Early Career Researcher Section

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Scope economies in Australian distance education: Bayesian stochastic frontier analysis

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Outline of this presentation

- Motivation
- Methodology and data
  - Four stages to estimate economies of scale and scope
  - Two models to estimate the parameters
- Results
  - Use one of the two models to calculate the scale and scope economies.
- Further studies

Motivation

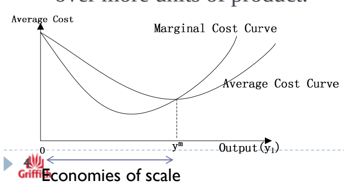
- Australian universities: Toward to a larger and more comprehensive institutions
  - 1965-1987: Binary system
    - A College of Advanced Education sector: teaching-oriented
    - A university sector: research-oriented
  - 1988-now: A unified national system
    - Dawkins Reform of 1988
      - Institutions lower than 2000 FTE students are forced to merger with other institutions.
    - The number of universities is slashed down from 70 to 41.
  - The scale of student number has been increased and the scope of provided service has also been expanded in each university
- Beliefs behind these mergers:
  - Economies (cost savings) could be gained from larger scale and scope!
  - However, is there any theory to support them?

Motivation
Economies of scale vs. economies of scope

Economies of scale

been extensively applied to many resource-using industry

- How many **quantities** of output should I produce?
- **Average cost** is lower at large firms than the cost at small firms
  - the fixed costs are spread over more units of product.

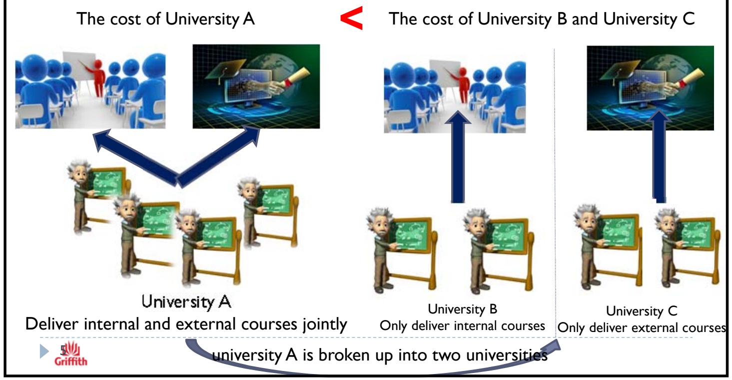


Economies of scope

- How many **types** of output should I produce?
- **Total cost** of producing different types of products jointly is less than the cost of producing them separately.
  - Result from the sharing utility of inputs

Motivation
Economies of scope

- The cost of producing different types of products jointly is less than the cost of producing them separately



Motivation
Major Gaps in Literature

- 29 studies (from 1989 to 2013) have applied analyses to higher education in nine areas (Australia, China, German, Japan, Italy, Spain, Taiwan, UK, and US).
- Major Gaps
  - Out-of-date data
    - Most studies still use the dataset before 2006.
    - In Australia, the demand driven funding system has remove the limitation of enrolment in 2012 (partial uncapping starts in 2008)
      - Make estimating scale and scope economies more meaningful, because universities have more freedom to modify their own scales and scopes.
  - The discussion of output is not complete
    - Another possible form of instruction output, distance education, is obviously ignored by previous studies.

Methodology

Stage One.
Constructing the cost structure in higher education

Stage Two.
Specifying a functional form

Stage Three.
Building an appropriate model

Stage Four.
Analysing the degree of scale and scope economies

Methodology

Stage 1. Constructing the cost structure in higher education

- Whole 37 Australian public universities over the years 2010-2012.
- 7 Outputs (y_i)
  - The number of degrees conferred
  - Internal completions (y_1 ,y_2 ,y_3)
  - External completions(y_4 ,y_5 ,y_6)
  - Research grants (y_7)
- 3 Prices(w_p)
  - Labour (staff) (w_1,w_2)
  - Physical capital (w_3)

Stage 2. Specifying a functional form

- Associate the cost with outputs and other variables constructed in stage one
- Quadratic cost function (QCF)
  - Permit an output to have zero value without further transformation like other two cost functional forms.
    - Constant elasticity of substitution (CES)
    - Hybrid translog (TL) function

Methodology
Stage 3. Building an appropriate model

$$C'_{ht} = C(\boldsymbol{y},\boldsymbol{w}) + \varepsilon_{ht}$$

Impose Linear homogeneity in prices
(w_3) as a numeraire price and will be omitted

$$= \left\{\alpha + \sum_{i=1}^{7} \beta_i y_{iht} + 0.5 \sum_{i=1}^{7} \beta_{ii} (y_{iht})^2 + \sum_{i,j=1;\, i\neq j}^{21} \beta_{ij} y_{iht} y_{jht} + \sum_{p=1}^{3-1} \beta_p w'_{pht}\right\} + \varepsilon_{ht}$$

Total cost and other factor prices are divided by numeraire price .

