Amartya Kumar Sinha
PPHA 39930
Assignment 3
February 10, 2024

I. Adaptation Policy Analysis

Let's take a look at how and where the state of Punjab fits on the IPCC map.

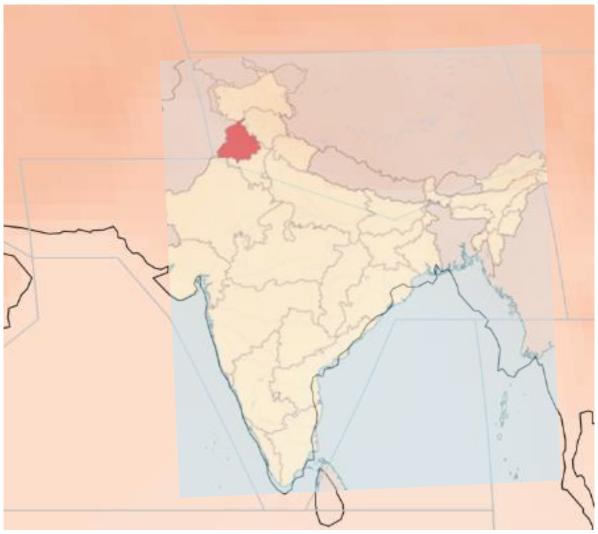

Figure 1: Approximate location of Punjab on the IPCC map

From Figure 1, we can see that Punjab clearly lies (almost) fully in the Tibetan Plateau region of the IPCC map.

For all questions related to Punjab, I will be applying the "Land only" mask for the Tibetan plateau region so that Punjab's temperatures are better represented when compared relative to its location (since the state is almost entirely plain save for its North-East border). However, while analyzing the South Asian region, I have used no masks to maintain an accuracy of the temperatures over the entire region/rest of India. I believe this ultimately helps increase our analyses' accuracy, if only by a slight amount, since we are comparing Punjab's geography to the rest of the region/country, since the Tibetan Plateau is otherwise mostly, well, a plateau instead of the mostly plain land that Punjab is.
Hence, I shall be using the visual heatmap of the Tibetan Plateau region with a Land only mask as a loose proxy for data about Punjab and compare it to the South Asia region without a mask to answer questions. Apart from visual inspection of the IPCC maps for analysis, below are the tables extracted to answer part 1 of the assignment:

Table 1: Medium-term (2041-2060) SSP3-7.0 (baseline 1981-2010) Annual projections

Comparison point (median values)	*South Asia (no mask)*	*Tibetan Plateau (Land only mask)*
Average temperature	+1.5°C	+2.3°C
Minimum temperature	+1.8°C	+2.5°C
Maximum temperature	+1.3°C	+2.3°C
Bias adjusted TX35	+23.6 days	+2 days
Total precipitation	+6.7%	+7.2%
Maximum 5-day precipitation	+10.2%	+10.3%
Consecutive dry days	+2.1 days	-1.9 days
Surface PM2.5	+10.1 ug/m^3	+2.5 ug/m^3

Table 2: Medium-term (2041-2060) SSP3-7.0 (baseline 1981-2010) March-May projections

Comparison point (median values)	*South Asia (no mask)*	*Tibetan Plateau (Land only mask)*
Average temperature	+1.5°C	+2.1°C
Minimum temperature	+1.8°C	+2.4°C
Maximum temperature	+1.4°C	+2.1°C
Bias adjusted TX35	+8.3 days	+0.8 days
Total precipitation	+2.9%	+8.6%
Maximum 5-day precipitation	+4.3%	+9.3%
Surface PM2.5	+7.8 ug/m^3	+2.1 ug/m^3

Table 3: Medium-term (2041-2060) SSP3-7.0 (baseline 1981-2010) May-July projections

Comparison point (median values)	*South Asia (no mask)*	*Tibetan Plateau (Land only mask)*
Average temperature	+1.4°C	+2.1°C
Minimum temperature	+1.7°C	+2.4°C
Maximum temperature	+1.3°C	+2.1°C
Bias adjusted TX35	+17.2 days	+0.8 days
Total precipitation	+6%	+11%
Maximum 5-day precipitation	+20.4%	+19.8%
Surface PM2.5	+10.4 ug/m^3	+1.9 ug/m^3

