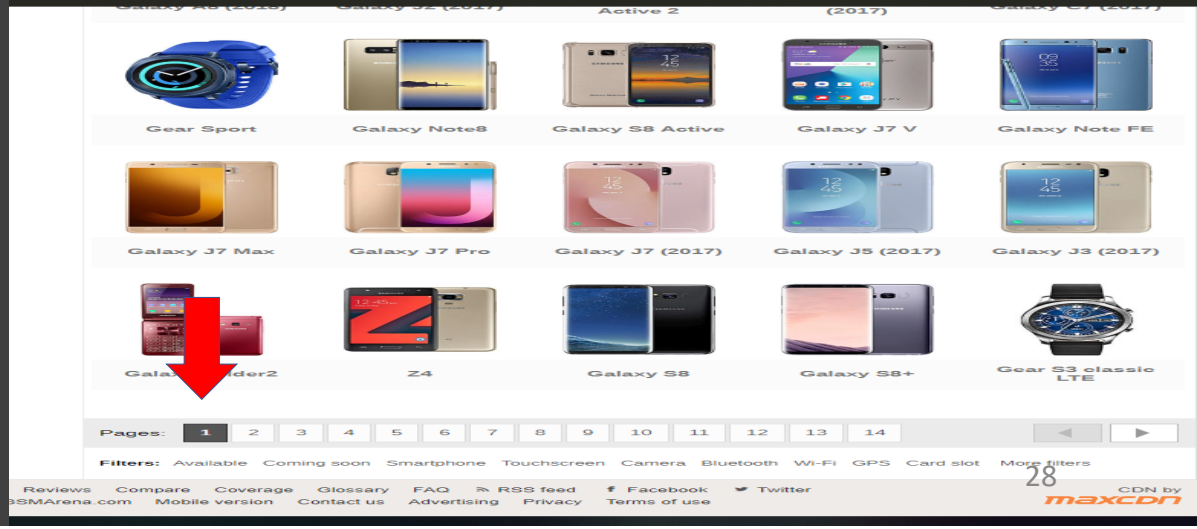
Data Gathering

Step 2: Obtain PHP links to iterate through all the pages regarding company's phones.

```
<div class="review-nav pullNeg col pushT10 ">

<div class="nav-pages">
<span>Pages:</span>
<strong>1</strong> <a href="samsung-phones-f-9-0-p2.php">2</a> <a href="samsung-phones-f-9-0-p3.php">3</a> <a href="samsung-phones-f-9-0-p4.php">4</a> <a href="
samsung-phones-f-9-0-p5.php">5</a> <a href="samsung-phones-f-9-0-p6.php">6</a> <a href="samsung-phones-f-9-0-p7.php">7</a> <a href="samsung-phones-f-9-0-p8.php">8</a> <
href="samsung-phones-f-9-0-p9.php">9</a> <a href="samsung-phones-f-9-0-p10.php">10</a> <a href="samsung-phones-f-9-0-p11.php">11</a> <a href="samsung-phones-f-9-0-p12.ph
12</a> <a href="samsung-phones-f-9-0-p13.php">13</a> <a href="samsung-phones-f-9-0-p14.php">14</a> </div>
<div class="col col-1-5 pages-next-prev float-right">
<a class="disabled pages-prev" href="#1" title="Previous page"></a> <a class="pages-next" href="samsung-phones-f-9-0-p2.php" title="Next page"></a>
</div>


</div>
```



II. Data and Analysis in Stata

Data Gathering

Step 3: Once accessed the page, then gather specs for each phone on the page.

```
<table cellspacing="0">
<tr class="tr-hover">
<th rowspan="15" scope="row">Network</th>
<td class="ttl"><a href="network-bands.php3">Technology</a></td>
<td class="nfo"><a href="#" class="link-network-detail collapse" data-spec="nettech">HSPA / LTE</a></td>
</tr>
<tr class="tr-toggle">
<td class="ttl"><a href="network-bands.php3">2G bands</a></td>
<td class="nfo" data-spec="net2g">N/A</td>
</tr><tr class="tr-toggle">
<td class="ttl"><a href="network-bands.php3">3G bands</a></td>
<td class="nfo" data-spec="net3g">HSDPA 900 / 2100 - Global</td>
</tr>
<tr class="tr-toggle" data-spec-optional>
<td class="ttl"> </td>
<td class="nfo">HSDPA 850 / 1900 - SM-T927A</td>
</tr>
<tr class="tr-toggle">
<td class="ttl"><a href="network-bands.php3">4G bands</a></td>
<td class="nfo" data-spec="net4g">LTE band 1(2100), 3(1800), 5(850), 7(2600), 8(900), 20(800) - Global</td>
</tr>
<tr class="tr-toggle" data-spec-optional>
<td class="ttl"> </td>
<td class="nfo">LTE band 2(1900), 4(1700/2100), 5(850), 12(700), 14(700), 29(700), 30(2300), 66(1700/2100) - SM-T927A</td>
</tr>
<tr class="tr-toggle">
<td class="ttl"><a href="glossary.php3?term=3g">Speed</a></td>
<td class="nfo" data-spec="speed">HSPA, LTE-A</td>
</tr>

<tr class="tr-toggle">
<td class="ttl"><a href="glossary.php3?term=gprs">GPRS</a></td>
<td class="nfo" data-spec="gprstext">Yes</td>
</tr>
<tr class="tr-toggle">
<td class="ttl"><a href="glossary.php3?term=edge">EDGE</a></td>
<td class="nfo" data-spec="edge">Yes</td>
</tr>
</table>
```

