Primal and Dual Approaches to Fishing Capacity: The Impact of Convexity

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Outline of the presentation

1. Introduction
2. Convexity versus Non-Convexity
3. Primal Capacity Notions
4. Dual Capacity Notions
5. Technology and Cost Functions
6. Empirical Results
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1. Introduction

Importance of Capacity in Fishery Policy

- Excess capacity of fishing fleets is one of the most pressing problems facing the world's fisheries and the sustainable harvesting of resource stocks.

- Since 1990, both world marine fish catches and the world-wide number of vessels (but with increasing productivity) have leveled off, with many species fully or over-exploited and with a general excess number of vessels.

- Adoption of the Precautionary Principle (= calling for resource stocks higher than those for maximal sustainable yield and correspondingly lower sustainable catch levels) exacerbates the excess capacity problem.

1. Introduction

Excess Capacity Creates Several Issues:

- It generates pressure to harvest past the point of sustainability to keep the fleet ongoing as much as possible. With many vessels operating under little or no profits, reductions in fleet size become politically and socially more difficult.
- Excess capacity encourages inefficient allocation and constitutes a major waste of economic resources. Overinvestment occurs (i.e., excessive amounts of variable inputs are used).
- Excess capacity also complicates the fishery management process, particularly in regulated open access fisheries, by frequently leading to micro-regulation.
- Excess capacity substantially reinforces the tendency for management decisions to become primarily (re)allocation decisions.

1. Introduction

Empirical Estimations of Capacity

- We focus on non-parametric approaches.
- There have been parametric applications using both primal and dual approaches (mainly Morrison, Squires and co-authors).
- The non-parametric approach has been applied by several authors to fisheries all over the world.
- In several instances capacity utilization measures are relatively low. Plugging these into planning models leads to high decommisioning rates. The latter results are not easy to "sell" to policy makers.
- For researchers, it is important to be sure that the conclusions obtained reflect the technology and behaviour of fishermen. Some considerations are:
  - Production period (single trip, or longer?)
  - What are meaningful choices of inputs? Outputs (aggregation, bycatch,...).
  - Any difference between the primal and dual approach?
  - Is the assumption of convexity appropriate?

2. Convexity versus non-convexity

Basic Concern Regarding Convexity/Non-Convexity

- Conventional empirical production analysis maintains convexity: Implicit or explicit assumption that non-convexities do not impact empirical results.

- Some reasons for non-convexities in technology:
  1. Indivisibilities
  2. Economies of scale
  3. Economies of specialization (e.g., nonrival inputs in new growth theory)
  4. Externalities

- ***Theoretical results pointing to impact of convexity:***
  1. Jacobsen (1970), Shephard (1970, 1974), Färe (1988): cost function is non-decreasing and convex (non-convex) in outputs when technology is convex (non-convex).
  2. Briec et al. (2004): cost function on convex technology $\leq$ cost function on non-convex technology (identical under single output & CRS).

- Convexity can then only be maintained if there is well-established empirical evidence that its impact on most or some specific applications is negligible.

2. Convexity versus non-convexity

Empirical Evidence Revealing Impact of Convexity

Traditional analysis:

- Non-convexities in electricity generation due to minimum up and down time constraints, multi-fuel effects, etc. lead to non-convex and non-differentiable variable costs (Bjørndal & Jörnsten (2008), Park et al. (2010)).
- Car manufacturing cost are non-convex due to changes in (i) number of shifts and (ii) shutting down of plants for some time (e.g., Copeland & Hall (2011)).

Frontier analysis:

- Cummins & Zi (1998) and Grifell-Tatjé & Kerstens (2008) offer cost frontier estimates and cost efficiency ratios for USA life insurance and Spanish electricity distribution respectively that are different from convex results.
- For oil field petroleum data, Kerstens & Managi (2012) report substantial differences in Luenberger productivity indicator between convex and non-convex technologies and only find both convergence for latter technology.
- Wheelock & Wilson (2009): 5 inputs & 5 outputs; 11993, 9585 & 6075 USA banks for 1985, 1994 & 2004. All observations in each year are on the NC-frontier. Only 7.9 to 8.8 % are on C frontier. Thus, inefficiency is solely due to convexity.

2. Convexity versus non-convexity

Use of Non-parametric Convex and Non-convex Capacity Measures

We explore differences in:

- Primal capacity estimates on firm level for convex and non-convex specifications alike.
- Dual cost frontier-based capacity estimates on firm level based on convex and non-convex cost functions.
- The effect of these convex and non-convex capacity estimates in a second stage industry model planning the fishing sector.

