Productividad y Recursos Naturales

(and other 'poorly priced' netputs)

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1) Productivity or Welfare? When some goods are 'poorly' priced.

2) What is productivity? What for?

3) Productivity measurement with natural resource and other 'poorly' priced netputs

4) Examples

1) Productivity or Welfare? When some goods are 'poorly' priced.

Productivity main source of growth of nations

Output/Input

Measurement motivated by effect of additional output on *consumers'* standard of living

Productivity taken as index of welfare

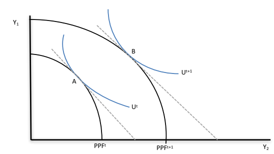
Thermodynamics Law of Conservation of Mass and Energy:

Nothing lost, all is transformed → Systems have unit productivity

But our interest is *human* welfare → inputs and outputs that affect human welfare

Productivity concept is *anthropocentric*

- But traditional productivity studies focus on shift of the production frontier rather than changes in welfare



Why?

1) the economy's production frontier is a constraint on consumers' utility so its expansion is of inherent interest;

2) if there are no market failures, measures of shifts in the production frontier and welfare change coincide.

- We weight inputs and outputs relative to their importance in human welfare

Perfect markets:
  use market prices as weights (MRT=MRS)
    equal shifts of PPF and welfare function

Market failure:
  market prices ≠ MRT≠ MRS
  Shifts of PPF ≠ welfare function

Reasoning collapses in the presence of market failure

Examples:

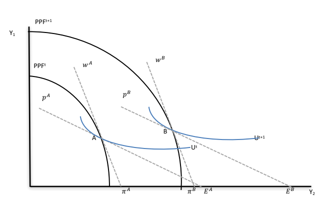
1) Bads, "gives off smoke"

2) Public goods, infrastructure, R&D

3) Second best economy, policy distortions present

4) Markups due to imperfect competition

5) Common property, unpriced or 'badly' priced resources



- Focus on production introduces three potential sources of error.

1) Use of producers' evaluations rather than consumers'
   Rate of technical change vs. Hicks EV/CV

2) Perfect markets vs. Markets with externalities, 'poorly priced' netputs and policy distortions

3) Omission of induced price effects
   general equilibrium vs. partial equilibrium

When market prices do not reflect shadow prices.

1) Shadows to measure shifts in the production frontier to refine **productivity** measures
short fluctuations, quasifixed netputs, capacity utilization
non-CRS
internal and external cost economies
market structure
regulatory structure (pollution abatement)

2) Shadows to measure shifts in consumer **well-being**
Green accounting (stay-at-home, police force, services of nat. resources)
Lagrange multipliers intertemporal max of welfare (Dasgupta and Mäler, 1995)

3) Shadows can be estimated from prevailing (rather than optimum) structure of production and consumption
expenditure, cost, production functions, distance functions, **Hicks marginal valuations**
contingent valuation, from marketed goods

- In the case of 'poorly priced' commodities we have shown that:

1. MFP and EV are equivalent when there are no biases in technical change and preferences are homothetic
2. If not they will differ by a price effect, or a 'poorly priced' good effect, of both

$$EV = MFP + (\boldsymbol{s} - \boldsymbol{k})\boldsymbol{\Sigma}_{xp}\frac{dln\boldsymbol{p}}{d\tau} + (\boldsymbol{s} - \boldsymbol{k})\boldsymbol{\Sigma}_{xv}\frac{dln\boldsymbol{v}}{d\tau}$$

References: Perrin and Fulginiti AJAE 1996, Perrin and Fulginiti AJAE 2001, Fulginiti and Perrin JPA 2005.

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Productivity: What is it?

- Single factor: output per input Y/X = Average Product

output per acre, output per labor, output per water used

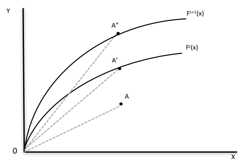
- Multifactor: index of outputs/index of inputs = Average Product

Fisher, Tronquist (superlative)

- MFP growth rate = % change in outputs - % change in inputs = Change in AP

Thermodynamics, Y/X = 1

Average Product

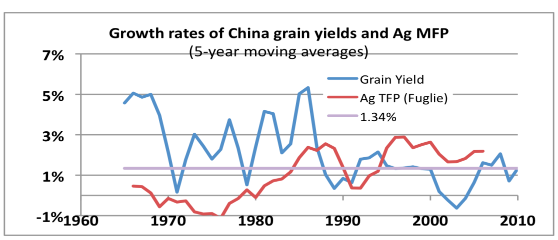


Productivity Measurement: What is it?

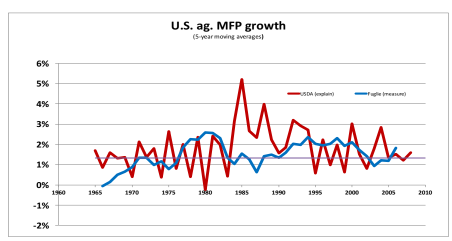
- What's the purpose?
  - Solow (1957) - identify progress, new returns to labor
  - Schultz (1956) - explain where progress comes from
  - When explained, it is gone – where does it go?
  - First law of thermodynamics - there is no progress

- Both objectives are useful

Crop yields vs MFP - China



Measure it vs explain it – US ag productivity



So what do we learn from this?