NETWORK	Technology	GSM / CDMA / HSPA / EVDO / LTE / 5G EXPAND ▾
LAUNCH	Announced	2019, August
	Status	Coming soon. Exp. release 2019, August 23
BODY	Dimensions	162.3 x 77.2 x 7.9 mm (6.39 x 3.04 x 0.31 in)
	Weight	198 g (6.98 oz)
	Build	Front/back glass (Gorilla Glass), aluminum frame
	SIM	Nano-SIM
		Samsung Pay (Visa, MasterCard certified)
		IP68 dust/water proof (up to 1.5m for 30 mins)
		Stylus (Bluetooth integration, accelerometer, gyro)
DISPLAY	Type	Dynamic AMOLED capacitive touchscreen, 16M colors
	Size	6.8 inches, 114.0 cm^2 (~91.0% screen-to-body ratio)
	Resolution	1440 x 3040 pixels, 19:9 ratio (~498 ppi density)
	Protection	Corning Gorilla Glass
		HDR10+
		Always-on display
PLATFORM	OS	Android 9.0 (Pie); One UI
	Chipset	Exynos 9825 (7 nm) - EMEA/LATAM
		Qualcomm SDM855 Snapdragon 855 (7 nm) - USA/China
	CPU	Octa-core (2x2.73 GHz Mongoose M4 & 2x2.4 GHz Cortex-A75 & 4x1.9 GHz Cortex-A55) - EMEA/LATAM
		Octa-core (1x2.84 GHz Kryo 485 & 3x2.42 GHz Kryo 485 & 4x1.78 GHz Kryo 485) - USA/China
	GPU	Mali-G76 MP12 - EMEA/LATAM
		Adreno 640 - USA/China
MEMORY	Card slot	microSD, up to 1 TB (dedicated slot)
	Internal	256/512GB, 12GB RAM
MAIN CAMERA	Quad	12 MP, f/1.5-2.4, 27mm (wide), 1/2.55", 1.4µm, Dual Pixel PDAF, Dual OIS
		12 MP, f/2.1, 52mm (telephoto), 1/3.6", 1.0µm, PDAF, Dual OIS, 2x optical zoom
		16 MP, f/2.2, 12mm (ultrawide), 1.0µm
		TOF 3D VGA camera
	Features	LED flash, auto-HDR, panorama
	Video	2160p@30/60fps, 1080p@30/60/240fps, 720p@960fps, HDR10+, dual-video rec., stereo sound rec., gyro-EIS & OIS
SELFIE CAMERA	Single	10 MP, f/2.2, 26mm (wide), 1.22µm, Dual Pixel PDAF
	Features	Dual video call, Auto-HDR
	Video	2160p@30fps
SOUND	Loudspeaker	Yes, with stereo speakers
	3.5mm jack	No
		32-bit/384kHz audio
		Active noise cancellation with dedicated mic
		Dolby Atmos/AKG sound

II. Data and Analysis in Stata

Step 1: Gather links leading to each companies.

```
from lxml import html,etree
import requests
import re
import pandas as pd
import numpy as np
import codecs
import urllib3
from functools import reduce
from socket import timeout
import logging
from urllib3.exceptions import MaxRetryError
import urllib
```

```
import os
```

```
#Target website
page = requests.get('https://www.gsmarena.com')
tree = html.fromstring(page.content)

#specify html div that contains all the links
link_to_all = tree.xpath("//div['brandmenu-v2 light l-box clearfix']")

link_html = tree.findall(".//div[@class='brandmenu-v2 light l-box clearfix']")

#retrieve the html
urllib.request.urlretrieve('https://www.gsmarena.com', "view-source.html")
with open("view-source.html", 'r', errors='ignore') as f:
    content = f.readlines()

#narrow it down to the links that contain phones
content = [x.strip() for x in content]
f = codecs.open("view-source.html", 'r', errors='replace')
for line in content[:]:
    prelink += re.findall('.*?\-.*?\-[0-9]{1,3}.php"',line)
links = []
for line in prelink[:]:
    links += re.findall('=.*?\-.*?\-[0-9]{1,3}.php"',line)
links = [x.strip('="') for x in links]
links = ["https://www.gsmarena.com/"+x for x in links]
links
```

