SOLUTION

Engineering Systems Analysis for Design

Mid-Semester Quiz **October 22, 2009**

This is a closed book exercise.

Computers and other wireless enabled devices for communication with web and outside are not allowed.

You may use old-fashioned, non-communicating calculators that are not miniature computers with extensive memory (if you have them! And if so, show me first…)

In any case, you should not need any mechanical aid.

Organization of Quiz
It has 4 parts:
1. Concepts concerning Flexibility in General
2. Concepts of Evaluation and Production Functions
3. Mechanics of Deterministic Evaluation
4. Mechanics of Production Functions

Grade Table
There are 90 points possible. Points associated with each question correspond to the estimated time it might take to answer them.

Item	**Score**	
	Max	**Yours**
Your Name (provided we can read it)	1	
Concepts concerning Flexibility	25	
Concepts of Evaluation and Production Functions	32	
Mechanics of Deterministic Evaluation	11	
Mechanics of Production Functions	21	
Total	90	

I have completed this test fairly, without copying from others, a book, or the web.

Please sign your name legibly JOHN Q. SOLUTION **(1 point)**

SOLUTION

1. Concepts Concerning Flexibility (25 points)

Respond to these questions:

"The forecasting methods on technology and market are established"
Discuss: Is it true? What are its implications for our ability to forecast accurately? **(3 points)**

While it is true that forecasting methods – relying on statistics and other complex mathematical models – might indeed be established, models used for predictions are only as good as the assumptions put into it. That is, statistical models (and others) need to make a series of assumptions about the historical data range to use (if any is available), the kind of relationship that best captures the overall trend, the underlying probability distributions for different variables causing the observed data, the relationship between the probability distributions (e.g. addition, multiplication), etc. Therefore even if the techniques are established, there is absolutely no guarantee forecasts will be accurate. Trend breakers exist and always will – we have just noticed one with the recent economic crisis. As seen in class with many examples, most forecasts are wrong (oil, technology, weather, etc). Our ability to forecast accurately is therefore extremely limited.

3 pts for answering the questions, and for quality of overall discussion (i.e. no need to have the specified points exactly as said above).

Discuss our current ability to forecast future conditions for our designs: what kind of accuracy do you think is possible in your field (plus or minus what percent in how many years)? Justify your response. **(4 points)**

Our ability to forecast future conditions in many fields for our designs is extremely limited. This is because many engineering systems that we design today will operate (hopefully) over long lifecycles (~10 years). Therefore, it is most likely these systems will "see" many changes in their environment over such a long time period, affected by markets, technology, amount of resources available, etc.

The accuracy assessment depends on the example quoted. One observation to be made is that typically we are overoptimistic about predictions, and overconfident about the accuracy, as demonstrated in class by the simple question-and-answer game (e.g. length of Nile River, population of Butan, etc.)

3 pts for answering the questions, and for quality of overall discussion

To what extent will better statistical techniques enable us to improve predictions? **(2 points)**

It is unlikely that statistical techniques relying on historical data, even if "better" from a mathematical standpoint, will enable us to improve predictions (1 pt.). This is because these techniques are subject to many different critical assumptions about the data (e.g. range selected, assumption about relationship between variables, choice of relevant independent and dependent variables, etc) that can greatly affect their predictive powers. As mentioned in, they are highly subject to the GIGO (Garbage In = Garbage Out) principle.

3 pts for answering the questions, and for quality of overall discussion

Why might we need flexibility in design? **(3 points)**

Because we do not know exactly how the future will unfold, we need to recognize explicitly that it is most likely to change in a way that we cannot envision today, and position ourselves to adapt to different possible futures. To ease switching between different design configurations, we need to plan physical contingencies in the design in the early stages of design. Switching might be possible even without planning contingencies, but most likely at a higher cost. Thinking ahead will help positioning ourselves to reduce exposure to downside events, but also capture unexpected upside opportunities with the goal of improving the expected value and performance of the system.

3 pts for answering the questions, and for quality of overall discussion

How can flexibility add value to design? **(3 points)**

As mentioned above, thinking ahead helps position the system to reduce exposure to downside events, and to capture unexpected upside opportunities. Reducing the negative effects of downside risk by reducing initial investment, or by lowering switching cost between different scenarios help reduce expected costs and therefore increase the expected value. Positioning the system to capture unexpected upside opportunities is also a contributing factors to value improvement. Flexibility allows us to play on both sides of uncertainty: the downsides but also the upsides!