Use of non-parametric convex and non-convex production and cost functions:

- There are hardly any alternative semi-parametric or parametric specifications that easily allow for testing convexity.
- This non-parametric approach coincides with the non-parametric nature of the axioms under scrutiny.
  "Given the qualitative, non-parametric nature of the fundamental axioms, this suggests … that the more relevant tests will be non-parametric, rather than based on parametric functional forms, even very general ones." Fuss, McFadden & Mundlak (1978: 223).

3. Primal Capacity Notions

Technical-Engineering Notions of Capacity

- Plant capacity (Johansen (1968), Färe, Grosskopf & Valdmanis (1989)): potential output given fixed inputs (with no restrictions on variable inputs).

- Plant capacity utilization is ≤ 1 (actual outputs/potential outputs)

- ***Example:*** Assuming strong disposal of inputs and outputs and constant returns to scale, a non-parametric inner-bound approximations of true technology is:

$$T^{\Lambda} = \left\{ (x, y) : x \geq \sum_{k=1}^{K} x_k z_k , y \leq \sum_{k=1}^{K} y_k z_k , z_k \in \Lambda \right\},$$

where $\Lambda \in \{C, NC\}$,

with (*i*) $NC = \left\{ z_k \in \Re_+^K : \sum_{k=1}^{K} z_k = 1 \quad \text{and} \quad z_k \in \{0, 1\} \right\}$,

(*ii*) $C = \left\{ z_k \in \Re_+^K : \sum_{k=1}^{K} z_k = 1 \quad \text{and} \quad z_k \geq 0 \right\}$.

3. Primal Capacity Notions

Technical-engineering Notions of Capacity (2)

Solving the linear programming problem for each firm relative to this production possibilities set gives the following efficiency measure:

$$E_o(x, y) = \max\{\theta: (x, \theta y) \in T\}.$$

Plant capacity utilization of firm k based on observed output is:

$$CU_{oo}^{k} = \frac{1}{\theta_1^{*k}}$$

There is also an unbiased plant CU-measure adjusting for technical efficiency.

This primal plant CU-measure employing non-parametric frontiers is popular (but, only for convex technologies).

3. Primal Capacity Notions

Industry Capacity

- Summing firm-level capacity outputs offers an estimate of the aggregate industry capacity output. Hence, a measure of overcapacity at the industry level.

- But, firm-level capacity levels preclude insight into the optimal restructuring and configuration of the industry. For example, the plant capacity measure implicitly assumes that production of capacity output is feasible and that the necessary variable inputs are available.

- In fisheries, overall production is limited by the productivity of the fish stock.

- Relevant questions at the industry level are:
  - What is the optimal firm-structure given current aggregate outputs?
  - How can reallocation of inputs and outputs be performed between firms?
  - How does this reallocation changes if certain policy concerns are included?
  - What are the costs of pursuing these policy issues in terms of allocating more inputs than necessary?

3. Primal Capacity Notions
Short-Run Industry Model

- The focus of the short run industry model is on reallocation of resources between production units in an industry by explicitly allowing improvements in technical efficiency and capacity utilization rates.

- The industry model is developed in two steps as follows:
  - **Step1:** From the firm level model an optimal activity vector is provided and hence capacity output and its optimal use of fixed and variable inputs (frontier figures) can be computed for each firm.

  - **Step2:** These "optimal" frontier figures at the firm level are used as parameters in the industry model. In particular, the industry model can minimize the industry use of fixed inputs such that total production remains at the current total level (or at a desired target level) by reallocation of resources between firms.

3. Primal Capacity Notions
Formulation of the Short-Run Industry Model

$$\min_{\theta, w, X_v} \theta$$

$$\text{s.t.} \quad \sum_{j=1}^{J} y_{jm}^{*} w_j \geq Y_m, \qquad m = 1, \ldots, M,$$

$$\sum_{j=1}^{J} x_{fj}^{*} w_j \leq \theta X_f, \qquad f = 1, \ldots, F,$$

$$\sum_{j=1}^{J} x_{vj}^{*} w_j \leq X_v, \qquad v = 1, \ldots, V,$$

$$0 \leq w_j \leq 1, \quad \theta \geq 0, \quad j = 1, \ldots, J.$$

where y* and x* is the firm level capacity output and optimal inputs, and Y and X is the total production and total use of inputs.
Note: the activity parameters have another function here than in traditional production models.

