

This exam has 67 points. There are eight questions on the exam; you should work all of them. Most of the questions are worth 8 points each but Questions 1, 3, and 5 are worth 9 points each.

Put your answers to the exam in a blue book or on blank sheets of paper.

Answer the questions using as much precision and detail as the time allows. Correct answers which are unsupported by explanations will not be awarded points. Therefore, even if you think something is “obvious,” do not omit it. If you omit anything, you will not get credit for it. You get credit for nothing which does not explicitly appear in your answer. If you have questions about the adequacy of an explanation of yours during the exam, ask me.

For the question involving a figure, you may either draw on the original figure, then remove it from the exam and include it with your answers; or you may redraw the figure on your answer sheet. If you choose the first option, write your first name on each page (to prevent confusion if the page gets separated from the rest of your exam).

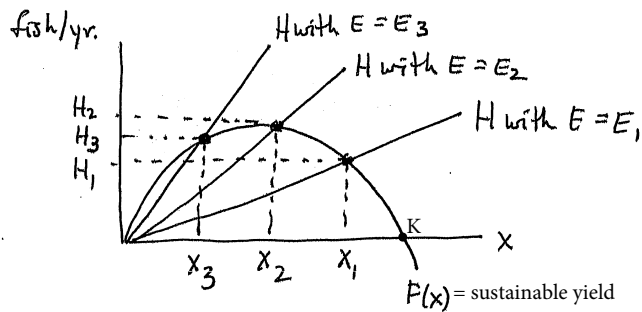


Figure 1

Answer all of the following eight questions.

1. **[9 points]** Explain everything about Figure 1. For some examples: what are the axes? Why is " $F(x) = \text{sustainable yield}$ "? Why are the F and H functions shaped as they are? What is E ? What is surprising about the relationship shown between H and E ?
2. **[8 points]** Figures 2 and 3 explain the intuition of entropy in different ways. Explain which one is more correct and, briefly, why. In Figure 2, ignore its points (1), (2) and (4). In Figure 3, the first two paragraphs are the most important.

3.5 THERMODYNAMICS

The thermodynamics and the rate of a reaction determine whether the reaction proceeds. The thermodynamics of a system is described in terms of several important functions:

- (1) ΔE , the change in **energy**, equals q_v , the heat transferred to or from a system at constant volume:
 $\Delta E = q_v$.
- (2) ΔH , the change in **enthalpy**, equals q_p , the heat transferred to or from a system at constant pressure: $\Delta H = q_p$. Since most organic reactions are performed at atmospheric pressure in open vessels, ΔH is used more often than is ΔE . For reactions involving only liquids or solids: $\Delta E = \Delta H$. ΔH of a chemical reaction is the difference in the enthalpies of the products, H_p , and the reactants, H_R :

$$\Delta H = H_p - H_R$$

If the bonds in the products are more stable than the bonds in the reactants, energy is released, and ΔH is **negative**. The reaction is **exothermic**.

- (3) ΔS is the change in **entropy**. Entropy is a measure of randomness. The more the randomness, the greater is S ; the greater the order, the smaller is S . For a reaction,

$$\Delta S = S_p - S_R$$

- (4) $\Delta G = G_p - G_R$ is the change in **free energy**. At constant temperature,

$$\Delta G = \Delta H - T\Delta S \quad (T = \text{absolute temperature})$$

For a reaction to be spontaneous, ΔG must be negative.

Figure 2. Excerpt from p. 36 of *Schaum's Outline of Theory and Problems of Organic Chemistry* by Herbert Meislich (1999).

