Answer each of the questions below. Round off values to one decimal place where necessary.

**Question 1. Taxes or Standards? (20 points)**
Motor vehicles release nitrogen oxide ("NOX") and volatile organic compounds ("VOCs") that react with sunlight to produce ground-level ozone. Ground-level ozone is the primary ingredient in smog and can have harmful effects on human health and the environment. Suppose the state of California is considering a policy to control ground-level ozone pollution with one of two environmental policies: (1) a tax on gasoline; or (2) a standard on the quantity of gasoline service stations can sell. Suppose the marginal social cost per gallon of gasoline is known, but the government is unsure of consumer demand for gasoline. Do you believe demand for gasoline is elastic or inelastic? Based on your answer, which of the two policies would you recommend? Justify your position with a diagram.

Part 1 (5 points). You can get 5 points for either answer (elastic or inelastic) as long as you justify it. Gasoline demand is fairly inelastic in California, because there are not many good substitutes available.

Part 2 (15 points). Graph and discuss.

Suppose true demand for gasoline is given by MB_T. The regulator, not knowing this, is just as likely to overestimate pollution demand as MB_1 as to underestimate it as MB_2. If the regulator believes demand to be MB_1, she will set the pollution standard at X_1^S. If the regulator believes pollution demand to be MB_2, she will set the pollution standard at X_2^S. Both policies miss the mark. X_2^S is less than X*, while X_1^S is greater than X*. Under a tax, if the regulator believes demand to be MB_1, she will set the pollution tax at t_1 (the price that satisfies MB_1 = MSC). Since the true demand of firms is MB_T, firms cut back pollution to X_1^T under a tax of t_1. If the regulator believes demand to be MB_2, she will set the pollution tax at t_2. Since the true pollution demand of firms is MB_T, firms cut back pollution to X_2^T. Either way, the outcome of regulation is always closer to X* under a standard than under a tax.

**When demand is inelastic, taxes perform better than standards.**
**Question 2. Transferable Permits (20 points).** Suppose two firms pollute a common water medium, and the water medium is well-mixed so that the damage from water pollution does not depend on the identity of the polluter. Firm 1 receives total benefit \( B_1(X_1) \) from polluting and firm 2 receives total benefit \( B_2(X_2) \) from polluting and these benefits differ; i.e., \( B_1(X) \neq B_2(X) \) for any (common) pollution level \( X \). Pollution creates external costs in the economy and marginal external cost is increasing in the pollution level. Draw a diagram that shows the socially optimal level of pollution to be allocated between the two firms. Label the region(s) that represent the efficiency gain from a transferable permit policy in the case where all permits are given to firm 1. Label the equilibrium permit price on your diagram.

![Diagram showing socially optimal level of pollution and the efficiency gain from trading permits.]

The permit price is \( P^* \) and the shaded regions represent the efficiency gain from trading. Firm 1 sells permits from \( \chi^* \) to \( X_1^* \) at price \( P^* \) and gives up the area under \( MB_1 \) in pollution benefits. Firm 2 buys \( X_2^* = (\chi^* - X_1^*) \) permits and receives “consumer surplus” in the permit market as the total pollution benefit (area under \( MB_2 \) curve) less permit cost of \( P^*X_2^* \).

(5 points) Show by formally considering the pollution decision of firm(s) that the socially optimal outcome arises in a competitive permit market regardless of the initial distribution of permits across firms.

FP (consider firm 1 with initial allocation of \( \lambda \) permits): \[ \max B_1(X_1) + P(\lambda - X_1) = B_1(X_1) - PX_1 + P\lambda \]

The first-order condition of the firm is: \( B_1'(X_1) - P = 0 \). This condition is independent of the initial allocation of permits (whatever \( \lambda \) happens to be). The same holds for firm 2, so \( B_1'(X_1) = B_2'(X_2) = P \) and the same allocative efficiency criterion is met for any initial distribution of permits.

**Question 3. Monopoly Permit Market (25 points)**
An issue with pollution markets, as with any market, is the potential for firm(s) to “corner” the market by acquiring all the permits and then selling them at monopoly prices. Suppose a permit market consists of two polluting firms: Firm 1 has total benefit from pollution \( X \) given by \( B_1(X_1) = 100X_1 – 0.5X_1^2 \), and firm 2 has total benefit from pollution given by \( B_2(X_2) = 100X_2 – 0.5X_2^2 \). The total external cost of pollution is given by the damage function \( D(X) = 50X \), where \( X = X_1 + X_2 \).

A. (5 points) Calculate the socially optimal pollution level \( (X^*) \) and the optimal distribution of pollution across the two firms \( (X_1^* \text{ and } X_2^*) \)

\[
W = B_1(X_1) + B_2(X_2) - D(X) = 100X_1 – 0.5X_1^2 + 100X_2 – 0.5X_2^2 - 50(X_1 + X_2)
\]

FOC: \[
dW/dX_1 = 100 - X_1 - 50 = 0 \Rightarrow X_1^* = 50
\]
\[
dW/dX_2 = 100 - X_2 - 50 = 0 \Rightarrow X_2^* = 50\text{ and } X^* = 100
\]