There are unmeasured/unpriced netputs that have led to 'bias' in measuring productivity

- Water
- Climate
- R&D
- Infrastructure
- Ecological support

Productivity Measurement: What for?

1. Gauge progress (Solow)–
Human welfare from relatively fixed resources, such as land, water, climate, ecosystem resilience

2. Explain progress (Schultz, Griliches)-
How it is achieved is important for policy
But don't use the result as a metric for progress

Thermodynamics, again -there is no progress
When explained, productivity growth is gone

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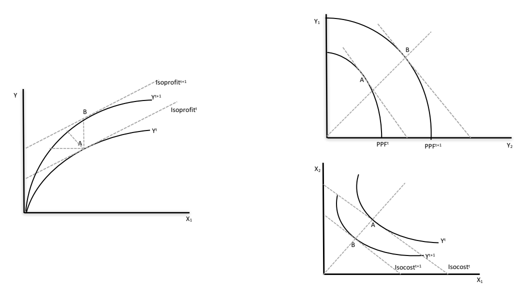

Productivity Measurement: Approaches

1) Quantities versus Prices

Primal Space: production function, PPF, Isoquants, transformation function, distance functions

Dual Space: profit function, cost and revenue functions, dual distance functions.

2) With and without inefficiency: frontier versus non-frontier

3) Parametric and non-parametric

Index numbers

Perfect competition

Constant returns to scale

$Y = f(\mathbf{X}) + residual_1 \quad \mathbf{X} = (\mathbf{K}, \mathbf{L})$ Solow, residual or 'measure of our ignorance'

Output is a flow
Inputs are flows.

$$\frac{\dot{Y}}{Y} - \boldsymbol{\varepsilon_L} \frac{\dot{\boldsymbol{L}}}{\boldsymbol{L}} - \boldsymbol{\varepsilon_K} \frac{\dot{\boldsymbol{K}}}{\boldsymbol{K}} = \%\Delta residual_1 = \%\Delta MFP_1$$

Estimate production elasticities of each factor

OR

Replace production elasticities by input shares
(CRS, perfect competition, price taking)

No estimation is needed, all information is observed → Index number approach
(nonparametric, nonstochastic, superlative, steady state)

Physical man-made Capital is a stock (machinery, buildings). Usually owned rather than rented. No market transaction.

Capital stock calculated based on gross I, 'perpetual inventory' method, by asset type

$$K_t = I_t + (1-d_{t-1})K_{t-1}$$

d is rate of efficiency decline
I is gross investments

Need to calculate the service flow from this stock or capital services/flows.

Calculate **rental or user price of capital services** *(private)*

$$p_{K,t} = p_{A,t}\,(r_t + p_D) - (p_{A,t} - p_{A,t-1})$$

p_A = asset price
r = interest cost or opp cost of capital in other uses
p_D = depreciation rate, loss of value with age

Evaluate the service of capital at the rental rate.

Add Land (N):

Y = $f(\mathbf{X}) + residual_2 \quad \mathbf{X} = (K, L, N)$ Schultz, Griliches, etc. for ag sector

$$\%\Delta MFP_2 = \frac{\dot{Y}}{Y} - \varepsilon_L \frac{\dot{L}}{L} - \varepsilon_K \frac{\dot{K}}{K} - \boldsymbol{\varepsilon_N} \frac{\dot{\boldsymbol{N}}}{\boldsymbol{N}} = \%\Delta\, residual_2$$

MFP_1 growth ≠ MFP_2 growth

Land is a natural resource stock, a non-produced asset.
Owned **and** rented.

Market transactions reflecting the *private* rental or user price of land services
(if not we use the same approach as for physical capital but without depreciation)

Could allow for quality differences using hedonics.

Other Natural Resources (**R**):

$Y = f(\mathbf{X}) + residual_3 \quad \mathbf{X} = (K, L, N, \mathbf{R})$ (OECD, Brandt, Shreyer)

R = Natural resources such as mineral deposits, fish stocks, forests, *soil nutrients, water, pollination, grass for livestock.*

$$\%\Delta MFP_3 = \frac{\dot{Y}}{Y} - \varepsilon_L \frac{\dot{L}}{L} - \varepsilon_K \frac{\dot{K}}{K} - \varepsilon_N \frac{\dot{N}}{N} - \boldsymbol{\varepsilon_R} \frac{\dot{\mathbf{R}}}{\mathbf{R}} = \%\Delta\, residual_3$$

MFP_1 growth ≠ MFP_2 growth ≠ MFP_3 growth

Extractions from stock (groundwater, fish stocks, minerals, etc.)