19.2 Dispersal of Energy: Entropy

We have shown that we cannot use energy itself as an indicator of spontaneity because energy is conserved in any process; we always end up with the same amount of energy as we had at the beginning. Imagine dropping this book on the floor. (But don't actually do it!) It would fall spontaneously. The initial potential energy it has from being a certain distance above the floor is converted to kinetic energy. When the book hits the floor, the kinetic energy of the book is converted into other forms of kinetic energy: acoustic energy and thermal energy of the book, floor, and air, since these are all heated up somewhat. Through all of these processes, the total energy is conserved. There is a directionality to this process, however. The book will spontaneously fall to the ground, but we will not observe a book on its own jump spontaneously from the floor up to a desk. Is there a way to predict this directionality?

Let us consider the initial and final states for this process. Initially, the energy is concentrated in the book—the book has a certain potential energy as it is held above the floor. At the end of the process, the energy has been dispersed to the air, floor, and book. The energy has gone from being concentrated to being more dispersed. This is the indicator for which we have been searching. *In a spontaneous process, energy goes from being more concentrated to being more dispersed.*

There is a state function (◀ Section 5.4) called **entropy** (S) that allows us to quantify this. The **second law of thermodynamics** states that *a spontaneous process is one that results in an increase of the entropy of the universe*. In a spontaneous process, therefore, $\Delta S(\text{universe})$ is greater than zero; this corresponds to energy being dispersed in the process.

Because thermal energy is caused by the random motion of particles, potential energy is dispersed when it is converted to thermal energy. This conversion occurs when energy is transferred as heat, q . It is therefore not surprising that q is a part of the mathematical definition of ΔS . This is not the whole picture, however, in part because q is not a state function. In addition, the effect of a given quantity of energy transferred as heat on energy dispersal is different at different temperatures. It turns out that a given q has a greater effect at a lower temperature than at a higher temperature; that is, the extent of energy dispersal is inversely proportional to the temperature.

Our proposed definition for ΔS is thus q/T , but this is still not quite correct. We must be a little more specific about q . The value of q used in the calculation of an entropy change must be the energy transferred as heat under what are called *reversible conditions*, q_{rev} (see *A Closer Look: Reversible and Irreversible Processes*). Adding energy by heating an object slowly (adding energy in very small increments) approximates a reversible process. Our mathematical definition of ΔS is therefore q_{rev} divided by the absolute (Kelvin) temperature:

$$\Delta S = \frac{q_{\text{rev}}}{T} \quad (19.1)$$

As this equation predicts, the units for entropy are J/K.

■ **Entropy** For a more complete discussion of entropy, see the papers by F. L. Lambert, such as "Entropy Is Simple, Qualitatively," *Journal of Chemical Education*, Vol. 79, pp. 1241–1246, 2002, and references therein. See also Lambert's site: www.entropysite.com. Finally, see A. H. Jungermann, "Entropy and the Shelf Model," *Journal of Chemical Education*, Vol. 83, pp. 1686–1694, 2006.

Figure 3. Excerpt from p. 863 of *Chemistry and Chemical Reactivity* by Kotz, Treichel, and Townsend (2008).

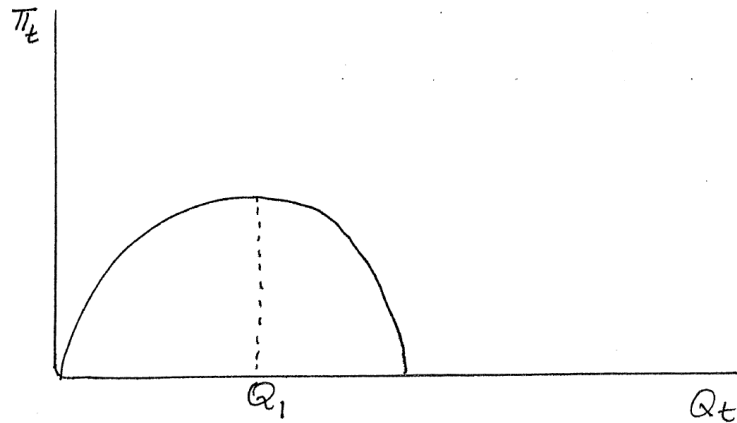


Figure 4

3. [9 points]

Suppose an exhaustible resource firm's graph of instantaneous profit π_t versus instantaneous quantity Q_t looks like Figure 4. Why, according to standard neoclassical theory, is Q_1 not the firm's optimal quantity? Tell me everything you know about the firm's optimal quantity or quantities.