II. Data and Analysis in Stata

Step 2: Obtain PHP links to iterate through all the pages

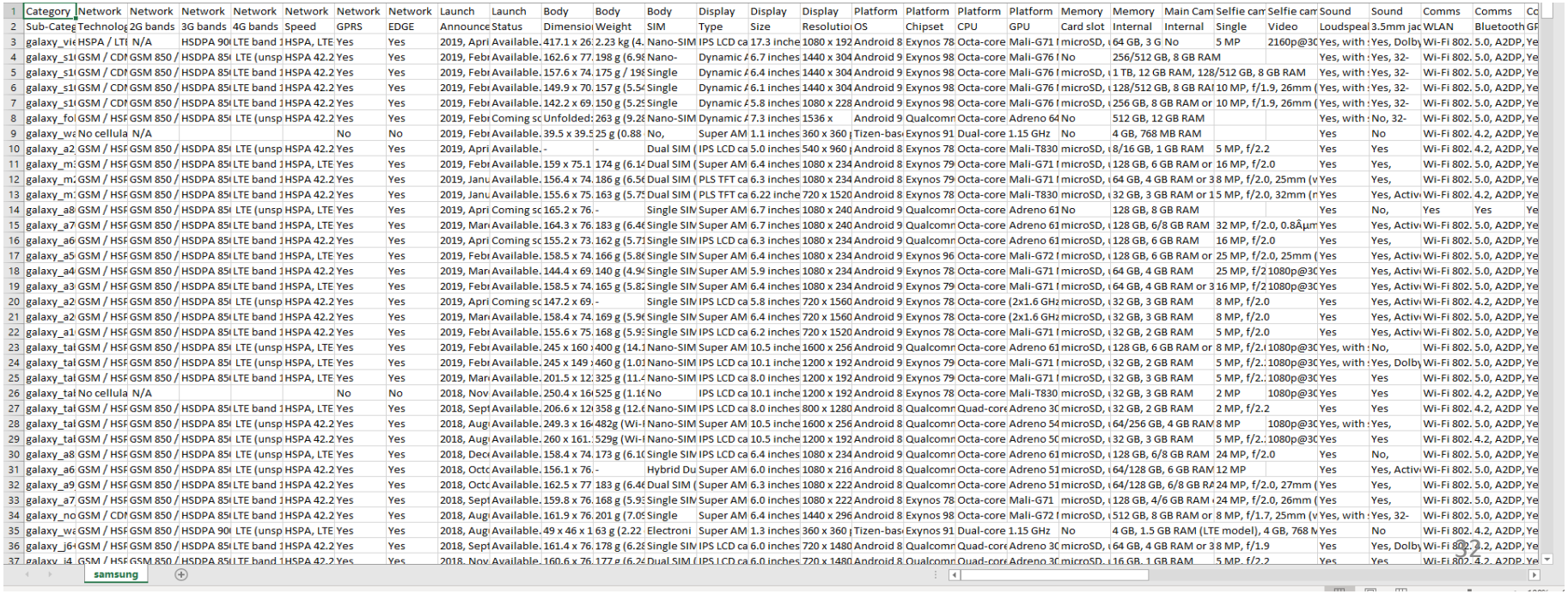
Step 2: Obtain PHP links to iterate through all the pages regarding company's phones.

- The pseudo code:

```
for each company in range(0,len(list_of_companies)):
    get the links for each page
    for each page in range(0,len(main_page_num)):
        get the phones from each page
        for each phone in range(0,length_phone_links):
            iterate through and retrieve the specs
            create a dataframe and concatenate each phones
```