3 pts for answering the questions, and for quality of overall discussion

Why is Expected Value an important concept for the discussion of flexible design **(2 points)**

Because it recognizes that reality deals with a possible distribution of value outcomes. The expected value is a good metric to guide decision-making about design, although one needs to recognize this value may never be observed. Expected value enables us to consider both the downsides and the upsides, which are two important facets of uncertainty. It is also a middle ground between decision-makers that have risk-seeking and risk-averse preferences. Because an expected value may not occur explicitly, it forces decision-makers to recognize there is a range of possible value outcomes, rather than one. This changes the design paradigm to optimizing design to a limited set of forecasted conditions, to recognizing a priori the range of outcomes and therefore planning the design accordingly. It removes the notion of a "best" or "optimal" design, because no one design will be "best" in all possible conditions.

2 pts for answering the questions, and for quality of overall discussion

"Flexibility is nice to have, but it's always an extra cost"
"Flexibility can provide win-win solutions, better performance at lower cost"
Discuss these contrasting statements. Which is true? **(8 points)**

The first statement is false, while the second is correct (2 pts.).

As demonstrated with the parking garage case study, a flexible design may sometimes come at a lower cost due to smaller design, phased expansion, and lower initial CAPEX. In other cases, it is true that planning for contingency might come an additional cost, but the fact that examples exist that have a lower cost than a benchmark design falsifies the first statement

3 pts for quality of overall discussion and examples provided to support assertion.

Similarly as demonstrated in many case studies (e.g. aerospace, mining, oil, real estate), flexibility can indeed provide better value at lower cost. It is therefore a win-win solution for decision-makers that are often concerned with high profit opportunities that minimize initial investment cost (and risk).

3 pts for quality of overall discussion and examples provided to support assertion.

SOLUTION

2. Concepts Concerning Production Functions (32 points)

Write short definitions or explanations of the following.
Full marks only for conceptually precise responses.

Production Function **(2 points)**

…is the functional relationship between a set of inputs **(1 pt.)** and the maximum or technically efficient **(1 pt.)** output. Commonly modeled for the one-output form via the Cobb-Douglas function **(0 pts.)**.

Technical Efficiency **(2 points)**

The maximum production level or amount of output **(1 pt.)** that can be achieved for a given **(1 pt.)** set of inputs.

Isoquant **(2 points)**

The set of all input combinations that yield the same output **(1 pt.)** in a technically efficient **(1 pt.)** process.

In light of the above, to what extent is it possible to justify a statement that "This is the optimal technical design" **(2 points)**

Unless the isoquant has only one element from a strict technical perspective, there are many equally efficient designs and none of them are better than the others (1 pt.). Therefore, speaking of an optimum is not meaningful (1 pt.).

Returns to Scale **(2 points)**

The level at which production or output changes (1 pt.) when all inputs are changed or scaled by a particular amount (1 pt.)

Increasing returns to scale: define, give reasons for their occurrence in practice, and give examples of industries that have this feature **(2 points)**

Occur in a production function when the same change in scale in **all** input levels **(1 pt.)** leads to a greater corresponding change in the scale of the level of output **(1 pt.)**. **1 pt** if correct example provided (e.g. ships, aircraft, thermal power plants)

Economic Efficiency: define and contrast with Technical Efficiency **(2 points)**

Economic efficiency is defined by combination of technical efficiency (production function) **(1 pt.)** and economic (in general, value) **(1 pt.)** relationships. Defining economic efficiency as the most economic output was not acceptable; you need to define economic! The difference between economic and technical efficiency is that the former maximizes value **(1 pt)**. Two points max.

Optimality conditions for Economic Efficiency **(2 points)**

The point where the budget line and isoquant are tangent for a particular budget and production levels (1 pt.). Mathematically, this is $MPx/MPy = MCx/MCy$ (1 pt.)

SOLUTION

Meaning and Significance of "Balanced Design" **(2 points)**

The characteristic of a balanced design is that each factor input contributes to product equally per unit value (1 pt.) -- MP/MC is same (balanced) for all inputs (1 pt.).