Table 4: Medium-term (2041-2060) SSP3-7.0 (baseline 1981-2010) October-December projections

Comparison point (median values)	*South Asia (no mask)*	*Tibetan Plateau (Land only mask)*
Average temperature	+1.5°C	+2.5°C
Minimum temperature	+1.9°C	+2.7°C
Maximum temperature	+1.3°C	+2.5°C
Bias adjusted TX35	+4.5 days	+0.2 days
Total precipitation	+3%	-3.2%
Maximum 5-day precipitation	+24.7%	+21.6%
Surface PM2.5	+16.9 ug/m^3	+3.5 ug/m^3

Table 5: Medium-term (2041-2060) SSP3-7.0 (baseline 1981-2010) December-March projections

Comparison point (median values)	*South Asia (no mask)*	*Tibetan Plateau (Land only mask)*
Average temperature	+1.5°C	+2.4°C
Minimum temperature	+1.8°C	+2.5°C
Maximum temperature	+1.5°C	+2.4°C
Bias adjusted TX35	+5.6 days	+0.1 days
Total precipitation	-9%	-0.5%
Maximum 5-day precipitation	+30.8%	+28.4%
Surface PM2.5	+7.8 ug/m^3	+2.5 ug/m^3

The below graphs are a visual representation of the tables above:

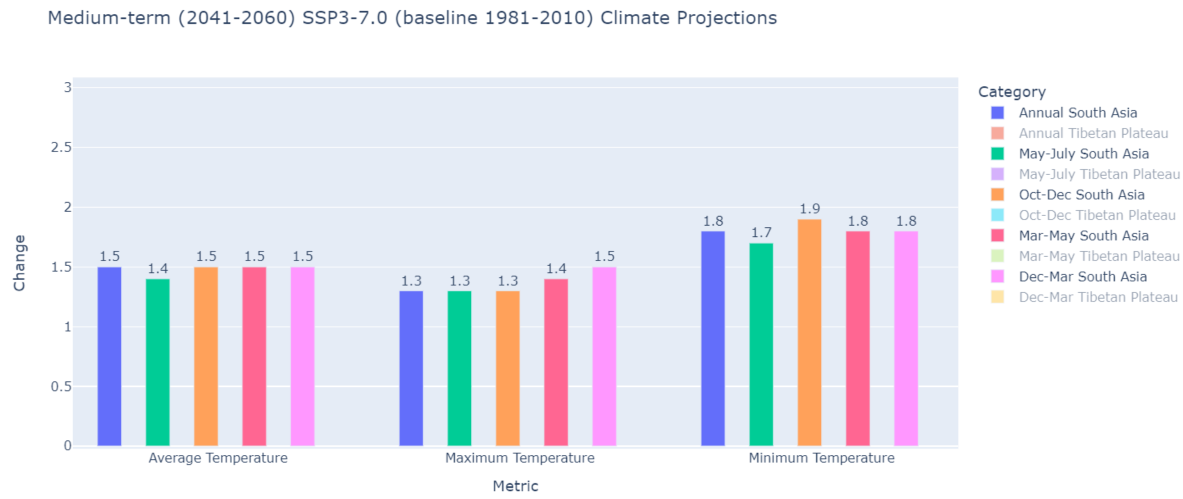

Figure 2

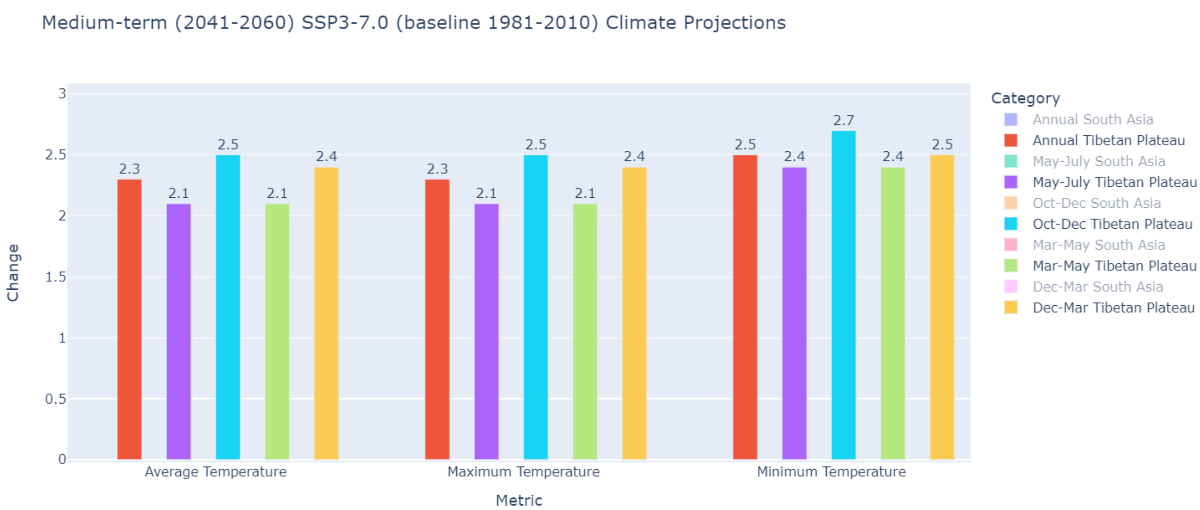

Figure 3

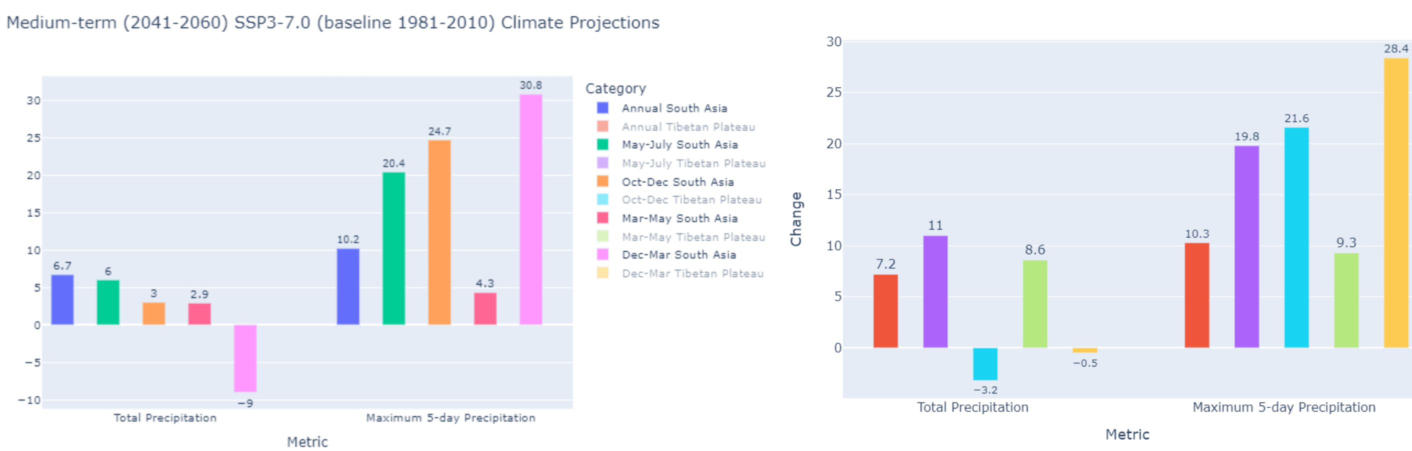

Figure 4

Q1. a) The region of South Asia is projected to experience about 1.5°C change in the average temperature, between 1.3°C-1.5°C for the maximum temperature and between 1.7-1.9°C for the minimum temperature (depending on the group of months). Total precipitation and maximum 5-day precipitation both are projected to increase (although there is low model agreement for these two metrics), but their amount varies significantly depending on the time of the year. On average, total precipitation is projected to increase by 6.7% annually, although the increase is much less at around 3% for from October-December and March-May; however, the December-March period is projected to decrease by 9%. The total precipitation metric is interesting to compare to the maximum 5-day precipitation metric (aka RX5day, also has low model agreement), since month groups with a lower increase in total projection appear to have the highest increase in RX5day rates – signaling that while the total amount of rain received by the South Asia region may not be indicative of the type or intensity of rains, since this metric indicated more intense rains over shorter bursts of time.
The temperature increases may also lead to a more violent river, since the increasing temperatures may also melt glaciers faster. This may lead to loss in productive farmland area, apart from potential damage to crops in case the river floods during heavier, more erratic projected precipitation (see below)

Punjab appears to follow a different trajectory compared to the average of South Asia. Based on the visual heatmap and the above figures, Punjab is projected to have higher average, maximum and minimum temperatures compared to South Asia by about 0.5°C to 0.7°C (depending on the season). However, the precipitation projections are slightly more aligned with South Asia. We see that average annual precipitation for Punjab is also projected to increase by a similar amount (7.2% compared to 6.7% for South Asia going by numbers), and the colors on the heatmap appear to be similar to the west region of the state of Rajasthan (which is one of the driest states in India, for reference).