II. Data and Analysis in Stata

Step 2's result



Category	Network	Network	Network	Network	Network	Network	Network	Launch	Launch	Body	Body	Body	Display	Display	Display	Platform	Platform	Platform	Platform	Memory	Memory	Main Cam	Selfie cam	Selfie cam	Sound	Sound	Comms	Comms	Co
Sub-Categ	Technolog	2G bands	3G bands	4G bands	Speed	GPRS	EDGE	Announce	Status	Dimensio	Weight	SIM	Type	Size	Resolutio	OS	Chipset	CPU	GPU	Card slot	Internal	Internal	Single	Video	Loudspeal	3.5mm jac	WLAN	Bluetooth	GF
galaxy_vi	HSPA / LT	N/A	HSDPA 90	LTE band 1	HSPA, LTE	Yes	Yes	2019, Apri	Available.	417.1 x 26	2.23 kg (4.	Nano-SIM	IPS LCD ca	17.3 inche	1080 x 192	Android 8	Exynos 78	Octa-core	Mali-G71 (	microSD, (	64 GB, 3 G	No	5 MP	2160p@3(	Yes, with :	Yes, Dolb	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_s1	GSM / CDI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA 42.2	Yes	Yes	2019, Febr	Available.	162.6 x 77.	198 g (6.9	Nano-	Dynamic A	6.7 inches	1440 x 304	Android 9	Exynos 98	Octa-core	Mali-G76 (	No	256/512 GB, 8 GB RAM				Yes, with :	Yes, 32-	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_s1	GSM / CDI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2019, Febr	Available.	157.6 x 74.	175 g / 198	Single	Dynamic A	6.4 inches	1440 x 304	Android 9	Exynos 98	Octa-core	Mali-G76 (	microSD, (	1 TB, 12 GB RAM, 128/512 GB, 8 GB RAM				Yes, with :	Yes, 32-	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_s1	GSM / CDI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2019, Febr	Available.	149.9 x 70.	157 g (5.5	Single	Dynamic A	6.1 inches	1440 x 304	Android 9	Exynos 98	Octa-core	Mali-G76 (	microSD, (	128/512 GB, 8 GB RAI		10 MP, f/1.9, 26mm (		Yes, with :	Yes, 32-	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_s1	GSM / CDI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2019, Febr	Available.	142.2 x 69.	150 g (5.2	Single	Dynamic A	5.8 inches	1080 x 228	Android 9	Exynos 98	Octa-core	Mali-G76 (	microSD, (	256 GB, 8 GB RAM or		10 MP, f/1.9, 26mm (		Yes, with :	Yes, 32-	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_fo	GSM / HSI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA 42.2	Yes	Yes	2019, Febr	Coming sc	Unfolded:	263 g (9.2	Nano-SIM	Dynamic A	7.3 inches	1536 x	Android 9	Qualcomn	Octa-core	Adreno 64	No	512 GB, 12 GB RAM				Yes, with :	No, 32-	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_w	No cellula	N/A				No	No	2019, Febr	Available.	39.5 x 39.5	25 g (0.88	No,	Super AM	1.1 inches	360 x 360	Tizen-bas	Exynos 91	Dual-core	1.15 GHz	No	4 GB, 768 MB RAM				Yes	No	Wi-Fi 802.	4.2, A2DP,	Ye
galaxy_a2	GSM / HSI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA 42.2	Yes	Yes	2019, Apri	Available.	-	-	Dual SIM (	IPS LCD ca	5.0 inches	540 x 960	Android 8	Exynos 78	Octa-core	Mali-T830	microSD, (	8/16 GB, 1 GB RAM		5 MP, f/2.2		Yes	Yes	Wi-Fi 802.	4.2, A2DP,	Ye
galaxy_m	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA, LTE	Yes	Yes	2019, Febr	Available.	159 x 75.1	174 g (6.1	Dual SIM (	Super AM	6.4 inches	1080 x 234	Android 8	Exynos 79	Octa-core	Mali-G71 (	microSD, (	128 GB, 6 GB RAM or		16 MP, f/2.0		Yes	Yes,	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_m	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2019, Janu	Available.	156.4 x 74.	186 g (6.5	Dual SIM (	PLS TFT ca	6.3 inches	1080 x 234	Android 8	Exynos 79	Octa-core	Mali-G71 (	microSD, (	64 GB, 4 GB RAM or 3		8 MP, f/2.0, 25mm (v		Yes	Yes,	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_m	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2019, Janu	Available.	155.6 x 75.	163 g (5.7	Dual SIM (	PLS TFT ca	6.22 inche	720 x 1520	Android 8	Exynos 78	Octa-core	Mali-T830	microSD, (	32 GB, 3 GB RAM or 1		5 MP, f/2.0, 32mm (n		Yes	Yes, Activ	Wi-Fi 802.	4.2, A2DP,	Ye
galaxy_a8	GSM / HSI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA, LTE	Yes	Yes	2019, Apri	Coming sc	165.2 x 76.	-	Single SIN	Super AM	6.7 inches	1080 x 240	Android 9	Qualcomn	Octa-core	Adreno 61	No	128 GB, 8 GB RAM				Yes	No,	Yes	Yes	Ye
galaxy_a7	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA, LTE	Yes	Yes	2019, Mar	Available.	164.3 x 76.	183 g (6.4	Single SIN	Super AM	6.7 inches	1080 x 240	Android 9	Qualcomn	Octa-core	Adreno 61	microSD, (	128 GB, 6/8 GB RAM		32 MP, f/2.0, 0.8µm		Yes	Yes, Activ	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_a6	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2019, Apri	Coming sc	155.2 x 73.	162 g (5.7	Single SIN	IPS LCD ca	6.3 inches	1080 x 234	Android 9	Qualcomn	Octa-core	Adreno 61	microSD, (	128 GB, 6 GB RAM		16 MP, f/2.0		Yes	Yes,	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_a5	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA, LTE	Yes	Yes	2019, Febr	Available.	158.5 x 74.	166 g (5.8	Single SIN	Super AM	6.4 inches	1080 x 234	Android 9	Exynos 96	Octa-core	Mali-G72 (	microSD, (	128 GB, 6 GB RAM or		25 MP, f/2.0, 25mm (		Yes	Yes, Activ	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_a4	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2019, Mar	Available.	144.4 x 69.	140 g (4.9	Single SIN	Super AM	5.9 inches	1080 x 234	Android 9	Exynos 78	Octa-core	Mali-G71 (	microSD, (	64 GB, 4 GB RAM		25 MP, f/2	1080p@3(	Yes	Yes, Activ	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_a3	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA, LTE	Yes	Yes	2019, Febr	Available.	158.5 x 74.	165 g (5.8	Single SIN	Super AM	6.4 inches	1080 x 234	Android 9	Exynos 79	Octa-core	Mali-G71 (	microSD, (	64 GB, 4 GB RAM or 3		16 MP, f/2	1080p@3(	Yes	Yes, Activ	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_a2	GSM / HSI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA 42.2	Yes	Yes	2019, Apri	Coming sc	147.2 x 69.	-	Single SIN	IPS LCD ca	5.8 inches	720 x 1560	Android 9	Exynos 78	Octa-core	(2x1.6 GHz	microSD, (	32 GB, 3 GB RAM		8 MP, f/2.0		Yes	Yes, Activ	Wi-Fi 802.	4.2, A2DP,	Ye