- Goal: estimate $C(\boldsymbol{y},\boldsymbol{w})$ (i.e. their parameters α and β)
  - Q1 Inefficient production
    - Stochastic frontier model (SF model)
      - $\varepsilon_{ht} = v_{ht} + u_{ht}$; $v_{ht} \sim Normal$; $u_{ht} \sim Exponential$
      - u_{ht} is one-sided error and accounts for the cost inefficiency
  - Q2 Heterogeneity across universities
    - Random stochastic frontier model- still based on SF model
      - Allow slope coefficients to vary with universities

Methodology Stage 3.
Account for heterogeneity across universities

$$C'_{ht} = \alpha + \sum_{i=1}^{7} \beta_i y_{iht} + 0.5 \sum_{i=1}^{7} \beta_{ii} (y_{iht})^2 + \sum_{i,j=1;\, i\neq j}^{21} \beta_{ij} y_{iht} y_{jht} + \sum_{p=1}^{3-1} \beta_p w'_{pht} + \varepsilon_{ht}$$

$$\beta_{k,k=\{i,ii,ij,p\}} \sim N(\overline{\overline{\beta_k}}, \Omega)$$

modify basic SFA model by allowing parameters to vary

Fixed **stochastic frontier model**

- $\Omega = 0$
- Each institution shares the same cost function
  - Institutions share homogenous characteristics.
- Maximum Likelihood Estimation (MLE)
  - Unknown parameters are assume to be **fixed**
- Most past studies use this model.

Random **stochastic frontier model**

- $\Omega \neq 0$
- Each institution has its own cost function
  - Account for heterogeneity across universities
- Bayesian estimation
  - Unknown parameters are assume to be **random**
- ***No*** study applies this model to universities.

Methodology
Stage 4. Analysing the degree of scale and scope economies

- Economies (diseconomies) of scale would exist when estimate is larger (less) than ***one***.
- Estimates of economies of scale
  - Ray scale economies
    - $S(RAY) = \frac{C(y_1,y_2,y_3,y_4,y_5,y_6,y_7)}{y_1*\frac{\partial C}{\partial y_1}+y_2*\frac{\partial C}{\partial y_2}+y_3*\frac{\partial C}{\partial y_3}+y_4*\frac{\partial C}{\partial y_4}+y_5*\frac{\partial C}{\partial y_5}+y_6*\frac{\partial C}{\partial y_6}+y_7*\frac{\partial C}{\partial y_7}}$
    - The effect of a proportional increase of ***all*** types of output scale along a ray in output space while holding the composition of each firm's outputs constant
  - Product-specific scale economies ($\mathbf{S(y_i)}$)
    - $S(y_i) = \frac{C(y_1,y_2,y_3,y_4,y_5,y_6,y_7)-C(y_{-i})}{y_i*\frac{\partial C}{\partial y_i}}, i = 1 \ldots 7$
    - Allow only ***one*** type of output scale to vary at a time while holding all other types of outputs constant.

Methodology
Stage 4. Analysing the degree of scale and scope economies

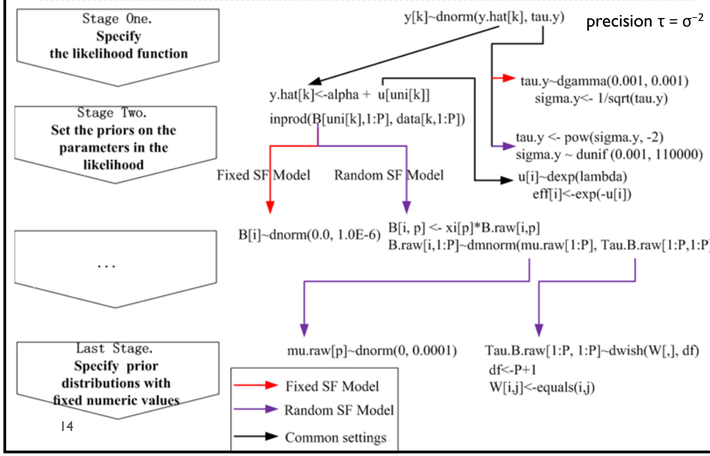
- Economies (diseconomies) of scope would exist when estimate is larger (less) than ***zero***.
- Estimates of scope economies
  - Global scope economies (GSE)
    - $GSE = \frac{\sum_{i=1}^{7} C(y_i)-C(y_1,y_2,y_3,y_4,y_5,y_6,y_7)}{C(y_1,y_2,y_3,y_4,y_5,y_6,y_7)}$
    - The percentage increase in costs from separate production
  - Product-specific scope economies (PSE)
    - $PSE(y_i) = \frac{C(y_i)+C(y_{n-i})-C(y_1,y_2,y_3,y_4,y_5,y_6,y_7)}{C(y_1,y_2,y_3,y_4,y_5,y_6,y_7)}, i = 1 \ldots 7$
    - Cost savings arise from joint production of ***a particular type*** (***i***)of output with other types of outputs.