However, while the total precipitation for the months of October-December appears to decrease by up to 10% as per the heatmap, west of Rajasthan for the same time period is projected to have an increase in total precipitation by up to 20%. Moreover, the plains in South Asia south of the Himalayas are also projected to have a decrease similar to Punjab, whose land lies largely to the East of the Himalayas. Punjab's location is hence poor in the long terms for agriculture, since it seems to be just far enough away from the seas to not receive monsoon winds (see transition from green zones to yellow zones as the border region changes from South Asia to the Tibetan plateau, which is exactly where Punjab lies as illustrated in figure 1), and the Himalaya mountain range appears to be further blocking that. This is illustrated in figure 5 below:

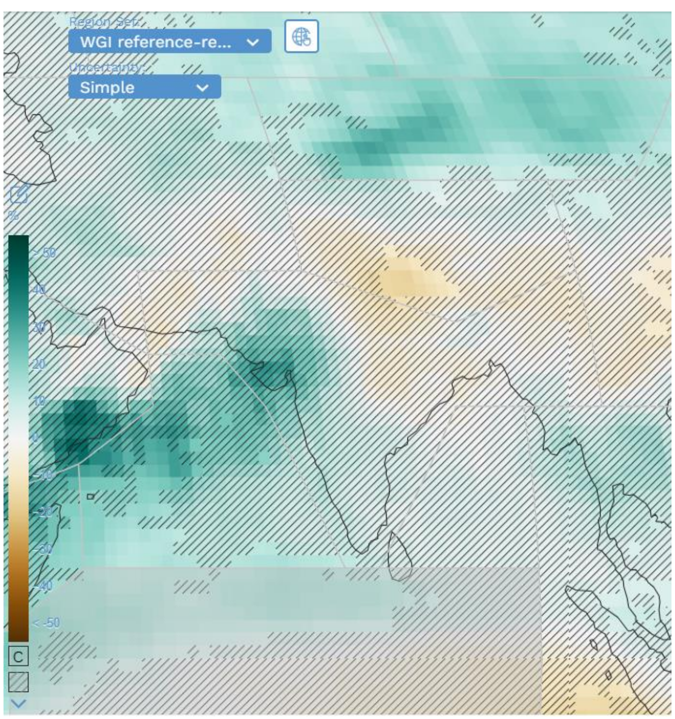

Figure 5: October-December medium term projections

It would hence appear that while rainfall for certain parts of South Asia will increase in the medium term, the same may likely not be the case for Punjab, especially for the periods which rely on the rains for crop irrigation (via rainfall as well as the water table) – for example, rice is planted from May to July and harvested from October to December; however, the temperatures are projected to increase by up to 2.5°C based on the heatmap colors which is accompanied by increased RX5day rate of 21.6% - which means that while the total amount of rainfall is decreasing by 3.2%, the amount of rain received per day may be much higher, which may lead to higher rice and cotton crop failures and/or damages. This would also affect wheat since it is planted in October, and hence could lead to crop damages and/or failures for wheat too. However, the March-May period shows a remarkably even increase both precipitation metrics.