Private rental or user price of natural resource flows: license fees, or calculated shadow price if user is owner
(reduction in value of nat capital stock from extracting, marginal resource rent)

Common Property Resource? Which shadows? Private? Social?

Add public goods (R&D, Infrastructure)

$Y = f(\mathbf{X}) + residual_3 \quad \mathbf{X} = (K, L, N, R, \mathbf{R\&D, I})$

R&D = Public R&D
I = Infrastructure

$$\%\Delta MFP_4 = \frac{\dot{Y}}{Y} - \varepsilon_L \frac{\dot{L}}{L} - \varepsilon_K \frac{\dot{K}}{K} - \varepsilon_N \frac{\dot{N}}{N} - \varepsilon_R \frac{\dot{R}}{R} - \boldsymbol{\varepsilon_{RD}} \frac{\dot{\mathbf{R\&D}}}{\mathbf{R\&D}} - \boldsymbol{\varepsilon_I} \frac{\dot{\mathbf{I}}}{\mathbf{I}} = \%\Delta\, residual_4$$

MFP_1 growth ≠ MFP_2 growth ≠ MFP_3 growth≠ MFP_4 growth

R&D stock constructed from expenditures in R&D
I stocks obtained from statistics on transportation

Flows are proportional to stock (so changes are equal)

Rental or user price: estimated

Add "Bads" (B)

$H = f(\mathbf{U}, \mathbf{X}) + residual_5 \quad \mathbf{U}=(Y, \mathbf{B}) \quad \mathbf{X}= (K, L, N, R, R\&D, I)$ (OECD, Brandt, Shreyer)

B = Damage created by production process, by-products, GHG, pollution, destruction of habitat, etc.

$$\%\Delta MFP_5 = \varepsilon_y \frac{\dot{Y}}{Y} + \boldsymbol{\varepsilon_B} \frac{\dot{\mathbf{B}}}{\mathbf{B}} - \varepsilon_L \frac{\dot{L}}{L} - \varepsilon_K \frac{\dot{K}}{K} - \varepsilon_N \frac{\dot{N}}{N} - \varepsilon_R \frac{\dot{R}}{R} - \varepsilon_{RD} \frac{\dot{R\&D}}{R\&D} - \varepsilon_I \frac{\dot{I}}{I} = \%\Delta\, residual_5$$

MFP_1 growth ≠ MFP_2 growth ≠ MFP_3 growth ≠ MFP_4 growth≠ MFP_5 growth

Flows are the ***emissions***.

Price of "bads": not observed unless there is a trading system or a tax; marginal abatement cost. Usually estimated.

C (w, Y, t) dual cost function w= input prices Y= output

Rate of cost diminution

$$\%\Delta MFP = \frac{\dot{C}}{C} - \frac{\dot{Y}}{Y} - \sum_{n=1}^{N} s_n \frac{\dot{w}}{w}$$

$$\%\Delta MFP = \frac{\dot{C}}{C} - \left(1 - \epsilon_{cy}\right)\frac{\dot{Y}}{Y} - \frac{\dot{TE}}{TE} - \frac{\dot{AE}}{AE} - \sum_{n=1}^{N} (s_n - s^v{}_n) - \frac{\dot{w}}{w}$$

Non CRS

Quasifixities

Imperfect competition

Not all inputs or outputs included or mis-measured

See Morrison-Paul 1999, Cowing and Stevenson 1981, Jr of Econometrics 1986

Issue for common property resources (fisheries, groundwater), public goods and "bads"

private user cost $\neq$ social user cost

Social user cost is non-observable

Estimation is necessary to obtain shadow price or marginal valuations

Approaches: econometrics, DEA, stated preferences, revealed preferences, from prices of marketed goods

Issues

1) Measurement of stock of natural resources, SEEA (UN)
2) Private versus social user cost (common property resource, property rights).
3) Environmental interactions: external costs and benefits, values beyond market: cultural/recreational service, existence value, option value, habitat value, sink, water regulation, other services?
4) Bads (excess N and P in water/river systems, capture of GHG emissions; destruction of habitat). Measurement of flows. Prices not reflected in output market prices.
5) Adjustment costs for durables (not at steady state), renewables and non renewables.
6) Other important capital inputs in agricultural productivity analysis that need attention : inventories (breeding stock, milk cows, fruit and nut trees; pollination; grass for livestock); R&D (intangible capital; private and public).

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Example 1: Parametric production function and shares

"Crop Yields in U.S. 41 Parallel : Irrigation, SOM, and Weather Effects" Trindade, Fulginiti, Perrin (2016)

Translog production function estimation

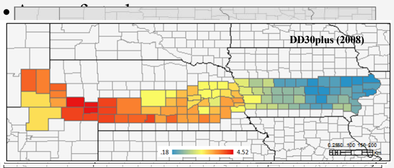
First order conditions of profit maximization for fertilizers and chemicals.

Simultaneous estimation of prod func and cost share equations.