Expansion Path **(2 points)**

The set of inputs that minimize cost **(1 pt.)** for all levels of production **(1 pt.)** or the locus of input combinations that define economically efficient design

Why might the expansion path be non-linear? What are the design implications of this possibility? **(3 points)**

The expansion path might be non-linear due to the non-linear nature of the production function and input cost function… (1 pt.) The implication is that designs, in general, do not scale up or down linearly, there are changes in proportions as we scale up or down (1 pt.). We should expect changes in the relative inputs (1 pt.).

Output Cost Function: define and compare with input cost function **(3 points)**

Total cost as a function of the output **(1 pt.)**, assuming technical and economic efficiency **(1 pt.).** The input cost is the relationship between the inputs that create the budget cost available **(1 pt)**.

Discount Rate: define and compare with interest rate **(3 points)**

Rate (percent /period) used to evaluate the cash flows of a project over time **(1 pt.).**
The discount rate represents the opportunity cost of the resources used for the project **(1 pt.)**
An interest rate (e.g. at the bank, obligation, or a bond) is typically a minimum, or a safe investment, and you would not reasonably accept a risky project unless it returned more – had a higher opportunity cost – than the interest rate (1 pt.)

WACC: define concept and discuss advantages and disadvantages for use as discount rate **(3 points)**

Weighted Average Cost of Capital **(1 pt.)**
… the rate of return achieved by an organization on previous projects having similar risk **(1 pt.)**
… or as average rate required by lenders and investors external to the project. **(1 pt.)**
… often used as a measure of the discount rate that should be used for an average project **(1 pt.)**
… In financial terms, this is $R = Re \times E/(E+D) + Rd \times D/(E+D) \times (1-t)$ **(1 pt.)**
Advantage: provides a "systematic" way of determining the discount rate for a given project, reflecting the return required to a particular level of risk (1 pt.)
Disadvantage: is a "static" measure, and therefore does not account for the dynamics and changes in risk level as a project evolves in time (1 pt.)
Three points max.

SOLUTION

3. Deterministic Evaluation of Projects (11 points)

Consider the project with the following revenues and costs:

	Year				
	0	1	2	3	4
Revenues		250	400	520	360
Costs	1000	30	37	55	68
Net Cash Flow	**-1000**	**220**	**363**	**465**	**292**
$(1+r)^N$	**1**	**1.10**	**1.21**	**1.33**	**1.46**
Present value net cash flow	**-1000**	**200**	**300**	**350**	**200**

Assume a discount rate of r = 10%. Use no more than 3 significant figures

Define Net Present Value and calculate it for this case (**5 Points**)

Net present value is the sum total of net cash flows **(1 pt.)** appropriately discounted to the present time **(1pt.)** using appropriate discount factor. Here, NPV = 50. **(3 pts.)**

According to conventional practice, how would you calculate the benefit/cost ratio? What are the major advantages and disadvantages of the benefit/cost ratio as a criterion of evaluation? **(3 points)**

The benefit-cost ratio is the ratio of the present values of **all** revenues to **all** costs. **(1 pt.)** That is, while the NPV can simply discount the net cash flow for each year, the B-C ratios discount each separately. Correspondingly, it is not 1050/1000

Formula for benefit-cost ratios:

$$\frac{Benefit}{Cost} = \frac{PV \;\; all \;\; revenues}{PV \;\; all \;\; costs} = \frac{PV \;\; R}{PV \;\; C_k + C_r} \quad \text{(1pt.)}$$

$$\frac{Net \;\; Benefit}{Cost} = \frac{PV \;\; all \;\; net \;\; revenues}{PV \;\; investments} = \frac{PV \;\; R - C_r}{PV \;\; C_k}$$

R represents the revenues, Ck the capital investment, and Cr the recurring cost.

Advantages: simple to calculate; allows a rating of the alternatives; unit-less **(1 pt.)**
Disadvantages: biased against recurring costs **(1 pt.)**; does not give a definitive ranking; may disagree with NPV

In high recurring costs projects, Cr is high compared to Ck because it incurs high operating/recurring costs (also typically associated with higher revenues). Given two projects, one with high recurring cost and one with lower recurring cost, having the same Ck, the B/C ratio will be lower for the high recurring cost project because Cr is higher, even though its NPV might be higher than the other project. This causes the bias against recurring projects with benefit-cost ratio approach.