The bias adjusted TX35 metric (low model agreement) shows that although there is only a 2% annual average projected increase for the land-areas of the Tibetan plateau, the same metric shows a staggering 23.6% increase in average for South Asia. This is most likely because there may likely have been a large number of days in the baseline where temperatures in the region were close to but not beyond 35°C, and the average temperature increase of about 2°C was just enough to push those days over the edge.

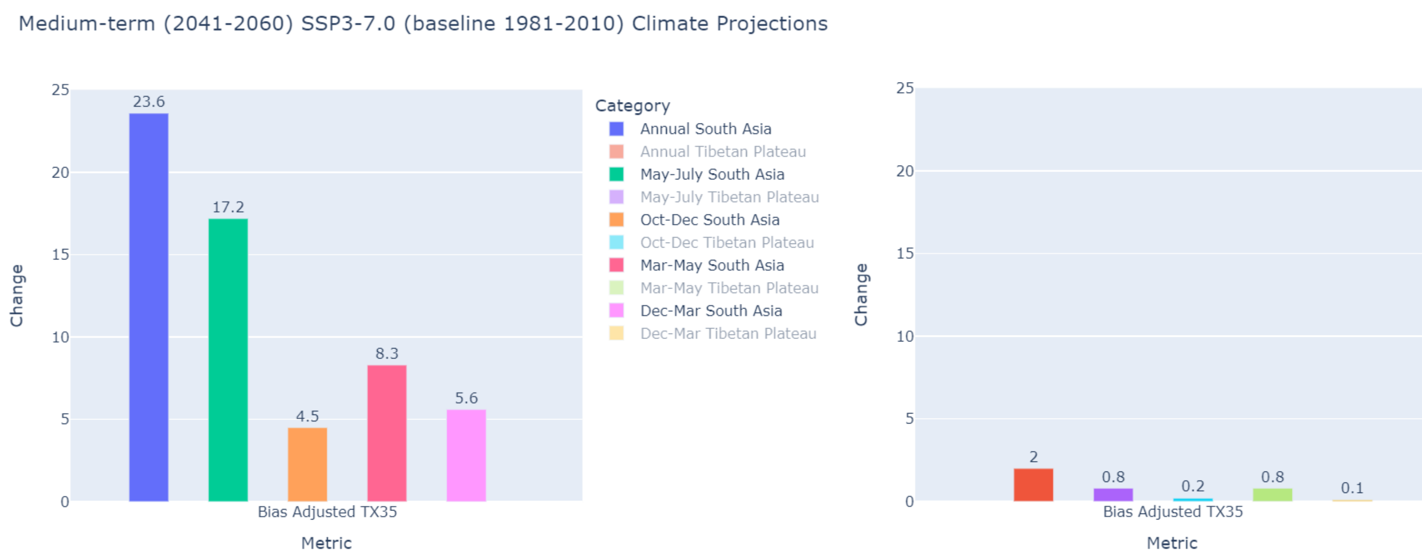

Figure 6

The last metric I would like to bring attention to is population density. Based on the time series plot (see Figure 7), all SSP scenarios except SSP3 project that population density in both Tibetan Plateau and South Asian regions (individually and when taken together) will peak in the medium-term (or just after it; around 2065).