3. Primal Capacity Notions

Empirical Applications of the Industry Model in Fisheries

- The short run industry model has been applied by:
  - Kerstens, Squires & Vestergaard (2006) on the Danish fishing fleet. Different policy options were adopted (e.g., protecting certain vessels groups). Basic scenario reduces fixed inputs by 36%.
  - Lindebo (2005) offers the first transnational application of this model to the flatfish fishery in the North Sea. His model shows an overall reduction in fixed inputs is 23% with large differences between countries.
  - Tingley & Pascoe (2005) apply the model to the Scottish fleet and note the economic benefits to the industry and employment impacts of achieving this capacity reduction and restructuring. They report the potential output to be 60% higher.
  - Kerstens, Squires & Vestergaard (2005) develop this model using non-convex technologies and observe that, comparing with convex technologies, more units remain active. They report around 10% more vessels remain active.
  - Yagi & Managi (2011) apply the same framework to Japanese fisheries and report up to an 80% reduction in the overall fleet.

4. Dual Capacity Notions

Economic Notions of capacity

Reference points of economic capacity notions in the multiple output case are defined as the quantities and prices corresponding to:

1) *Minimum of short run total cost function* $C(y,w^v,x^f \mid V)$: $C(y,w^v,x^f \mid C)$
2) *Tangency cost with modified fixed inputs* $C^{tang1}(y,w,x^{f*} \mid V)$:
   $C^{tang1}(y,w,x^{f*} \mid V) = C(y,w \mid V) = C(y,w^v,x^{f*} \mid V)$.
3) *Tangency cost with modified outputs* $C^{tang2}(y(p,w^f,x^f),w,x^f \mid V)$:
   $C^{tang2}(y(p,w^f,x^f),w,x^f \mid V) = C(y(p,w^f,x^f),w \mid V) = C(y(p,w^f,x^f),w^v,x^f \mid V)$.
4) *Minimum of long run total cost function* $C(y,w \mid V)$: $C(y,w \mid C)$,

whereby x^{f*} represents optimal fixed inputs, p is a vector of output prices, and $y(p,w^f,x^f)$ represents outputs that have been adjusted in terms of given output prices, fixed input prices, and the given fixed inputs.

Further economic capacity notions are around. Examples:

- Ray economic capacity measure involving short-run profit maximization (with output mix constant) is proposed by Coelli et al. (2002).
- Revenue (Segerson & Squires (1995)) and profit (Squires (1987)) based notions.

5. Technology and Cost Functions

Basic definitions

- Efficiency is measured using : - deterministic,
  - nonparametric technologies.

- Production technologies are based on *K* observations using a vector of inputs *x* to produce a vector of outputs *y*.

- Technology is represented by its production possibility set :

$$T = \{(x,y): x \text{ can produce } y\}.$$

- Input set $L(y)$ denotes all input vectors *x* producing the output vector *y:*

$$L(y) = \{x: (x,y) \in T\}.$$

- A convenient characterisation of technology is the input distance function:

$$D_i(x, y) \quad = \quad \max\{\lambda : \lambda \geq 0,\ x / \lambda \in L(y)\}.$$

- Radial input efficiency measure ($DF_i(x,y)$) is the inverse of the input distance function.

5. Technology and Cost Functions

Results on impact convexity on cost function (1)

Briec et al (2004) prove:

• Costs evaluated on non-convex technologies are higher or equal to costs evaluated on convex technologies:

$$C^{NC}(y,w) \quad \geq \quad C^{C}(y,w).$$

• In the case of (i) CRS and (ii) a single output:

$$C^{NC}(y,w) \quad = \quad C^{C}(y,w).$$

Note: The above convex technologies are similarly the most conservative, inner bound approximations of technology satisfying (A.1) to (A.5).

Source: Briec et al (2004) , p. 171.

Proposition 4: Let the non-convex cost function $C^{NC,\Gamma}(p,y) = \min\{p \cdot x : x \in L^{NC,\Gamma}(y)\}$ and let the convex cost function $C^{C,\Gamma}(p,y) = \min\{p \cdot x : x \in L^{C,\Gamma}(y)\}$. Then, we have the following properties:

(1) In general: $C^{C,\Gamma}(p,y) \leq C^{NC,\Gamma}(p,y)$.
(2) In the case of $\Gamma = CRS$ and a single output: $C^{C,\Gamma}(p,y) = C^{NC,\Gamma}(p,y)$.