Use of instrumental variables to correct for endogeneity.

$$y_{it} = \alpha_0 + \sum_{j=1}^{3} \beta_j x_{ijt} + \frac{1}{2}\sum_{j=1}^{3}\sum_{k=1}^{3} \beta_{jk} x_{ijt} x_{ikt} + \sum_{w=1}^{3} \omega_w d_{iwt} + \sum_{w=1}^{3} \omega_{w3} d_{iwt} x_{i3t} + \theta_1 r_{it} + \frac{1}{2}\theta_{11} r_{it}^2 + \theta_{13} r_{it} x_{i3t} + \theta_2 som_{it} + \theta_{23} som_{it} x_{i3t} + \tau_1 t_i + \frac{1}{2}\tau_2 t_i^2 + \sum_{j=1}^{3} \varphi_j t_i x_{ijt}$$

$$\frac{\partial \ln f(X,t)}{\partial \ln X_j} = \frac{\partial f(X,t)}{\partial X_j} \cdot \frac{X_j}{f(X,t)} = \frac{w_j}{p} \cdot \frac{X_j}{Y} = s_j$$

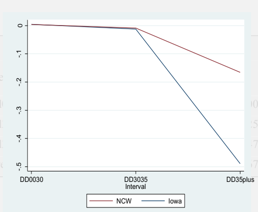


Data

Results:

Table 1 - Elasticities of production estimated at their means		
Variable	Elasticity	P-Value
Fertilizer	0.074	0.002
Chemicals	0.050	0.002
Irrigation ratio	0.234	0.019
Soil organic matter	0.072	0.051
Time Trend	0.011	0.000

Results:



Conclusions:

Technical change during the period was found to be 1.1% per year.

One full day 30-35ºC will decrease yields by 1%
over 35ºC will decrease yields by 27.1%. (nonlinear)

SOM not significant.

Effect of high temperatures can be offset by the use of irrigation.

Irrigation contribution 26%.

Contribution of fertilizer and chemicals to yield changes was significant.

Example 2 : DEA

Measuring Crop Residue Harvest Potentials (Lakoh, Perrin, Fulginiti, Liska, Milner).

What minimum level of SOM would ensure that production levels are maintained while some of the crop residue is being harvested for the production of cellulosic ethanol?

Crop residue harvest potentials across the plains

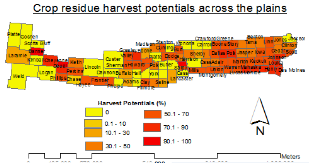


Table2 : % of counties within given harvest potentials

State	0 - 10%	11% - 30%	31%-50%	>50%
Co	50.00	0	0	50.00
Io	10.64	2.13	27.66	59.57
Ne	34.78	13.04	13.04	39.13
Wy	66.67	33.33	0	0

State	HP	SOC(Mg C/Ha)	Biomass(Mg C/Ha)
Co	32.45%	13.79	34.48
Io	53.16%	41.56	103.90
Ne	34.93%	17.55	43.87
Wy	7.97%	2.25	5.63
HP = Harvest Potential			

Example 3: Stochastic Frontier Production Function

"Agricultural Productivity and Climate Change in Sub-Saharan Africa: Water, Precipitation and Temperature". Kibonge and Fulginiti (2015)

- Output (agricultural production, FAO)
- Conventional inputs: fertilizer, livestock, machinery, labor and land (FAO)
- Efficiency-changing variables
  - ❑ weather (temperature, precipitation)
  - ❑ water (drought, irrigation)

Drought: dummy variable obtained from the Standard Precipitation Index (SPI).

The SPI (one month) for SSA was first constructed (next slide) and later converted into a drought dummy variable by counting all the driest months (SPI ≤ -2) in a given year.

Irrigation: ratio calculated from taking the area equipped for irrigation over the sum of all croplands (from FAO).

Years Independence	-0.003***
Conflicts	-0.057
War	0.030**
Great Britain FC	-0.288**
French FC	-0.112**
Belgium FC	0.140**
Portuguese FC	-1.932***
Drought	-0.033***
Irrigation	-0.429*

Precipitation	Temperature	Fertilizer	Livestock	Machinery	Labor	Land
0.000073**	0.000115*	0.03*	0.11**	0.02*	0.11***	0.60***

Results: Agricultural Performance in SSA

TABLE 2. Average weighted SSA TFP growth rate per decade (%)

Decades	TFP	TFP (with climate variables)
1960s	0.41	0.44
1970s	0.46	0.46
1980s	0.54	0.72
1990s	1.19	0.51
2000s	1.34	0.81
1960-2013	0.81	0.66

Example 4: Parametric dual cost function and input shares

"Rates of Return to Public Agricultural Research in 48 U.S. States." (Plastina and Fulginiti, 2012)