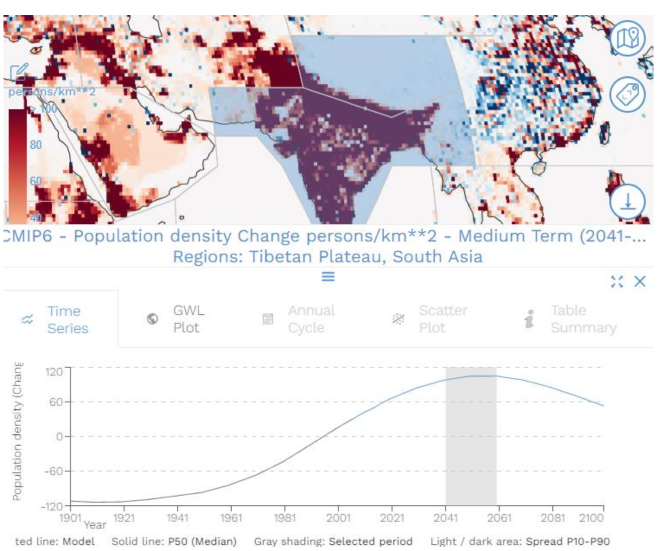

Figure 7: Medium-term population density

Q1. b) While the total average annual precipitation is increasing by about 5-10% in various regions of Punjab, this may be nullified by the increased temperatures across the state (by up to 2.5°C). Higher temperatures coupled with an increasing population density and intensive agriculture would likely mean that water could become a scarce resource in the state; hence all of this may lead to disastrous consequences for water supply if changes are not made to the current business as usual.

Q1. c) The level of uncertainty for most variables where models agree is fairly even in terms of the distance of standard deviations. It is interesting to note that while most models are very closely related to each other when it comes to mean temperature, the minimum and maximum temperatures are where models start deviating from each other. This can also be seen for other variables. This suggests that while models may be able to model the averages fairly well, extremes are likely more difficult to predict/model, which may likely be in part due to the probability of human as well natural events which may or may not take place.

Q1. d) Total and maximum 5-day precipitation levels along with TX35 are the variables with the most uncertainty in terms of the model, since there is low model agreement for large parts of South Asia and Tibetan Plateau. Additionally, another area of uncertainty could be how and whether the state will evolve in terms of its economy – I am assuming that the baseline period of 1980-2010 was chosen because that was the time when the Green Revolution in India was at its peak, and Punjab is seen as largely leading the charge for the same; and hence the temperatures and climate in this region would have started to be already, but likely not significantly, affected by this new era of agriculture.

Hence, the largest source of uncertainty would likely be the consistency of the intensity of rain coupled with the even higher temperatures throughout the year, and this will ideally affect planning for almost everything related to the state – from healthcare to economic policies to immigration norms to incentives and subsidies etc; and these policies should be motivated in no small part keeping in mind the surge of population that also needs to be dealt with at the same time.

Q2. a) With a focus on 2050, here are three policy outcomes for adaptation:

i) Since 46% of water for irrigation is abstracted from rivers and 54% from groundwater, the first focus would be on reducing freshwater usage. This may likely be achieved by incentivizing farmers to switch to less water intensive crops by means such as MSP and subsidies for seeds.

ii) Existing policies which incentivize unnecessary usage of water, such as almost free electricity, should be phased out in favour of a sliding scale policy where cost may be based on factors such as total units of usage or efficiency of electric devices, etc.

iii) Probably the policy that is least likely to be actually implemented in real life due to political reasons, is to gradually reduce Punjab's economy's dependence on agriculture as the major source of GDP. Growing the state GDP primarily via agriculture is unsustainable in the long run due to the reasons outlined in Q1, and Punjab will need more land and higher density housing to support the increasing population, apart from more freshwater. Hence, there should a focus on either disincentivizing agriculture or incentivizing other less water-intensive industries, or both.

Q2. b) Punjab has a high rate of domestic immigrants (from various states in India) and it also has a high number of emigrants (who aspire to eventually settle abroad, particularly Canada). This means the projected increase in population-density for Canada in the projections is likely based on increase in agriculture, and hence increase in higher number of migrants from India; a lower total population (by reducing number of migrants) and a higher number of more educated people in the state may mean better and less use of water. While the recommendations above do not focus directly on this issue, they may reduce brain drain and the variability population due to migrants by a large extent. All scenarios predict an increase in temperatures, and hence the recommendations may work well for tackling that. However, only SSP3-7.0 and SSP5-8.5 predict much higher RX5day levels, which means that phasing out agriculture may be slower than expected if the water table does not deplete as quickly as predicted by these scenarios.