Results

- Bayesian stochastic frontier model
  - Fixed stochastic frontier model
  - Random stochastic frontier model
- Software, BUGS (WinBUGS or OpenBUGS) will be used to obtain the estimates.
- Contents
  - DIC and pD will be used to to decide a better model.
  - Estimates of the scale and scope economies for the **Australian university sector**
    - Constructed at different ***percentage*** mean output with estimated parameters
    - All prices are set to their respective means in all of the calculations.
    - R codes have been developed.

Building **Bayesian** Fixed and Random Stochastic Frontier (SF) Model with BUGS

Classification Based on Koop, G. (2003). *Bayesian Econometrics*. England: Wiley-Interscience.



Results
Model selection

zstimated from the software, BUGS, running with a burn-in of 20,000 iterations, with 200,000 retained draws

Model 1:	Fixed Parameter Frontier Model	
Model 2:	Random Parameter Frontier Model	
Model	DIC	pD
1	2236.00	44.75
2	-71680.00	-74400.00

- The lower DIC value implies a better model fit.
- But…Negative pD in Bayesian random SF model further shows the potential conflicts between the prior and data

Limitation: It could not be completely comparable because

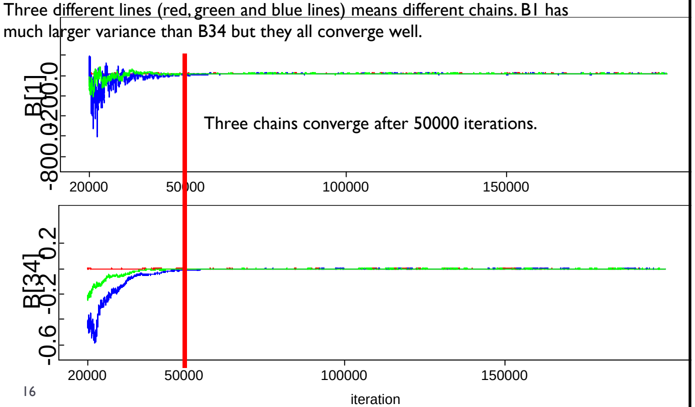
- Both models use different prior distribution for standard deviation of data y
  - Model 1: Gamma(can't use uniform because BUGS will give very weird efficiency scores (most of them are zero)
  - Model 2: Uniform (can't use gamma because BUGS will show "undefined real result")

Decision: Estimates from Bayesian fixed SF model could be more appropriate.

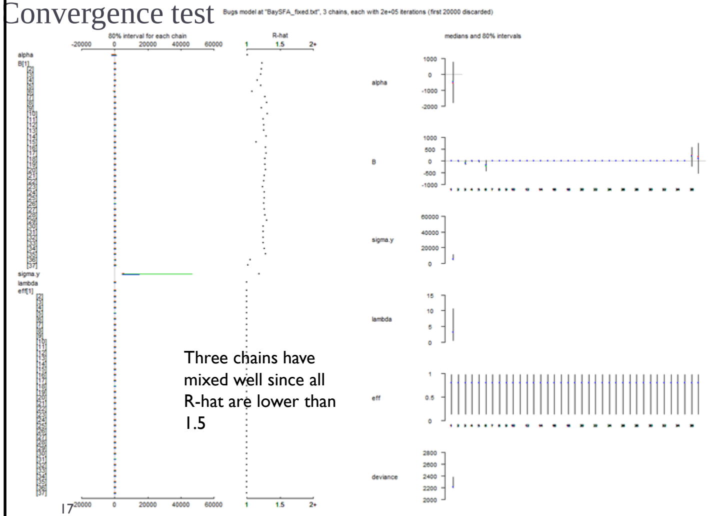
Convergence test (Bayesian fixed SF model)
Three chains with three types of initial values

Run 3 chains using different initial values to assess convergence.