B. (5 points) If firm 1 acquires all the permits, calculate the marginal cost (MAC) for selling permits.

If firm 1 is allocated all \( X=100 \) permits, the firm could use all of them and receive a positive MB for each unit of pollution \( (X_1^*=100 \text{ is the unregulated optimum for firm 1}) \). If the firm chooses to sell permits, the marginal cost of selling a permit in the permit market is the opportunity cost of not polluting that unit. Since not polluting a unit for the sake of selling the unit to firm 2 entails abating a unit of pollution, the marginal cost of selling a permit is MAC: That is, abatement is \( A = 100 - X_1 \), so \( B_1'(X_1) = 100 - X_1 = 100 - (100 - A) \)

\[
MC = MAC = A \quad \text{(where } A \text{ = abatement = number of permits sold)}
\]

C. (5 points) For firm 2, calculate the (inverse) demand for permits. Calculate the marginal revenue function facing plant 1 in the permit market.

Firm 2 has no pollution rights and therefore must buy a permit for each unit of pollution. The (inverse) demand for permits for firm is the marginal benefit of pollution: \( P = B_2'(X_2) \), or \( P = 100 - X_2 \)

Since firm 2 must purchase a permit for each unit of pollution, \( X_2 = A \) (the amount abated by firm 1).

Inverse demand for permits is therefore \( P = 100 - A \).

Marginal revenue has twice the slope of linear (inverse) demand, so: \( MR = 100 – 2A \)

(Formally, \( TR = (100 – A) A = 100A – A^2 \Rightarrow MR = 100 – 2A \))
D. (5 points) Draw a graph that shows the monopoly outcome and the socially optimal allocation. Show the deadweight loss from the monopoly permit market on your graph.

E. (5 points) How many permits will a monopolist operating firm 1 sell to firm 2 in the permit market? What is the monopoly permit price? How much will each firm pollute? Explain why this outcome is inefficient.

A monopoly permit seller sets MR = MC => 100 – 2A = A => 100 = 3A => A_M = 33.33

The monopoly permit price is a point on inverse demand, so: p_M = p(A=33.33) = 100 − 33.33 = $66.67.

A monopoly permit seller rations permit sales to drive permit prices up.

In the monopoly equilibrium, the pollution levels are X_2^M = A_M = 33.33 and X_1^M = 100 − 33.33 = 67.33;

The outcome is inefficient, because allocative efficiency is not met.

4. Question 4. Honeybees (35 points)

A bee-keeper produces honey and sells it in a competitive market. The total private cost of producing honey (per gallon) is given by TPC = 2Q + 1.5Q^2. Consumers derive total private benefit for honey given by TPB = 50Q - 0.5Q^2. It turns out that there are two types externality associated with the bee-keeper’s bees. The bees fly across the North fence to a neighboring orchard and pollinate the trees; however, the bees also fly across the South fence and sting people in the neighboring village. No compensation is made for either effect. The total external benefit of honey production across the North fence is given by TEB = 30Q + 0.25Q^2 and the total external cost of honey production across the South fence is given by TEC = 8Q + 0.75Q^2

A. (5 Points). Find the competitive output level, Q_C, and price, P_C, in an unregulated market.

\[ \text{MPB} = 50 - Q; \quad \text{MPC} = 2 + 3Q \]

\[ \text{Competitive equilibrium: } 50 - Q = 2 + 3Q \Rightarrow 48 = 4Q \Rightarrow Q_C = 12 \]

\[ P_C = 50 - 12 = $38.00 \]
B. (10 points). What is the socially-optimal (i.e., welfare maximizing) level of honey production, Q*?

\[ \text{MEB} = 30 + 0.5Q, \quad \text{so} \quad \text{MSB} = \text{MPB} + \text{MEB} = 80 - 0.5Q \]
\[ \text{MEC} = 8 + 1.5Q, \quad \text{so} \quad \text{MSC} = \text{MPC} + \text{MEC} = 10 + 4.5Q \]

Socially optimal outcome: 80 - 0.5Q = 10 + 4.5Q => 70 = 5Q => Q* = 14

Q* > Qc, so the external benefits outweigh the external costs on the margin.

C. (10 Points). Draw a graph that shows the private and social equilibrium levels of honey production and the deadweight loss (DWL) associated with the private market outcome.

DWL is from under-production and is the difference between MSB and MSC for all the units the private market fails to produce (Q* - Qc).

| $\text{MPB}$ | $\text{MPC}$ |
| $\text{P*}$ |
| $\text{PC}$ |
| $\text{DWL}$ |

D. (10 points). In a regulated market, is the optimal policy to achieve Q* a tax or a subsidy? Calculate the level of the tax or subsidy that will correct the market failure in the honey market. Verify that this tax or subsidy rate leads to Q* honey production in the market.

The optimal policy in this case will be a subsidy, because the private market does not produce enough. We can conceive the policy to be the sum of an externality tax, t = MEC(Q*), and an externality subsidy, s = MEB(Q*). If we did this, the tax that internalized the negative externality would be, t* = 8 + 1.5(14) = 29. The subsidy that internalized the negative externality would be, s* = 30 + 0.5(14) = 37. So, in total, a subsidy of S* = s* - t* = 8 would induce the private market to provide Q* = 14 units.

Verify. The private market sets MPB + S* = MPC, or 50 - Q + 8 = 2 + 3Q => 4Q = 56

Qc = Q* = 14 under S*