5. Technology and Cost Functions

Results on impact convexity on cost function (3)

This relation reflects the property that cost functions are non-decreasing in outputs and convex (non-convex) in the outputs depending on whether the technology is convex (non-convex) (see Jacobsen (1970): Proposition 5.2) or Shephard (1970, 1974).

Source: Jacobsen (1970): Proposition 5.2 (Q9) on p. 765.

PROPOSITION 5.2: (Q.9): *If P has a convex graph then Q is convex in u;*

(Q.10): *if P is positively homogeneous of degree k ($\neq 0$), then Q is positively homogeneous of degree $1/k$ in u;*

(Q.11): *if P has a closed graph,*[7] *then for all $p > 0$, Q is l.s.c. in u.*

Source: Shephard (1974): Proposition 5.2 on p. 15.

Q.10 $Q(u,p)$ is a convex function of u on R^m_+ if the graph of $u \to L(u)$ is convex.

5. Technology and Cost Functions

Results on impact convexity on cost function (4)

Figure: VRS Cost Function in the Single Output for Hydro-power Plant 5

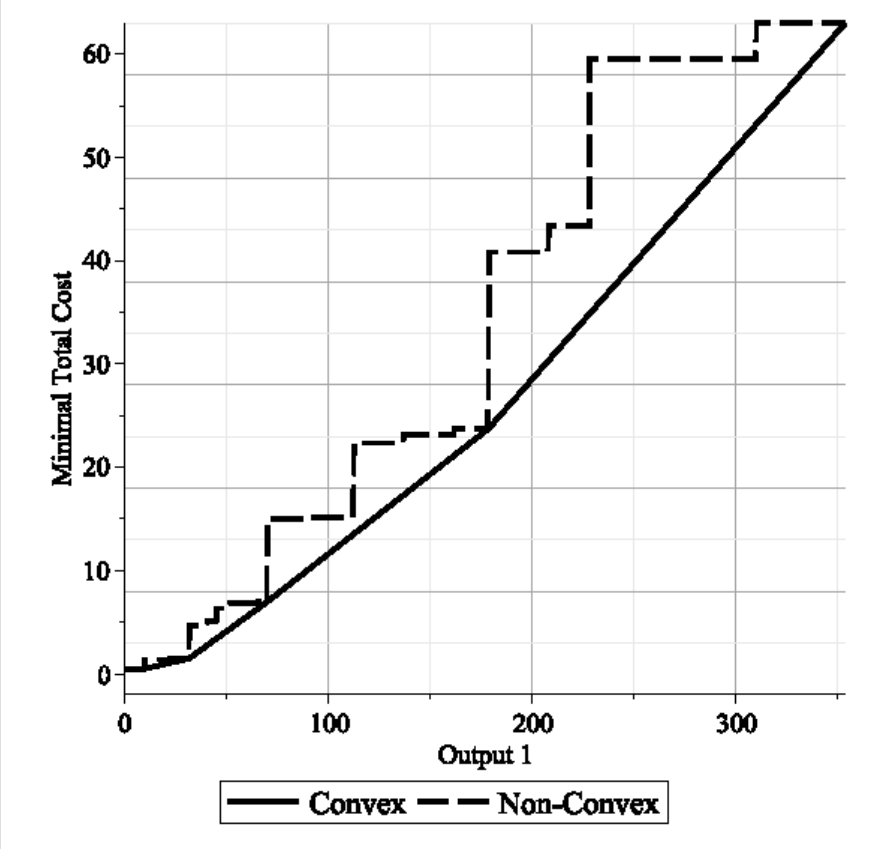
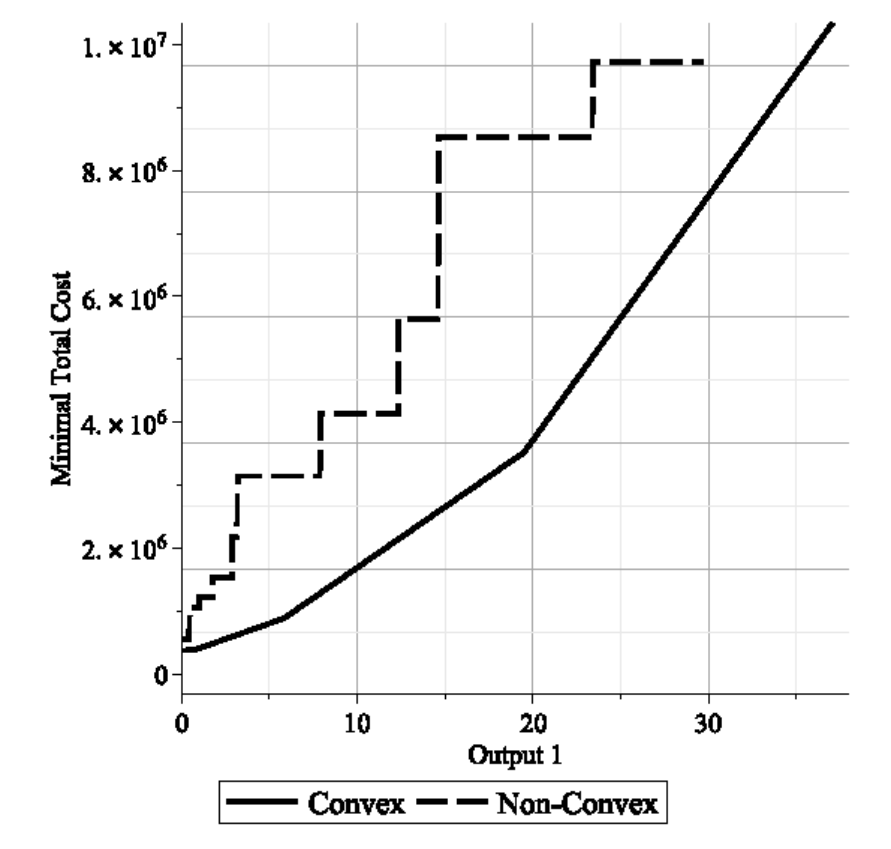