Aggregate technology: variable cost function $c(w, y, v, V)$

- 1 Aggregate agricultural output (y)
- 3 Variable inputs (w):
  - *labor, L*
  - *capital, K*
  - *purchased inputs, M*
- 1 Private Fixed input (v): *land, T*
- 2 Public Fixed inputs (V):
  - *Own-state stock of public ag. R&D, G*
  - *Spill-in stock of R&D from neighboring states, S*

$$Z_G = -\frac{\partial c}{\partial G}$$

$$Z_S = -\frac{\partial c}{\partial S}$$

Model 2. With SAR. Selected estimates of Z_G , B and r

STATE	Z_G	*B*	*r (%) [95% CI]*
Iowa	37.1 (18.19)	1.2 (0.165)	18.38 [0.0;22.5]
Kansas	62.3 (14.88)	2.01 (0.135)	21.5 [17.6;24.0]
Nebraska	52.4 (14.32)	1.69 (0.13)	20.44 [15.8;23.2]
New York	8.6 (3.78)	0.28 (0.034)	10.31 [0.3;13.7]
South Dakota	70.8 (21.84)	2.28 (0.198)	22.3 [16.6;25.4]
Nat'l Average	31.55 (10.48)	1.02 (0.095)	16.54 [8.6;19.8]

Model 2. With SAR. Selected estimates of F, $B*$ and r_1

STATE	*F*	*B**	r_1 *(%) [95% CI]*
Iowa	390.4 (46.32)	12.59 (0.419)	34.1 [32.1;35.7]
Kansas	313.0 (33.41)	10.1 (0.302)	32.43 [30.7;33.9]
Nebraska	525.6 (56.47)	16.96 (0.511)	36.41 [34.5;38.0]
New York	20.7 (17.32)	0.67 (0.157)	15.02 [0.0;20.8]
South Dakota	420 (49.68)	13.55 (0.449)	34.66 [32.6;36.3]
Nat'l Average	247.4 (30.52)	7.98 (0.276)	29.31 [26.5;29.3]

Example 5: Cost function and input shares

"Benefits of Public R&D in U.S. Agriculture: Spill-Ins, Extension, and Roads" (Wang, Plastina, Fulginiti, Ball, 2012)

Cost Elasticity of R&D, Extension, Roads, and R&D spill-ins (shadow shares)

Elasticity	Model 1		Model 2		Model 3		Model 4	
	mean	dard devia	mean	dard devia	mean	dard devia	mean	ndard devia
R&D	-0.129	0.090	-0.152	0.086	-0.135	0.081	-0.151	0.089
Extension	-0.248	0.021	-0.233	0.019	-0.242	0.019	-0.243	0.020
Road	-0.036	0.004	-0.054	0.005	-0.061	0.005	-0.058	0.005
Spill-ins	-0.164	0.010	-0.014	0.006	-0.058	0.006	-0.040	0.004

- One percent increase
  - in own R&D reduces TVC by 0.13-0.15percent.
  - in extension reduces TVC by 0.23-0.25 percent.
  - in spill-ins reduces TVC by 0.01-0.16 percent.
  - In roads reduces TVC by 0.04-0.06 percent.

Example 6: Dual Dynamic Cost Function with Public Input and shares of variable inputs
"Public Inputs and Dynamic Producer Behavior: Endogenous Growth in U.S. Agriculture." (Onofri and Fulginiti, 2008)

$$\underset{I(t)>0}{Min}\int_0^{\infty} e^{-\rho t}[C(y,Z,I;G)+p'Z]dt \qquad (1)$$

$$subject\ to\ \dot{Z}=I-\delta Z$$
$$Z(0)=Z_0$$
$$Z(t)>0 \qquad \forall t$$

The value function that solves (1) is J(Z, y, p; G)

Dynamic Duality
or

$$C(y,Z,I;G)=\underset{p}{Max}[\rho J(Z,y,p;G)-p'Z-J_z(Z,y,p;G)(I-\delta Z)]$$
$$\rho J(Z,y,p;G)=\underset{I}{Min}[C(y,Z,I;G)+p'Z+J_z(Z,y,p;G)(I-\delta Z)]$$

1. NEGATIVE LONG-RUN EFFECT OF PUBLIC INPUTS ON THE COST FUNCTION

(Positive Shadow Price: Pg* = - ρJg > 0)

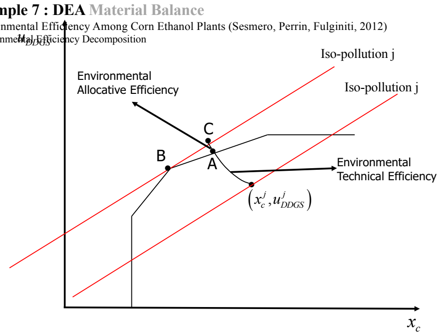
Joint Estimation of the Demands for Private Inputs
- (K) Capital
- (L) Labor
- (M) Materials

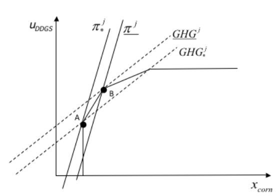
Instrumental Variables for Public Inputs
- (G) Stock of Public Infrastructure
- (R) Stock of Public R&D