galaxy_a2	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2019, Mar	Available.	158.4 x 74.	169 g (5.9	Single SIN	Super AM	6.4 inches	720 x 1560	Android 9	Exynos 78	Octa-core	(2x1.6 GHz	microSD, (	32 GB, 3 GB RAM		8 MP, f/2.0		Yes	Yes, Activ	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_a1	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2019, Febr	Available.	155.6 x 75.	168 g (5.9	Single SIN	IPS LCD ca	6.2 inches	720 x 1520	Android 9	Exynos 78	Octa-core	Mali-G71 (	microSD, (	32 GB, 2 GB RAM		5 MP, f/2.0		Yes	Yes, Activ	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_tal	GSM / HSI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA, LTE	Yes	Yes	2019, Febr	Available.	245 x 160	400 g (14.1	Nano-SIM	Super AM	10.5 inche	1600 x 256	Android 9	Qualcomn	Octa-core	Adreno 61	microSD, (	128 GB, 6 GB RAM or		8 MP, f/2.(	1080p@3(	Yes, with :	No,	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_tal	GSM / HSI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA, LTE	Yes	Yes	2019, Febr	Available.	245 x 149	460 g (1.01	Nano-SIM	IPS LCD ca	10.1 inche	1200 x 192	Android 9	Exynos 79	Octa-core	Mali-G71 (	microSD, (	32 GB, 2 GB RAM		5 MP, f/2.	1080p@3(	Yes, with :	Yes, Dolb	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_tal	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA, LTE	Yes	Yes	2019, Mar	Available.	201.5 x 12	325 g (11.4	Nano-SIM	IPS LCD ca	8.0 inches	1200 x 192	Android 9	Exynos 79	Octa-core	Mali-G71 (	microSD, (	32 GB, 3 GB RAM		5 MP, f/2.	1080p@3(	Yes	Yes	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_tal	No cellula	N/A				No	No	2018, Nov	Available.	250.4 x 16	525 g (1.16	No	IPS LCD ca	10.1 inche	1200 x 192	Android 8	Exynos 78	Octa-core	Mali-T830	microSD, (	32 GB, 3 GB RAM		2 MP	1080p@3(	Yes	Yes	Wi-Fi 802.	4.2, A2DP,	Ye
galaxy_tal	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA, LTE	Yes	Yes	2018, Sept	Available.	206.6 x 12	358 g (12.6	Nano-SIM	IPS LCD ca	8.0 inches	800 x 1280	Android 8	Qualcomn	Quad-core	Adreno 30	microSD, (	32 GB, 2 GB RAM		2 MP, f/2.2		Yes	Yes	Wi-Fi 802.	4.2, A2DP	Ye
galaxy_tal	GSM / HSI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA 42.2	Yes	Yes	2018, Aug	Available.	249.3 x 16	482g (Wi-I	Nano-SIM	Super AM	10.5 inche	1600 x 256	Android 8	Qualcomn	Octa-core	Adreno 54	microSD, (	64/256 GB, 4 GB RAM		8 MP	1080p@3(	Yes, with :	Yes,	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_tal	GSM / HSI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA 42.2	Yes	Yes	2018, Aug	Available.	260 x 161.	529g (Wi-I	Nano-SIM	IPS LCD ca	10.5 inche	1200 x 192	Android 8	Qualcomn	Octa-core	Adreno 50	microSD, (	32 GB, 3 GB RAM		5 MP, f/2.	1080p@3(	Yes	Yes	Wi-Fi 802.	4.2, A2DP,	Ye
galaxy_a8	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA, LTE	Yes	Yes	2018, Dec	Available.	158.4 x 74.	173 g (6.1	Single SIN	Super AM	6.4 inches	1080 x 234	Android 9	Qualcomn	Octa-core	Adreno 61	microSD, (	128 GB, 6/8 GB RAM		24 MP, f/2.0		Yes	No,	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_a6	GSM / HSI	GSM 850 /	HSDPA 85	LTE (unsp	HSPA 42.2	Yes	Yes	2018, Octo	Available.	156.1 x 76.	-	Hybrid Du	Super AM	6.0 inches	1080 x 216	Android 8	Qualcomn	Octa-core	Adreno 51	microSD, (	64/128 GB, 6 GB RAM		12 MP		Yes	Yes, Activ	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_a9	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2018, Octo	Available.	162.5 x 77	183 g (6.4	Dual SIM (	Super AM	6.3 inches	1080 x 222	Android 8	Qualcomn	Octa-core	Adreno 51	microSD, (	64/128 GB, 6/8 GB RA		24 MP, f/2.0, 27mm (		Yes	Yes,	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_a7	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2018, Sept	Available.	159.8 x 76.	168 g (5.9	Single SIN	Super AM	6.0 inches	1080 x 222	Android 8	Exynos 78	Octa-core	Mali-G71	microSD, (	128 GB, 4/6 GB RAM		24 MP, f/2.0, 26mm (		Yes	Yes,	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_no	GSM / CDI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2018, Aug	Available.	161.9 x 76.	201 g (7.0	Single	Super AM	6.4 inches	1440 x 296	Android 9	Exynos 98	Octa-core	Mali-G72 (	microSD, (	512 GB, 8 GB RAM or		8 MP, f/1.7, 25mm (v		Yes, with :	Yes, 32-	Wi-Fi 802.	5.0, A2DP,	Ye
galaxy_w	GSM / HSI	GSM 850 /	HSDPA 90	LTE (unsp	HSPA, LTE	Yes	Yes	2018, Aug	Available.	49 x 46 x 1	63 g (2.22	Electroni	Super AM	1.3 inches	360 x 360	Tizen-bas	Exynos 91	Dual-core	1.15 GHz	No	4 GB, 1.5 GB RAM (LTE model), 4 GB, 768 M				Yes	No	Wi-Fi 802.	4.2, A2DP,	Ye
galaxy_j6	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2018, Sept	Available.	161.4 x 76.	178 g (6.2	Single SIN	IPS LCD ca	6.0 inches	720 x 1480	Android 8	Qualcomn	Quad-core	Adreno 30	microSD, (	64 GB, 4 GB RAM or 3		8 MP, f/1.9		Yes	Yes, Dolb	Wi-Fi 802.	4.2, A2DP,	Ye
galaxy_i4	GSM / HSI	GSM 850 /	HSDPA 85	LTE band 1	HSPA 42.2	Yes	Yes	2018, Nov	Available.	160.6 x 76.	177 g (6.2	Dual SIM (	IPS LCD ca	6.0 inches	720 x 1480	Android 8	Qualcomn	Quad-core	Adreno 30	microSD, (	16 GB, 1 GB RAM		5 MP, f/2.2		Yes	Yes	Wi-Fi 802.	4.2, A2DP,	Ye