Hint: You may use the following formula without any mathematical explanation of how it was derived:

$$\delta = \frac{-C'_{X8}}{MII_7} + F'_8 \frac{MII_8}{MII_7} + \frac{MII_8 - MII_7}{MII_7}.$$

4. [8 points] Criticize the significance of exponential exhaustion indexes.
5. [9 points] What important economic result does Figure 5 illustrate? Use Figure 5 to prove the result (at least in the special case illustrated by the figure).
6. [8 points] On p. 129 of your textbook, the authors write that
 ... economic theorists tend to dispute that WTP and WTA can differ so much simply because the theory says that they ought not to differ (and hence there must be something wrong with the empirical studies).

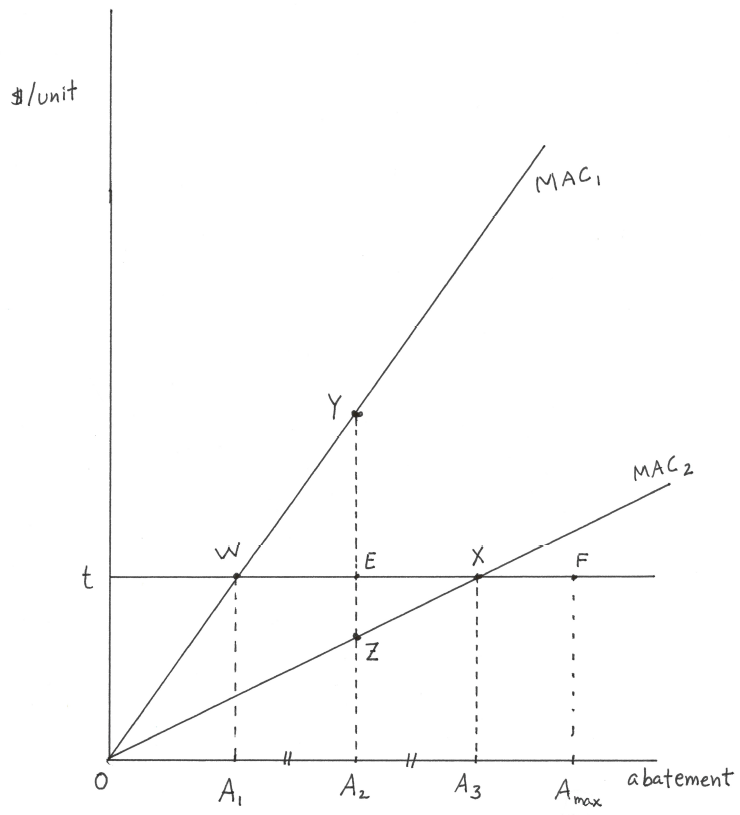


Figure 5

Critically evaluate this passage.

7. **[8 points]** In a blog post entitled “Bill Gates is very wrong” (<https://www.easterbrook.ca/steve/2010/01/bill-gates-is-very-wrong/>), a computer science professor at the University of Toronto who is interested in global warming wrote:

In a blog post that was picked up by the Huffington Post, Bill Gates writes about why we need innovation, not insulation [http://www.huffingtonpost.com/bill-gates/why-we-need-innovation-no_b_430699.html]. He sets up the piece as a choice of emphasis between two emissions targets: 30% reduction by 2025, and 80% reduction by 2050. He argues that the latter target is much more important, and hence we should focus on big R&D efforts to innovate our way to zero-carbon energy sources for transportation and power generation. In doing so, he pours scorn on energy conservation efforts, arguing, in effect, that they are a waste of time. Which means Bill Gates didn't do his homework.