1. NEGATIVE LONG-RUN EFFECT OF PUBLIC INPUTS ON THE COST FUNCTION
(Positive Shadow Price: $P_g^* = -\rho J_g > 0$)

Table 2B			Table 2D		
Shadow Prices of Public Inputs MCMC Estimates Average By Decade, Ball's Data Set, 1987=1			Shadow Prices of Public Inputs MCMC Estimates Average By Decade, Thirtle's Data Set, 1967=1		
Decade	**P*g**	**P*r**	**Decade**	**P*g**	**P*r**
			1926-1930	**2.90E-07**	0.000136
			1931-1940	**3.00E-07**	0.0000971
			1941-1950	**1.50E-07**	**0.0001746**
1949-1959	**8.00E-07**	**0.0004382**	1951-1960	**1.30E-07**	0.0001343
1960-1969	5.00E-07	**0.001426**	1961-1970	**1.10E-07**	**0.0001665**
1970-1979	**1.00E-06**	**0.0043971**	1971-1980	**4.00E-07**	**0.0003225**
1980-1989	**4.80E-06**	**0.0094812**	1981-1990	**1.12E-06**	0.0004988
1990-1994	**9.80E-06**	**0.0131529**			
1949-1994	**3.38E-06**	**0.0057791**	**1926-1990**	**3.70E-07**	**0.0002415**

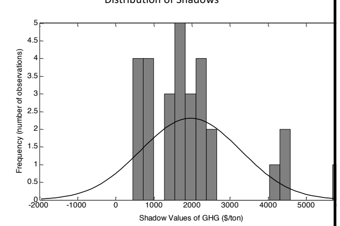
Example 7 : DEA Material Balance
Environmental Efficiency Among Corn Ethanol Plants (Sesmero, Perrin, Fulginiti, 2012)
Environmental Efficiency Decomposition





Calculation of shadows

Distribution of Shadows



Example 8: Directional Distance Function, DEA, parametric stochastic frontier
"Tradeoff between agriculture and forest preservation in the Brazilian amazon" (Silva, Fulginiti and Perrin, 2017)

The region (590 municipalities) Brazil

1. What is the **opportunity cost** of preserving the forest in terms of agricultural output? MRT and shadows
2. Has **technical change** allowed more or less agricultural output per hectare of deforestation? Shift
3. Has **technical change** been **biased** toward agricultural outputs or deforestation? Change in MRT.

Data Envelopment Analysis
"The cost of forest preservation in the Brazilian Amazon: the arc of deforestation. (Silva, Fulginiti, and Perrin, 2016)

156 municipalities in the "arc of deforestation" in 2006

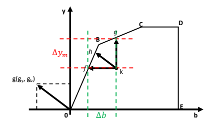


Figure 2: Output Set - *P(x)*, and directional output distance function

- 1) $\Omega_y = \sum_{m=1}^{M} p_m^k * \Delta y_m$
- 2) $\Omega_b = \Delta b$
- 3) $Tradeoff = \left(\frac{\Omega_y}{\Omega_b}\right),\ in \frac{US\$}{hectare}$.

Data Envelopment Analysis
156 municipalities in the "arc of deforestation" in 2006

- Outputs

i. Grains = soybean and corn (in tons)
ii. Livestock = sold cattle (units)
iii. Timber (in m^3)
iv. Average deforestation (in ha)

- Inputs
  - Labor (employees), Capital (units), Area (ha), and Expenses (US$ 1000): Fuel, Ag. Inputs and Cattle inputs

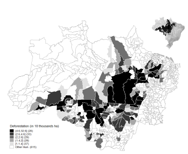


Figure 1 – Total deforestation (in 10,000 ha)

Results
156 municipalities in the "arc of deforestation" in 2006

- Our estimate price of tCO_2 is **US$12.41**
  - 10% discount rate and a carbon content of 155 tC per hectare.

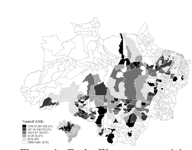


Figure 4 – Tradeoff between ag. activity (US$) and forest (ha)

Table 4 –Revenue foregone per hectare of forest (deforestation) and per tons of CO_2

State	Forest (ha) Shadow prices	tCO_2 Shadow prices
Rondônia (RO)	$812.47	$2.21
Acre (AC)	$1,233.74	$3.36
Amazonas (AM)	$604.82	$1.65
Para (PA)	$796.44	$2.17
Tocantins (TO)	$2,555.44	$6.96
Maranhão (MA)	$1,000.98	$2.73
Mato Grosso (MT)	$1,091.39	$2.97
"Arc of deforestation"	**$920.61**	**$2.51**

Stochastic Frontier approach

"Tradeoff between agriculture and forest preservation in the Brazilian Amazon." (Silva, Fulginiti, Perrin, 2017)
590 municipalities in the Legal Amazon in 2006

- Outputs
  - i. Agricultural Gross Domestic Product (US$ 1000)
  - ii. Average Deforestation (ha)
- Inputs
  - Labor (employees), Capital (units), Irrigation (ha), Credit (US$ 1000)

Efficiency variables :
- Shared of family owned farms, total forest area in 2006 and total hydrological area in 2005

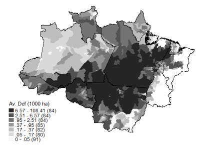


Figure A1 – Average deforestation (in 1,000 ha)

Results

590 municipalities in the Legal Amazon in 2006

- Our estimates price of tCO_2 are much higher than the US$5.00 used in official REDD+ transactions.
  - It ranges **US$14.00 to US$43.20** tCO_2.