samsung

Analysis of the problem

- Duplicate Columns/Rows
- NaN values
- STATA Incompatible
- Ugly to look at

The solution

- The data was recalculated accordingly,
  - Q - Quartile computed using a table of range 1990 (min) – 2019 (max)
  - OS - OS computed using a market share value per OS and evened them by making them a percentage based on their market share. Highest market shares being 100 percent.
  - CPU - Computed by adding up all the cores with their speeds
  - BC (Battery Capacity)- numeric as it is
  - SS (Size)- Dimension in mm not in inch. mm x mm x mm -> sum(mm+mm+mm)
  - R (Resolution)- x by x -> x times x
  - CC (Color Code)- 65k, 256 K, 262 K and 16 M -> 1, 2, 3, 4
  - PCP (Primary Camera Pixel)- Max of MP
  - SCP (Secondary Camera Pixel)- Max of MP
  - S (Sensors) – added functionalities
  - P (Price) – in $

Final result

cleaned_samsung

	Category	Q	OS	CPU	BC	SS	R	CC	PCP	S	C
0	galaxy_view2	118	8.1	12.8	12000	697.8	2073600	4	0	1	725.13408
1	galaxy_s10+	117	9	34.4	4100	239.5	4377600	4	16	11	1153.6224
2	galaxy_s10	117	9	34.4	3400	228.1	4377600	4	16	11	845.98976
3	galaxy_s10e	117	9	34.4	3100	220	2462400	4	16	11	747.10784
4	galaxy_fold	117	9	16.8	4380	285.7	3305472	4	16	8	1922.704
5	galaxy_watch_active	117	4	1.15	230	89.5	129600	4	0	9	274.672
6	galaxy_m30	117	8.1	13.2	5000	89.8	2527200	4	5	2	274.672
7	galaxy_m20	117	9.5	13.2	5000	239.7	2527200	4	5	5	241.71136
8	galaxy_m10	117	9.5	1.6	3400	238.9	1094400	4	5	5	109.8688
9	galaxy_a80	118	9	14.6	3700	251	2592000	4	8	2	714.1472
10	galaxy_a70	117	9	14.2	4500	248.9	2592000	4	8	6	439.4752
11	galaxy_a60	118	9	14.2	3500	237	2527200	4	8	6	296.64576
12	galaxy_a50	117	9	16	4000	240.9	2527200	4	8	4	384.5408
13	galaxy_a40	117	9	12.4	3100	221.5	2527200	4	5	6	274.672
14	galaxy_a30	117	9	13.2	4000	240.9	2527200	4	5	6	274.672
15	galaxy_a20	117	9	11	4000	240.9	1123200	4	5	4	219.7376
16	galaxy_a10	117	9	11	3400	239.1	1094400	4	13	5	131.84256
17	galaxy_tab_s5e	117	9	14.2	7040	21.4	4096000	4	13	2	461.44896
18	galaxy_tab_a_10_1_(2019)	117	9	13.2	6150	22.9	2304000	4	8	5	241.71136
19	galaxy_tab_advanced2	116	8	10.4	7300	425.1	2304000	4	8	2	219.7376
20	galaxy_tab_a_8_0_(2018)	115	8.1	1.4	5000	342.2	1024000	4	5	2	219.7376
21	galaxy_tab_s4_10_5	115	9	16.8	7300	420.7	4096000	4	13	2	637.23904
22	galaxy_tab_a_10_5	115	8.1	1.8	7300	177.6	2304000	4	8	7	307.63264
23	galaxy_a6s	116	8	16	3300	240.9	2332800	4	2	6	296.64576
24	galaxy_a9_(2018)	116	9	16	3800	176.7	2397600	4	8	5	395.52768
25	galaxy_a7_(2018)	115	9	14	3300	244.1	2397600	4	8	6	307.63264
26	galaxy_note9	115	9	36	4000	247.1	4262400	4	12	6	824.016
27	galaxy_watch	115	4	1.15	472	4.2	129600	4	0	12	318.61952
28	galaxy_j6+	115	8.1	1.4	3300	246.2	1065600	4	5	5	263.68512
29	galaxy_j4_core	116	8.1	1.4	3300	244.6	1065600	4	8	6	164.8032