The blog post author included Figure 6. Explain why one might think Gates was wrong to think near-term efforts to ameliorate global warming are rather unimportant. Figure 6 might be useful in your explanation.

8. **[8 points]** Some critics of Nicholas Stern's economic analysis of global warming say the discount rate he used was too low. If he had used a higher discount rate, what might have changed in his analysis? Why?

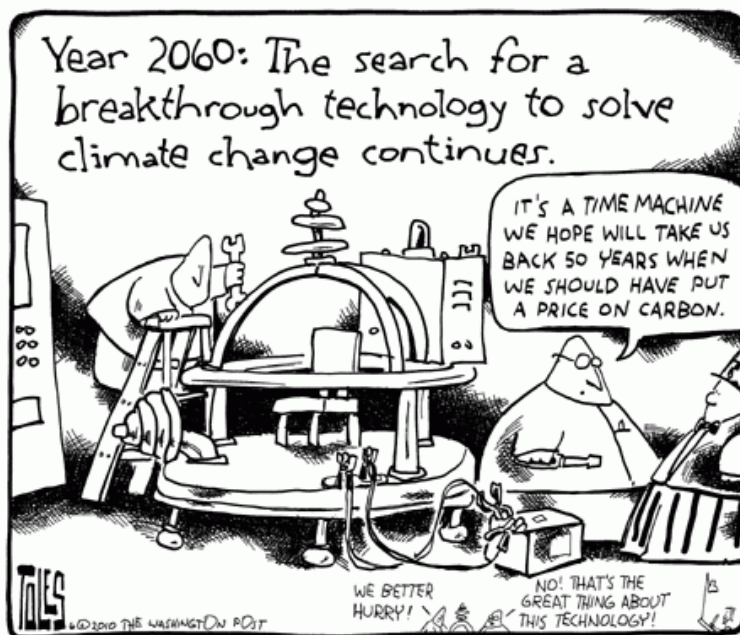


Figure 6

Answers to Exam 1, Econ. 5250, Fall 2019

1. [9 points] Ch. 16: new

The stock size (measured in biomass (kilograms) or in number of individuals) is x , the horizontal axis. The vertical axis is already correctly labeled as “fish/year.”

For any given x , the difference between the number of births and the number of natural (not human-caused) deaths is $F(x)$. At $x = 0$, births and deaths are zero, so the difference between them is zero, so $F(0) = 0$. At the carrying capacity K , births and deaths are again equal, so $F(K) = 0$. For $0 < x < K$, births exceed deaths, in this simple “logistic” model of growth, so $F(x) > 0$. For $x > K$, deaths exceed births, so $F(x) < 0$.

If humans kill H fish (H for “harvest”) then the fish population grows at a rate of $dx/dt = F(x) - H$. “Sustainable yield” is the value of H which makes $dx/dt = 0$ (so x is unchanging). If $dx/dt = 0$ then $H = F(x)$, explaining why $F(x)$ is sustainable yield.

With a constant level of effort E (E represents an index of inputs, such as number of fishermen (“fishers” is a gender-neutral term), size of nets, length of boats, etc.), the graph assume that H rises linearly with x , so a doubling of x would double H keeping E constant. This explains why H is linear in x holding E constant. If E increases ($E_1 < E_2 < E_3$), this greater effort brings forth greater H (holding x constant); this explains why as E gets larger, the straight lines in the graph become steeper. All the straight lines begin from the origin because with $x = 0$, $H = 0$ regardless of what E is.

When effort increases from E_1 to E_2 , steady-state H increases from H_1 to H_2 . This seems consistent with intuition: more fishing effort leads to more fish caught. However when effort increases even further, from E_2 to E_3 , steady-state H decreases, from H_2 to H_3 . This seems surprising. Its explanation is that with very high levels of effort and correspondingly low levels of stock size x , the only way to maintain sustainability is to have low levels of harvest.