Three different lines (red, green and blue lines) means different chains. B1 has much larger variance than B34 but they all converge well.



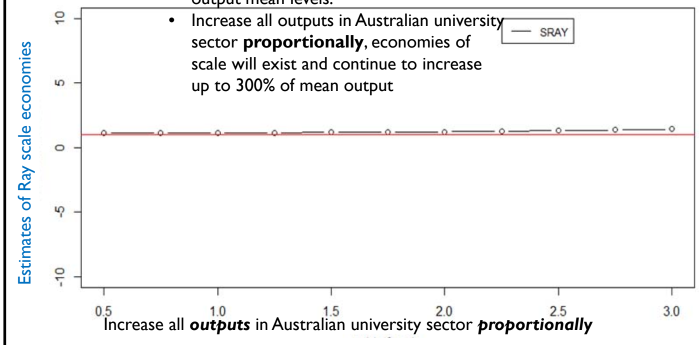
Convergence test



Three chains have mixed well since all R-hat are lower than 1.5

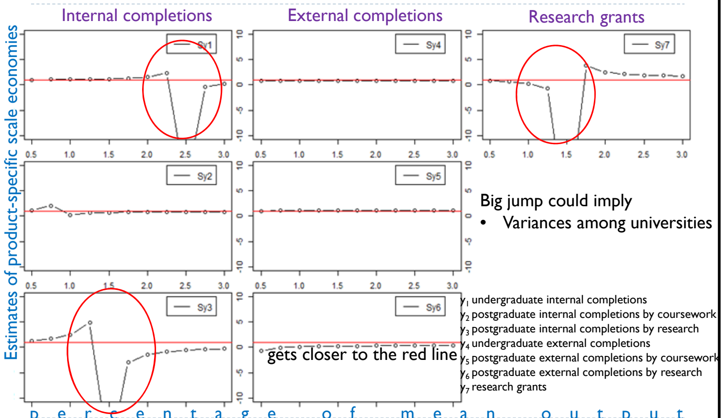
Results
Estimates of scale economies

- Ray scale economies exist up to 300% output mean levels.
- Increase all outputs in Australian university sector **proportionally**, economies of scale will exist and continue to increase up to 300% of mean output



Results
Estimates of product-specific scale economies

Increase the quantity in ***one*** type of output at a time.

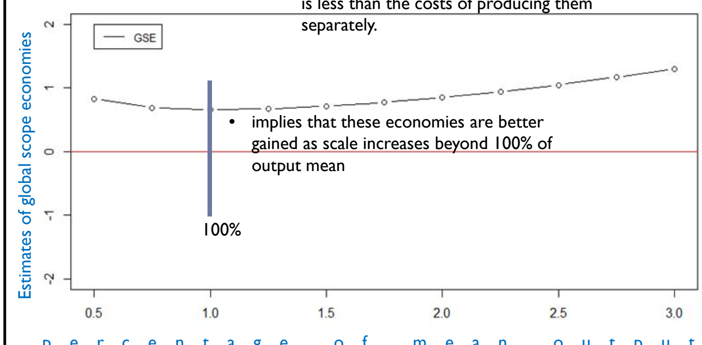


Big jump could imply
- Variances among universities

y_1 undergraduate internal completions
y_2 postgraduate internal completions by coursework
y_3 postgraduate internal completions by research
y_4 undergraduate external completions
y_5 postgraduate external completions by coursework
y_6 postgraduate external completions by research
y_7 research grants

Results
Estimates of global scope economies

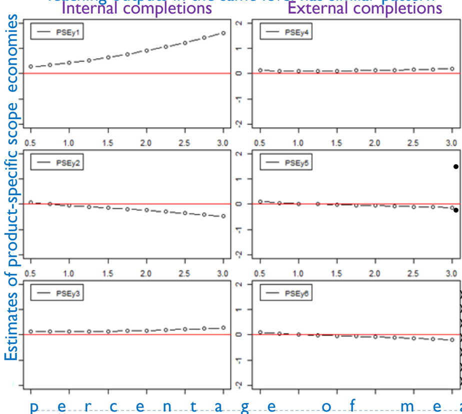
- the cost of producing current output jointly is less than the costs of producing them separately.