Figure: VRS Cost Function in Output 1 for Fruit Producer 19



5. Technology and Cost Functions

Results on impact convexity on cost function (5)

Advanced micro-economic textbooks ignore this issue when discussing duality (e.g., Varian (1992: p. 84)).

This proposition shows that the cost function for the technology $V(y)$ is the same as the cost function for its convexification $V^*(y)$. In this sense, the assumption of convex input requirement sets is not very restrictive from an economic point of view.

Let us summarize the discussion to date:

(1) Given a cost function we can define an input requirement set $V^*(y)$.

(2) If the original technology is convex and monotonic, the constructed technology will be identical with the original technology.

(3) If the original technology is nonconvex or nonmonotonic, the constructed input requirement will be a convexified, monotonized version of the original set, and, most importantly, the constructed technology will have the same cost function as the original technology.

We can summarize the above three points succinctly with the fundamental principle of duality in production: *the cost function of a firm summarizes all of the economically relevant aspects of its technology.*

Duality cost function & input distance f. established under convexity of input sets.
Empirical methodologies impose convexity on technology.
While this difference is known to matter for the cost function, textbooks ignore this issue.

5. Technology and Cost Functions

Results on impact convexity on cost function (6)

Advanced micro-economic textbooks ignore this issue when discussing the properties of the cost function (e.g., Jehle and Reny (2011: p. 138)).

THEOREM 3.2 ***Properties of the Cost Function***

If f is continuous and strictly increasing, then $c(\mathbf{w}, y)$ is

1. *Zero when $y = 0$,*
2. *Continuous on its domain,*
3. *For all $\mathbf{w} \gg 0$, strictly increasing and unbounded above in y,*
4. *Increasing in $\mathbf{w}$,*
5. *Homogeneous of degree one in $\mathbf{w}$,*
6. *Concave in $\mathbf{w}$.*

Moreover, if f is strictly quasiconcave we have

7. *Shephard's lemma: $c(\mathbf{w}, y)$ is differentiable in $\mathbf{w}$ at $(\mathbf{w}^0, y^0)$ whenever $\mathbf{w}^0 \gg 0$, and*

$$\frac{\partial c(\mathbf{w}^0, y^0)}{\partial w_i} = x_i(\mathbf{w}^0, y^0), \qquad i = 1, \ldots, n.$$

If this issue is not mentioned in these books, then it must not be important, no?
The answer is an empirical issue: we simply do not know whether it matters.

5. Technology and Cost Functions

Criticism of the convexity assumption (1)

Critique of convexity assumption can consider a variety of arguments:

• Convexity justified because of time divisibility of technologies:

This ignores setup costs (some of which may be sunk) that make switching between the underlying activities costly.

• Convexity is not a primitive axiom, but implied by additivity and divisibility.