2. [8 points] ch 2: new

Figure 2 (from a 1999 textbook in organic chemistry) bluntly says that “entropy is a measure of randomness.” This idea is incorrect, if one understands the word “randomness” in its ordinary sense; for example, the spontaneous (i.e., increasing-entropy) direction is for

a mixture of oil and water to separate, that is, to become more ordered, *less* “random.” This incorrect idea got its start in the late 19th century, when Boltzmann interpreted his quite correct equations of statistical mechanics as reflecting randomness, or probability, in nature, when they can more correctly be interpreted as having a combinatoric, non-probabilistic character. Erwin Schrödinger popularized this probabilistic interpretation of entropy in the mid-20th century.

Figure 3 (from a 2008 chemistry textbook) describes entropy in a much more subtle way, and does not mention “randomness” at all. Its primary definition is that entropy is a measure of energy concentration (and rising entropy corresponds to “dispersal of energy,” as the section title says). This is true in a mathematical, statistical-mechanical model, such as a model of electrons in different orbits around the nucleus of an atom, but the example in the first paragraph of the page (the book dropping to the floor) is not such a model: it is a macroscopic, non-mathematical model. So the definition is correct, even though the example does not really fit. (In the next few pages, which I did not give you, the book delves into statistical mechanics enough to give a better idea of what entropy “means” intuitively. However, when it then treats “dispersal of matter,” such as two ideal gases mixing, the authors, apparently unaware of the perfectly good 19th century explanation of why the gases spontaneously mix, start their explanation (p. 867) with: “[the 20th century theory of] quantum mechanics shows (for now, you will have to take our word for it) that. . .”)

(The marginal note in Figure 3 refers to Prof. F. L. Lambert, who I mentioned in class started the 21st century movement to reform how entropy is taught in undergraduate chemistry textbooks.)

3. **[9 points]** ch 18; Spr01 Final, question 4 (no old answer; this year’s question uses different and better mathematical notation in the equation, and adds a few words of clarification)

Q_1 is not the optimal quantity because it is not feasible to extract Q_1 tons of the resource every year forever, because the resource is exhaustible.

The equation given in the problem is the answer to a similar problem: maximizing the present value of profit for a competitive fishery. To alter it for the exhaustible resource case, set $F(x)$ (and hence F') equal to zero, because that is the rate at which a fishery stock naturally

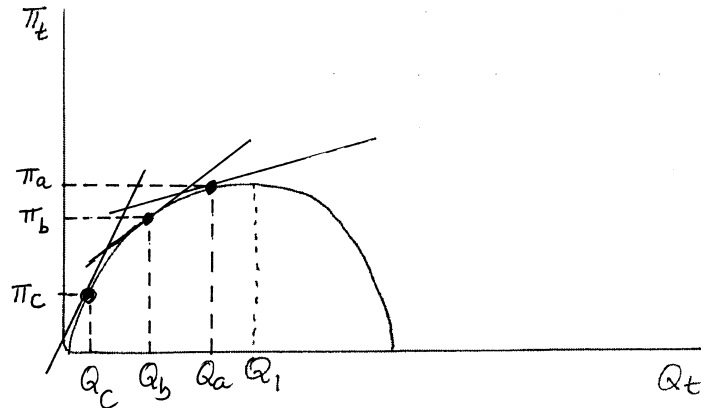


Figure 4

grows, and exhaustible resource stocks do not naturally grow. Also, for simplicity, assume there is no “stock effect,” so C'_{X8} is equal to zero. Then the equation becomes

$$r = \frac{M\Pi_8 - M\Pi_7}{M\Pi_7} \quad \text{or}$$

$$M\Pi_7 r = M\Pi_8 - M\Pi_7$$

$$M\Pi_7 r + M\Pi_7 = M\Pi_8$$

$$M\Pi_8 = (1 + r) M\Pi_7,$$

“marginal profit rises at the rate of interest,” which is the “Hotelling Rule.”