Table 4 – Average Shadow Prices of Forest Preservation in Terms of Ag. GDP (US$), in the Legal Amazon, 2006

State	Mean	Standard Deviation
Acre (AC)	552.87	57.00
Amazonas (AM)	603.16	117.23
Amapá (AP)	554.89	57.95
Maranhão (MA)	744.19	904.82
Mato Grosso (MT)	1252.85	2311.84
Para (PA)	669.38	340.87
Rondônia (RO)	616.02	264.04
Roraima (RR)	974.83	1420.30
Tocantins (TO)	689.47	653.52
Legal Amazon	**796.81**	**1206.76**

590 municipalities in the Legal Amazon in 2006

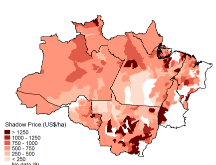


Figure 2 – Estimated shadow prices of deforestation in terms agricultural GDP in the Legal Amazon, Brazil, 2006

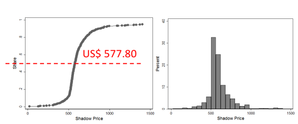


Figure 3 – Cumulative distribution and histogram of estimated shadow prices of forest preservation in terms of agricultural GDP for the Legal Amazon, Brazil, 2006

Note: The higher 5% percentile is not included in these graphs for scale reasons.

Example 9: Stochastic Frontier approach

"The effect of *technical change* on the tradeoff between agriculture and the Amazon forest in the Brazilian arc of deforestation". (Silva, Fulginiti, Perrin, 2017)

200 municipalities in the "arc of deforestation" in 2003/15

$$\vec{D}_o(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b}; g_y, g_b) = \max_{\alpha}\{\lambda: (\boldsymbol{y} + \lambda g_y, \boldsymbol{b} - \lambda g_b) \epsilon P(\boldsymbol{x})\}$$

$$\frac{d\lambda}{dt} = \frac{\partial \vec{D}_o}{\partial t}$$

$$B_{mj}(y, b, x, t) \equiv \frac{\partial \ln(MRT_{mj})}{\partial t} = \frac{\partial \ln(\nabla_{jt}\vec{D}_o / \nabla_{mt}\vec{D}_o)}{\partial t}$$

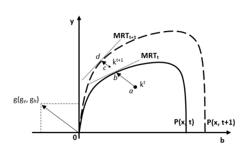


Figure 1 - Output Set - *P(x)*, and directional output distance function

Note: the scalars *q* and *p* represent price of undesirable and desirable outputs respectively.

200 municipalities in the “arc of deforestation” in 2003/15

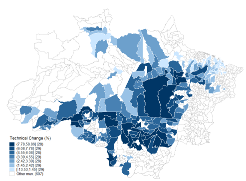


Figure 4 – Municipal technical change rate in the “arc of deforestation”, in 2012.

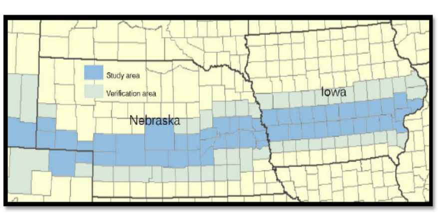
Table 3 – Average rates of technical change (%) for municipalities in the “arc of deforestation”, Brazil, 2003-2015.

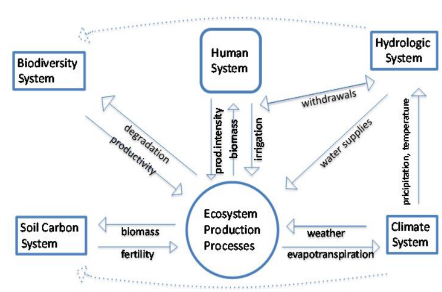
Year	RO	AC	AM	RR	PA	MA	MT	Yearly Average
2003	5.65	4.34	4.02	2.95	6.85	6.77	7.24	**6.40**
2004	6.06	4.59	4.45	2.38	5.78	1.94	8.13	**6.40**
2005	6.33	4.23	4.86	2.48	5.94	1.83	7.87	**5.49**
2006	5.98	4.30	4.37	1.88	5.76	1.82	7.02	**5.42**
2007	5.79	3.91	3.66	2.82	4.94	1.73	6.15	**5.11**
2008	5.24	3.56	3.56	3.18	5.14	1.78	5.63	**4.61**
2009	4.85	3.78	3.12	2.97	4.89	1.82	5.51	**4.43**
2010	4.70	3.24	2.79	2.67	4.72	1.87	5.39	**4.26**
2011	4.84	4.02	2.73	2.06	4.17	1.73	5.23	**4.12**
2012	5.61	4.16	2.96	2.57	4.17	1.59	5.34	**3.93**
2013	5.32	3.87	3.53	2.03	3.82	1.55	5.36	**3.99**
2014	5.44	3.58	3.59	2.18	3.96	1.59	5.58	**3.84**
2015	5.37	3.27	3.95	2.19	3.90	1.56	5.60	**3.91**
State Average	**5.47**	**3.92**	**3.66**	**2.51**	**4.91**	**2.12**	**6.23**	**4.58**