(i) Perfect divisibility of inputs and/or outputs is a most debatable assumption.

Most operations management problems in industry and distribution involve indivisibilities and input fixities resulting in integer, possibly non-linear optimization problems.

In general, all production processes have some lower limit below which a process cannot possibly be scaled down realistically.

Thus: Divisibility is questionable (see Scarf (1994) or Winter (2008))

5. Technology and Cost Functions

Criticism of the convexity assumption (2)

(ii) Additivity is essential to define free entry, but presupposes spatial separation and non-interaction which are both debatable (see Winter (2008)).
Since additivity relates to the aggregation of results of activities occurring in geographically distinct places, transportation and coordination costs must be small to be safely ignored.
When activities are close for transportation costs to be negligible, then the risk of production externalities looms when activities get "too close" to create interactions.

(iii) Additivity and divisibility do not only imply convexity, but also CRS.
The CRS assumption is at odds with indivisibilities and the lower bounds on the scaling of almost all production processes (see Scarf (1994: 114-115) for a sharp critique).

> Both linear programming and the Walrasian model of equilibrium make the fundamental assumption that the production possibility set displays constant or decreasing returns to scale; that there are no economies associated with production at a high scale. I find this an absurd assumption, contradicted by the most casual of observations. Taken literally, the assumption of constant returns to scale in production implies that if technical knowledge were universally available we could all trade only in factors of production, and assemble in our own backyards all of the manufactured goods whose services we would like to consume. If I want an automobile at a specified future date, I would purchase steel, glass, rubber, electrical wiring and tools, hire labor of a variety of skills on a part–time basis, and simply make the automobile myself. I would

6. Empirical Results
Capacity Results on a Test Data Set

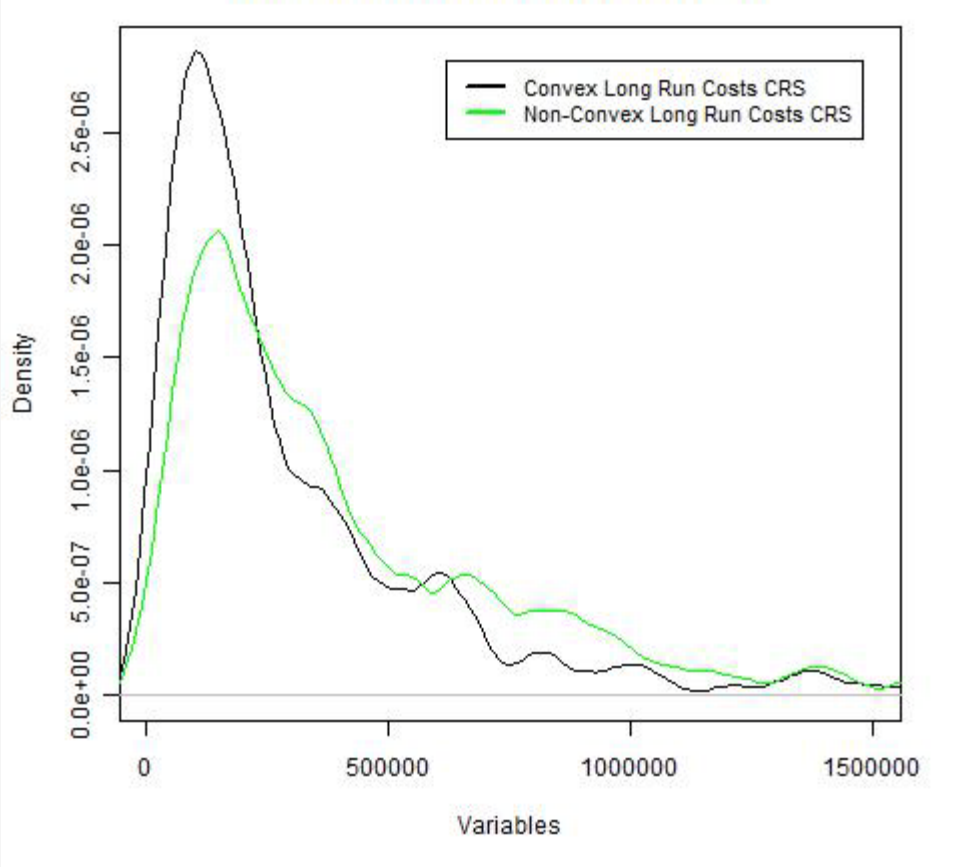
- As a preliminary empirical analysis, we apply 3 capacity notions to a small panel of 3 years of French fruit producers.