* Note: Q (Quarter), OS (Operating System), CPUS (CPU Speed in MHz), BC (Battery Capacity in mAh), SS (Screen Size in inches), R (Screen Resolution), CC (Colour Code), OF (Other Features), PCP (Primary Camera Performance), S (Sensors), SCP (Secondary Camera Performance (Shagun Srivastava & Madhvendra Misra, 2016).

II. Data and Analysis in Stata

❑ Analysis

❍ TFDEA Syntax

tfdea *inputvars* = *outputvars* , rts(*string*) ort(*string*) tf(*string*)

[option]

rts(*string*) is a returns to scale of DEA models. There are two types of returns to scale, rts(crs) and rts(vrs), which means constant returns to scale (CRS) and variable returns to scale (VRS), respectively. The default is rts(vrs).

ort(*string*) is an orientation of DEA models. There are two types of orientation, ort(in) means input-oriented analysis and ort(out) means output-oriented analysis. The default is ort(out).

tf(*string*) is a reference date for measuring technological rate of change (ROC) and forecasting. If you have a dataset between year 1960 to year 2000 and want to measure ROC until 1990 and forecast afterward, tf(*string*) is tf(1990). The default is the last date in the dataset.

II. Data and Analysis in Stata

❑ Analysis

❍ TFDEA results

·tfdea cost=OS CPU BC SS R CC PCP S C, rts(vrs) ort(out) tf(90)

dmu	tk	theta_tk	theta_tf	tk_ineff	tk_eff	ROC
m886_mercury	85	1	1	.	96.3333	.
optimus_~660	85	1	1.01647	85	96.4099	1.00132
i405_strat~e	85	1	1	.	.	.
galaxy_~7510	85	1	1	.	90.6196	.
galaxy_~5830	85	1	1	.	99.5	.
galaxy_~9210	85	1	1	.	95.6923	.
evo_4g+	85	1	1	.	98.8624	.
p6210_gala~s	85	1	1	.	95.49	.
us760_gene~s	85	1	1	.	99.625	.
atrix_4g	85	.	1	.	96.3077	.
triumph	86	1	1	.	95.0769	.
u8350_boul~r	86	1.24137	2	.	99.1795	.
status	86	1	1.30902	86	95.9169	1.02497

Annual Rate of Change (AROC) is 1.0210902 for the chosen data

II. Data and Analysis in Stata

❑ Analysis

❍ TFDEA results

dmu	tk	theta_tk	theta_tf	tk_ineff	tk_eff	ROC
impulse_4g	86	1	1	.	.	.
panache	86	1	1	.	95.7982	.
u8850_vision	86	1	1.85519	86	96.686	1.05431
c5_5mp	86	1	1	.	99.75	.
galaxy_~5512	86	1	1.07783	86	91.3741	1.01183
esteem_ms910	87	1	1	.	98.7692	.
jil_sander~e	87	1	1	.	97.9617	.
exhibit_~679	87	1	1	.	96.5749	.
u8520_duplex	87	1	1.07059	87	92.1471	1.01116
fire_xt	87	1	1.38179	87	90.3583	1.07702
torch_9860	87	1	1	.	100	.
600	87	1	1	.	93.3028	.
optimus_~730	87	1.12456	1.56613	.	94.1073	.
i927_capti~e	87	1	1	.	.	.
galaxy_~7000	87	1	1	.	97.1239	.
ascend_d_q~d	87	1	1	.	95.6341	.

II. Data and Analysis in Stata

❑ Analysis

❍ TFDEA results

dmu	tk	theta_tk	theta_tf	tk_ineff	tk_eff	ROC
mediapa~301w	87	1	1.28881	87	93.5689	1.03409
optimus_sl~r	87	1.34477	2.52369	.	92.5319	.
explorer	87	1	1.00061	87	91.0333	1.00012
optimus_black_(w	87	1	1	.	99.3846	.
galaxy_~5510	87	1	1.08708	87	96.9595	1.00765
701	87	1	1	.	98.7692	.
hero_s	87	1	1	.	.	.
p6810_gala~7	87	1	1	.	98.6909	.
ascend_ii	87	1.72156	2	.	97.8561	.
fire_xt311	87	1	1.12276	87	98.2924	1.00946
optimus_~640	87	1	1	.	99.875	.
galaxy_t~957	87	1	1	.	95.5197	.
titan	87	1	1	.	98.5626	.
ascend_p1s	87	1	1	.	96.7802	.
optimus_~935	87	1	1	.	94.6606	.
i9100g_gal~i	87	1	1	.	.	.
m930_trans~a	87	1	1.096	87	98.48	1.00737
omnia_w~8350	87	1	1	.	98.8683	.