Marginal profit $M\Pi$ is the slope of the curve in Figure 4, as shown by the slope of the tangent lines in this answer section’s version of Figure 4. In order for these slopes to rise over time, the temporal pattern has to be something like: first (Q_a, π_a) , then (Q_b, π_b) , then (Q_c, π_c) , So over time, marginal profit rises, profit π falls, and quantity Q falls.

4. [8 points] ch 19; Qu. 4 of Fall 2009 Final
5. [9 points] ch6; Qu. 3 of Fall 2010 Ex1

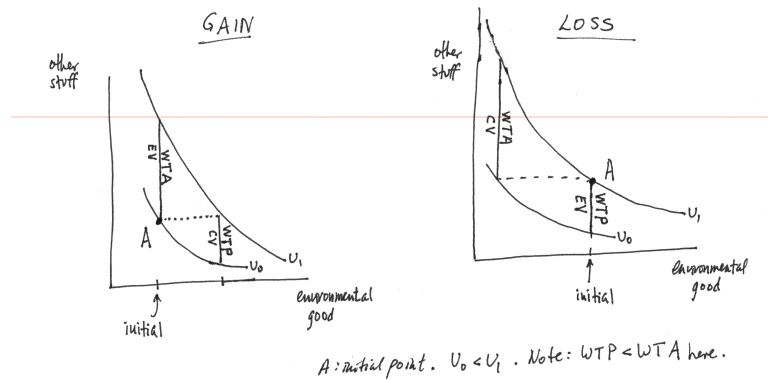


Figure 7. (Ignore the thin red horizontal line—it’s an artifact introduced by the scanner.)

6. [8 points] ch 9; Spring 2001 Ex1 Qu 4 (no old answer)

The textbook authors are addressing the fact that empirical studies show “willingness to pay” (“WTP”) for a policy typically less than “willingness to accept” (“WTA”) for the same policy. The textbook authors believe this contradicts economic theory, which says that WTP should equal WTA. However, I drew Figure 7 in class to illustrate that economic theory actually predicts that WTP and willingness to accept WTA are different, at least when indifference curves take their usual shape. In the first figure, the “gain” is a rightward movement in “environmental good,” increasing utility to U_1 . The consumer would be willing to pay, in “other stuff,” the amount shown by WTP, bringing the consumer back to U_0 , but the consumer would not be willing to pay any more “other stuff” in return for the improvement in environmental goods, because that would bring utility below U_0 . In lieu of the rightward movement, the consumer would be willing to accept “WTA” in other goods because that also brings the consumer to U_1 . In the figure, which shows indifference curves being convex as is typical, WTA is clearly more than WTP. Similar reasoning can be applied to Figure 7’s other graph, for a “loss” in environmental goods.

Another theoretical argument for the inequality of WTP and WTA is that WTP, for which a better name is “willingness *and ability* to pay,” is constrained by income, whereas WTA is not constrained by income (though it is still influenced by income).

7. **[8 points]** ch 13: new

While it is true that the largest effects of climate change will be felt starting a few decades from now, Bill Gates is wrong to think that the *cause* of these large effects will be what is happening at that time. With climate change, there are long lag times, so the cause of “warming in 2060,” for example, is *not* anything happening in 2060—instead the cause is what’s happening now, and in the next few years, and what happened well into the past. In other words, with climate change, “cause” and “effect” are not simultaneous; they are separated by very many years. (If climate “tipping points” exist, the argument becomes even stronger: one might not realize that a tipping point has been crossed until many years after it was crossed.) It follows that action to forestall “warming in 2060” is, as of this writing (2019), already overdue.

In addition, ignoring current climate mitigation technology in order to emphasize research and development of future climate change technology will turn out to have been a mistake if the future climate change technology does not materialize.

The point of the comic strip is that actions taken in 2060 to alleviate climate change will be too late.

8. **[8 points]** ch 14; Fall 2010 Ex1 Qu6