- Based on annual accounting data collected in a survey (Ivaldi et al. (1996)).
- Two outputs: (i) production of apples, and (ii) aggregate of alternative products.
- Prices and quantities of 3 inputs: (i) capital (incl. land), (ii) labour, & (iii) materials.
- 184 farms are available: 130, 135 & 140 have records in 1984, 1985 & 1986 resp. yielding 405 observations.

6. Empirical Results
Capacity Descriptive Statistics & Impact of Convexity

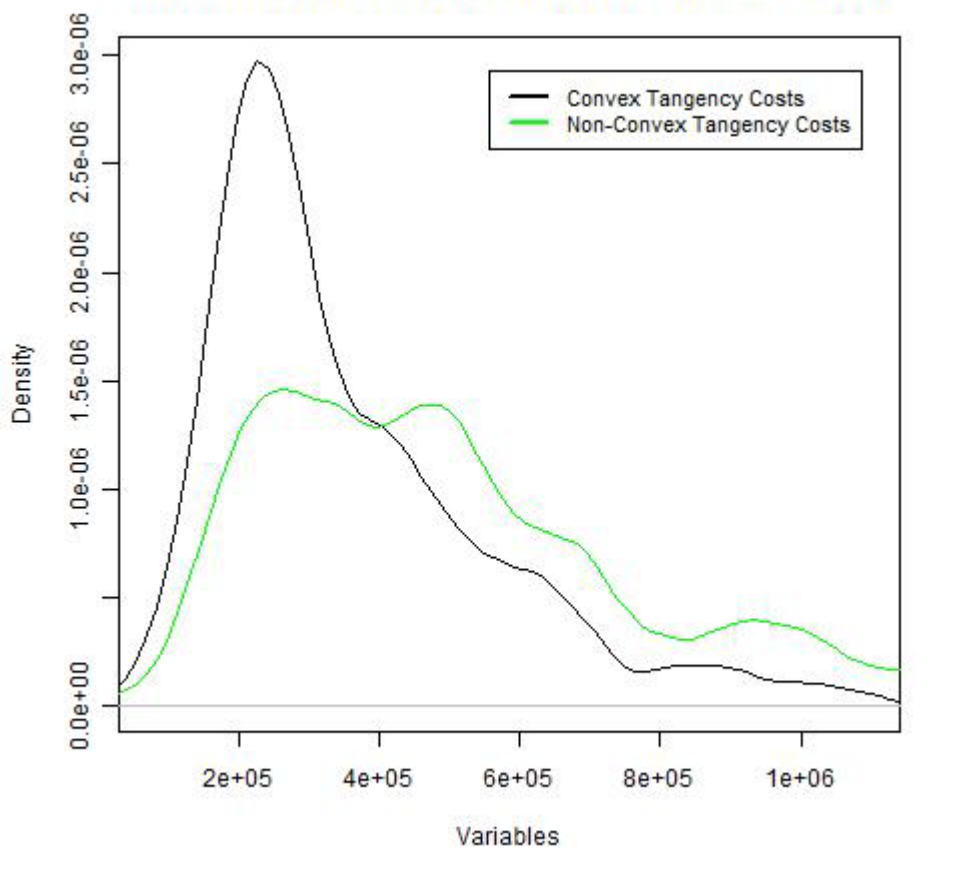
	Opt. Cost CRS		Tangency cost modified fixed inputs		PCU	
	Convex	Non-Convex	Convex	Non-Convex	Convex	Non-Convex
Trimmed mean	302046.0	430273.8	406443.6	646937.8	22.27	16.41
10th Percentile	59639.3	90648.5	171701.0	211163.7	2.48	1.97
25th Percentile	104092.9	159629.8	225669.2	310735.6	4.47	3.39
Median	201810.8	311058.8	302346.4	494061.9	9.94	6.98
75th Percentile	428748.3	655480.3	510322.6	845695.3	23.49	17.88
90th Percentile	834635.9	1127155.8	886693.0	1681899.8	95.77	75.02
Li - test	Ho rejected		Ho rejected		Ho rejected	