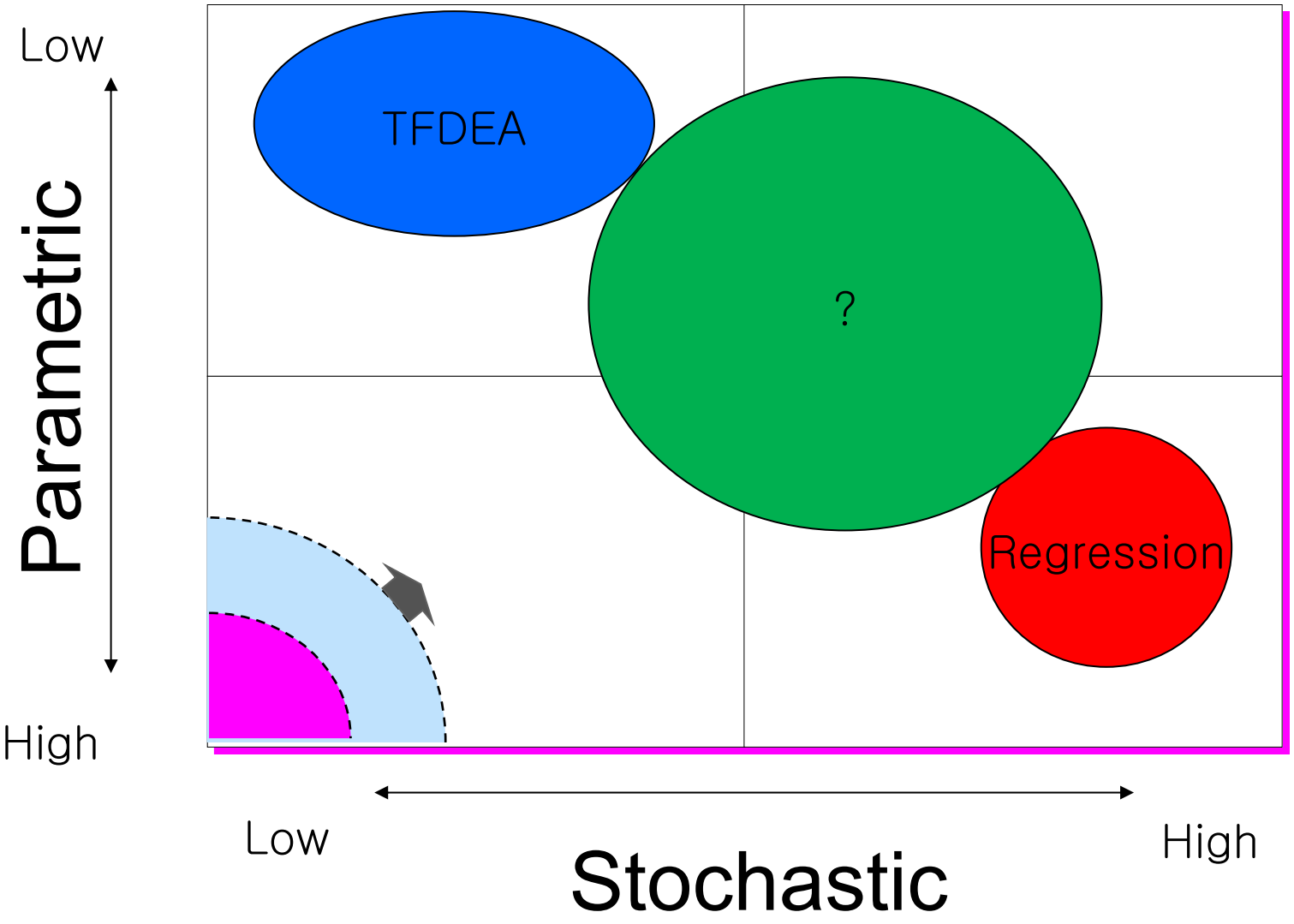
II. Data and Analysis in Stata

❍ TFDEA results

dmu	tk	SE_tf	tf_eff	tf_exp
m886_mercury	85	1	96.3333	95
optimus_~660	85	1.01647	96.4099	97
galaxy_~7510	85	1	90.6196	91
galaxy_~5830	85	1	99.5	99
galaxy_~9210	85	1	95.6923	94
evo_4g+	85	1	98.8624	97
p6210_gala~s	85	1	95.49	94
us760_gene~s	85	1	99.625	98

III. Remarks

❑ Dimension of TFDEA



III. Remarks

- Challenges of TFDEA
  - ✓ Some cases that are hard to solve exist when we specify variable returns to scale. For example, product with disruptive technology may cause multiple optima or NP-hard problem for super-efficiency calculation with VRS option.
  - ✓ How to interpret the results(inference).


Q&A

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Thank You !