Max 3 pts.

SOLUTION

Define and Calculate the Pay Back Period. What are the major advantages and disadvantages of this criterion of evaluation? **(3 points)**

Pay Back Period is the time period that will be required to recuperate the initial investment as based upon undiscounted **(1 pt.)** future cash flows

Formula for payback period:

$$Payback\ \ Period = \frac{Initial\ \ Investment}{Annual\ \ Net\ \ Undiscounted\ \ Cash\ \ Flows}$$

But this formula assumes the same annual net undiscounted benefits every year!

Here, we have different undiscounted cash flows every year. So we need to add up the cash flows every year until they get to 1000, which is the initial investment. The first two years contribute 220 + 360 = 580 towards this. So we already have 2 years counted. The third year, we need 1000 – 580 = 420 of the 465 available, which represents 420/465 = 90% of the year. So we count 2 years + 0.9 year ≈ 2.9 years.

$$PBP = 2 years + \frac{1000-(220+360)}{465} \approx 2.9\ \ years \qquad \textbf{(1 pt.)}$$

Advantages: useful when short turn-around is a priority; really simple; avoids the difficulty of picking the proper discount rate; avoids speculative long-term forecasts **(1 pt)**

Disadvantages: ignores cash flows after the initial pay-back period (that could turn negative), projects could become very profitable later on!; useless for ranking projects with lives beyond the shortest pay-back period; does not account for the time value of money **(1 pt.)**

Three points max, but must calculate the PBP correctly and have partial answers for each part in order to receive full credit.

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SOLUTION

4. What's the best design? (21 points)

Your production function is: $Z = R^{0.3} S^{0.8}$

And the cost of the resources is: $C = R^3 + 5 S^2$

Note: In calculating answers, you may leave exponents in fractional form rather than estimating numbers in decimal form. For example, $0.4^{2/3}$ would be acceptable.

What can you say immediately, by inspection, about the returns to scale? The economies of scale? Explain answers **(3 points)**

RTS: $\alpha_R + \alpha_S = 1.1 > 1$ Therefore IRTS **(2 pts.)**
EOS: it is too early to tell **(1 pt.)**

We need the output cost function and look at how cost behaves as we increase the output level, which is why it is too early to say anything.

What is the economically efficient relationship between the resources R and S? **(6 points)**

$$MP_R = \frac{\partial Z}{\partial R} = \frac{0.3Z}{R} \quad MP_S = \frac{\partial Z}{\partial S} = \frac{0.8Z}{S} \quad MC_R = \frac{\partial C}{\partial R} = 3R^2 \quad MC_S = \frac{\partial C}{\partial S} = 10S$$ **(4 pts.)**

$$\frac{MP_R}{MP_S} = \frac{MC_R}{MC_S} \Rightarrow \frac{3S}{8R} = \frac{3R^2}{10S} \Rightarrow 5S^2 = 4R^3 \quad or \quad S = (4/5)^{1/2} R^{3/2}$$ **(2 pts.)**

What is the associated cost function? **(8 points)**

Express Z as function of R (or S) using the expansion path relationship above, and express R (or S) as function of Z

$$Z = R^{3/10}\left((4/5)^{1/2} R^{3/2}\right)^{8/10} = (4/5)^{8/20} R^{6/20} R^{24/20} = (4/5)^{2/5} R^{3/2}$$

$$\Rightarrow Z^2 = \left((4/5)^{2/5} R^{3/2}\right)^2 = (4/5)^{4/5} R^3$$ **(4 pts.)**

$$\Rightarrow R^3 = (5/4)^{4/5} Z^2 = (5/4)^{4/5} Z^2$$

And plug into the input cost function to get an expression of C as a function of output Z

$$C = R^3 + 4R^3 = 5R^3 = 5 \cdot (5/4)^{4/5} Z^2$$ **(4 pts.)**

Note: if calculation error occurs, only penalize once, with maximum of 3 pts (which is half the points in previous part). Important is the reasoning.

What can you now say about the economies of scale? Explain why this is so **(4 points)**

Expressing C as a function of Z shows that C increases with a power law of 2 as Z increases, or a = 2 > 1 **(2 pts.)**. This case shows diseconomies of scale **(2 pts.)**