6. Empirical Results
Capacity Density Optimal Cost CRS



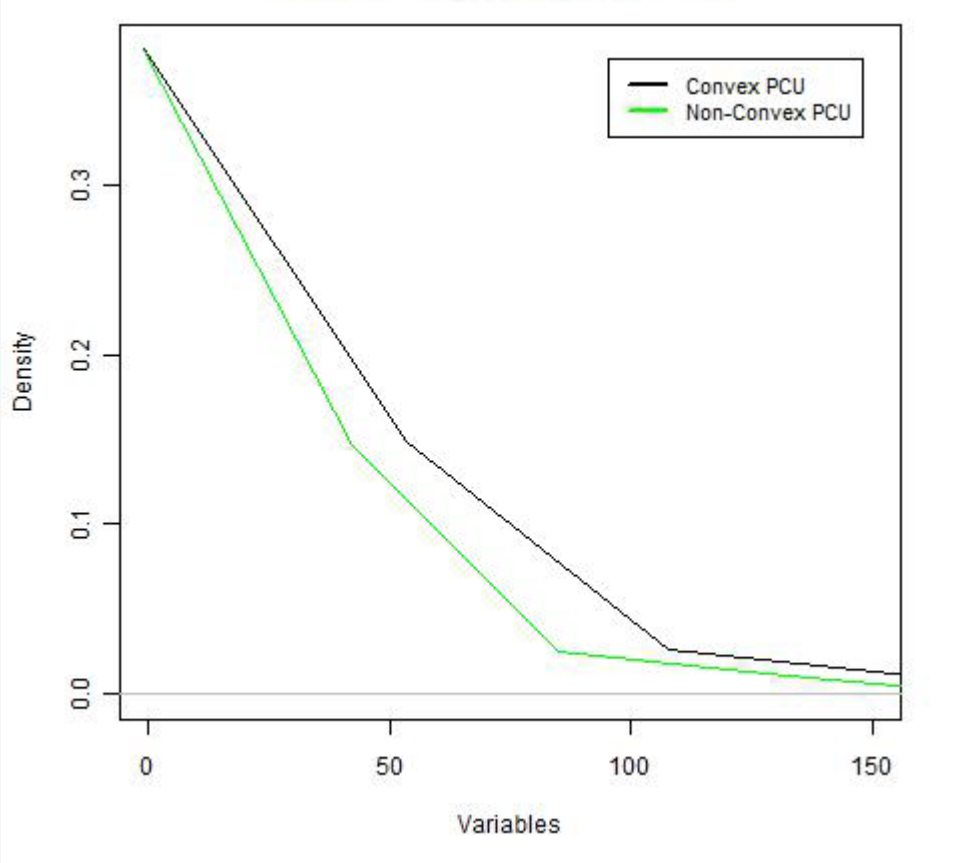
6. Empirical Results

Capacity Density Tangency Cost Modified Fixed Inputs



6. Empirical Results

Capacity Density PCU (output effic. measure without x_v limits)



6. Empirical Results

- We apply the primal approach to annual survey cost data from the US Albacore industry.
- There are 122 observations of catches of albacore and an aggregate output of other species. There is two variable inputs (labor and oil) and two fixed inputs (capital and other fixed cost).
- We find both plant capacity measures and industry under convex and non-convex technologies.
- The results are illustrative having the purpose to show the impact of the assumption of convexity.

6. Empirical Exercise and Results

Results from the Primal Approach – Albacore Data

Plant capacity measures: convex and non-convex

	PCU	NCPCU
Min	1,00	1,00
10%	1,00	1,00
25%	1,12	1,00
50%	1,95	1,17
75%	3,49	1,96
90%	5,58	4,10
Max	31,56	22,40

Plant capacity measures are in general lower under non-convexity.

E.g., the average value is 1.95 under convexity versus only 1.17 under non-convexity.

6. Empirical Exercise and Results

Results from the Primal Approach – Albacore Data

Industry configuration under convex vs. non-convex capacity estimates

	Convex	Non-convex
active	74	80
partly active	3	3
not active	45	39

Under non-convexity, the optimal industry configuration maintains 8% more active vessels than under convexity.

7. Conclusions

- We have raised questions concerning the assumption of convexity. In general, the assumption of non-convexity gives more ”conservative” results.

- Empirically it is possible to apply the primal approach under both convexity and non-convexity at the firm and industry level. The approach can handle both the single output and the multiple output case.

- Dual cost function approaches exists under both convexity and non-convexity (the latter hitherto ignored) and from an economic point of view these approaches have some advantages.

- Some other CU measures exist in the literature. Some of these measures are not yet developed at the industry level. Furthermore, the assumption of non-convexity has not yet been explored at the industry level.

- In general, one has to be careful about using these non-parametric measures to small scale fishermen?