- **Technical change** has been **progressive** in this region over the period from 2003/15.
  - It means that innovations have led to agricultural expansion with less deforestation.
- Technical change has been **biased toward grains, timber and livestock outputs** and against deforestation.
- Now is cheaper to expand output but more expensive to contract if regulations are imposed.

Example 7: Forty-first Parallel Agro-Ecosystem Sustainability and Productivity (econometric + optimal control)

Can we meet needs of food, feed and fuel through technical change without depleting resource stocks?





$$\min_{x,\,r} H = p_x x + p_r r + \gamma \dot{K} + \lambda[y - f(y,x,r,K,w)]$$

subject to equations of motion:

$$\dot{K} = g(K,x,r,w)$$

where:

p_x, and p_r are prices of x and pumping cost for r, respectively,

γ is a vector of shadow prices on natural resource stocks,

λ is the Lagrange multiplier for the output level constraint,

and other variables are as previously defined.

$f(y,x,r,K,w) = 0$, where:

y is a scalar representing ecosystem service flow, biomass production;

x represents a vector of indexes of variable inputs, tillage method and cropping intensity;

r represents irrigation rates,

K is a vector of natural resource stocks, specifically,

K_1 is groundwater reserves,

K_2 is sequestered soil carbon,

K_3 is an index of biodiversity;

w represents rainfall and other weather related variables.

Production Elasticities	Irrigation	Fertilizer	Chemicals	Rainfall	SOM	dd3035	dd3640	t
CD	0.84	0.12	0.06	0.05	0.26	-0.02	-0.23	0.01

$\dot{K}$ soil carbon:

Δ Soil carbon (Mg C/ha/yr) = $A_{\%corn}$(-0.348 - 0.00491*C_0 + 0.228*C_I) +$A_{\%soy}$(-0.0815 – 0.00701*C_0 + 0.219*C_I) + $A_{\%wheat}$(-1.321 – 0.00134*C_0 + 0.937*C_I)

$\dot{K}$ biodiversity:

Grassland Birds Ind. = 7.53 - 0.06 acres – 0.10 biomass – 0.43 chemicals

$\dot{K}$ groundwater:

ΔDW = -0.4 +1.81 (irr. acres)- 0.154 (precip) +0.117 (max temp) - 0.037 (sand)- 0.044 (silt)

Summary

1) It is well-being that we want to know about, weights should be consumers rather than producers
In the presence of market failure ('badly priced or non-priced') productivity measures depart from welfare measures due to technical change.

2) Interpretation of productivity depends on objective: growth or explain it all (Solow vs Schultz)

3) Social user cost should be used for natural capital, public goods, 'bads' as they are incorporated in an 'explain it all' productivity measure.

4) Measures of stocks and flows and estimation of user costs based on solid theoretical models (bioeconomic in most cases of natural capital, and institutional characteristics) and alternative approaches to estimation of the shadow values.

5) If an ecosystem approach is desired: a) other outputs should be included (provision, regulation, supporting, cultural) and b) existence and option value in addition to use value should be incorporated.

Useful references (applications):

- OECD manuals: Capital, Productivity, Natural Capital, Bads, Green Growth Indicators, Compendium of Agri-environmental Indicators, Eurostat-OECD compiltion Guide on Land Estimation, Greening Productivity Measurement (Schreyer, Brandt and associates).
- SEEA/UN, reports, SEEA-FFA/FAO report.
- World Bank reports (Where is the wealth of nations?)
- Australian Productivity Commission (minerals Topp, Syed and colleagues, intangibles)
- USDA/ERS (Ball, Nehring, Gollop and colleagues)
- Finechel and Abbot
- Zheng, Bloch (minerals)
- Morrison-Paul, and colleagues (minerals, infrastructure, fisheries)
- Cuddington (oil)
- Squires, Felthoven, Fox, Hanneson, Kirlkley and colleagues (fisheries)
- Ag. Canada (minerals)
- Lasserre, Ouellette
- Sedjo (forestry)
- RFF series on Understanding Productivity Change in Natural Resource Industries