- implies that these economies are better gained as scale increases beyond 100% of output mean

Results
Estimates of product-specific scope economies

Teaching outputs in the same level has similar pattern



- scope economies are exhausted for these three types of output
- some universities, the cost of producing these outputs with other outputs are more expensiv

y_1 undergraduate internal completions
y_2 postgraduate internal completions by coursework
y_3 postgraduate internal completions by research
y_4 undergraduate external completions
y_5 postgraduate external completions by coursework
y_6 postgraduate external completions by research
y_7 research grants

Joint production of ***a particular type*** (*i*) of output with other types of outputs

Further studies

- Use other software running random SF model:
  - Stan
- Add more data to a given unit
  - Expand the time trend from three to ten years.
- Calculate scale and scope economies under Bayesian framework.

Thanks for your attention!

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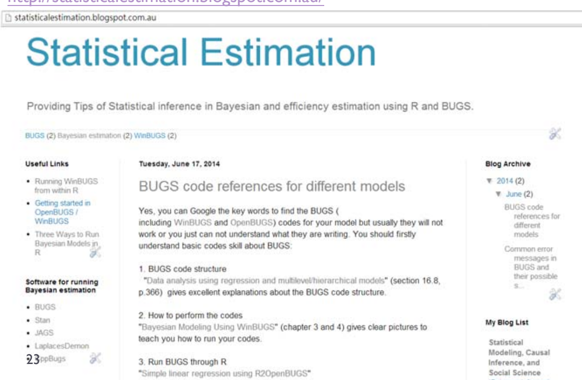
I summarize some useful information about BUGS programming in this website:
http://statisticalestimation.blogspot.com.au/



Appendix.

BUGS code for the Bayesian Fixed and Random Frontier Stochastic Model

Bayesian Fixed Stochastic Frontier Model

```
model
{

      for (k in 1:K){
      y[k]~dnorm(y.hat[k], tau.y)
      y.hat[k]<-alpha + inprod(B[1:P],
                  data[k, 1:P])+ u[uni[k]]
      uni[k]<- data[k, P+1]       }

      tau.y~dgamma(0.001, 0.001)
      sigma.y<- 1/sqrt(tau.y)

      for (i in 1:N) {
      u[i]~dexp(lambda)
      eff[i]<-exp(-u[i])       }
      lambda0<--log(rstar)
      lambda~dexp(lambda0)

      alpha~dnorm(0.0, 1.0E-6)

      for(i in 1:P){
      B[i]~dnorm(0.0, 1.0E-6)       }
}
```

Bayesian Random Stochastic Frontier Model

```
model
{

      for (k in 1:K){
      y[k]~dnorm(y.hat[k], tau.y)
      y.hat[k]<-alpha + inprod(B[uni[k],1:P],
                  data[k,1:P])+ u[uni[k]]
      uni[k]<- data[k, P+1]       }

      tau.y <- pow(sigma.y, -2)
      sigma.y ~ dunif (0.001, 110000)

      for (i in 1:N) {
      u[i]~dexp(lambda)
      eff[i]<-exp(-u[i])       }
      lambda0<--log(rstar)
      lambda~dexp(lambda0)

      alpha~dnorm(0.0, 1.0E-6)
      for (i in 1:N) {for (p in 1:P) {
      B[i, p] <- xi[p]*B.raw[i,p]         }
      B.raw[i,1:P]~dmnorm(mu.raw[1:P],
                              Tau.B.raw[1:P,1:P])
                                   }
      for(p in 1:P){
      mu[p] <-xi[p]*mu.raw[p]
      mu.raw[p]~dnorm(0, 0.0001)
      xi[p]~dunif(0,100)       }

      Tau.B.raw[1:P, 1:P]~dwish(W[,], df)
      df<-P+1

      for (i in 1:P){for (j in 1:P){
      W[i,j]<-equals(i,j)      }}
}
```

Note:

1. K= number of observations; N= number of universities; P= number of variables (including intercepts in random stochastic frontier model); y=C'_{ht} in equation (1); xi is used for redundant parameterizations to improve model fit (Gelman, Van Dyk, Huang, & Boscardin, 2008).
2. In Bayesian random stochastic frontier Model, it seems that the gamma distribution is not appropriate for being considered as the prior distribution for standard deviation of data y since we constantly get the error message "undefined real result" (Kéry & Schaub, 2012, pp.61). We use the uniform distribution following the advice of (Gelman & Hill, 2006).