Q2. c) Adaptations i) and iii) are likely the only ones robust to uncertainty about future climate change pressures, since the outcome of both of them focuses explicitly on reducing water usage. However, all these adaptations are highly susceptible to political pressures and how sincerely they are implemented and run. Perhaps most importantly, until climate change becomes an issue on the basis of which elections can be fought and won (compared to currently used topics such as partisan and higher growth rate of GDP/development no matter the ultimate cost), no adaptation policy may be robust enough to face political pressures.

Q2. d) No adaptations suggested above can be achieved autonomously. They will all require market intervention in order to make them work. This is because without market intervention, it will be very difficult to shift to a less water-intensive economy for the state. In fact, the reason why Punjab's economy is still so highly agrarian is because of market intervention by way of the Green Revolution from the 1960s onwards. The chief barrier to autonomous adaptation is likely economic incentive – the state currently has many incentives to partake in farming water intensive crops such as the MSP policy, cheap electricity, etc. Once people see that it is not just environmentally smart but also economically feasible to shift away from agriculture, there may be some hope for autonomous adaptation.

II. Mitigation policy comparison

Q1. Based on the working document where we analyzed this question in Python, we see that the below is the optimal production for each level of A:

i) For A = 10: 5 units
ii) For A = 20: 10 units
iii) For A = 30: 10 units
iv) For A = 40: 10 units

Hence, in this command-and-control scenario, the optimal level of production for all levels of A (except 10) is always 10 units since the firm reaches its maximum profit when it is emitting 10 units or less. For 5 units of A, it makes sense to produce only 5 units to maximize profit.

Q2. Based on the working document, we see that optimal production of each level of A, assuming t = 10, is:

i) For A = 10: 0 units
ii) For A = 20: 5 units
iii) For A = 30: 10 units
iv) For A = 40: 15 units

Hence, for a firm with A = 10, it is no longer profitable to produce any units in this case.

Q3. Below is the optimal production of each level of A, assuming p = 10 and N = 10:

i) For A = 10: 0 units
ii) For A = 20: 5 units
iii) For A = 30: 10 units
iv) For A = 40: 15 units

The production levels are the same as the market with just tax-based price control.

Q4. We know that each firm has to hold one permit for each unit of "stuff" produced. The market clears when the quantity of permits demanded equals the quantity supplied. So, at permit price p = 10:

- Firm A=10 does not produce any units, so it does not use any permits and has 10 to sell.
- Firm A=20 produces 5 units; hence it uses up 5 permits and has 5 to sell.
- Firm A=30 produces 10 units and hence it uses all of its permits and has 0 to sell.
- Firm A=40 produces 15 units, meaning it needs to buy 5 additional permits.

This means that there is a surplus of permits in the market; hence the market does not clear at permit price p = 10.

Now, if the permit price drops to p = 5, we see that the optimal production levels are as follows:

i) For A = 10: 2.5 units
ii) For A = 20: 7.5 units
iii) For A = 30: 12.5 units
iv) For A = 40: 17.5 units

This is what happens to the permit credits at this price:

- Firm A = 10 produces now 2.5 units, so it would not use all of its permits and has 7.5 permits to sell.
- Firm A = 20 produces 7.5 units, so it uses7.5 permits and has 2.5 permits to sell.
- Firm A = 30 produces 12.5 units, so it will need to buy 2.5 additional permits (buys from A=20).
- Firm A = 40 produces 17.5 units, and hence it needs to buy 7.5 additional permits (buys from A=10).

Therefore, at a permit price of p = 5, all permits are bought and sold, and the market clears.

In a real market, permits would not be sold in fractions, and the firms would likely adjust their production to whole numbers of permits. In this simplified scenario, however, with the given fractional values, the market for permits would clear at a price of p = 5.

Q5. A summary of findings from the various scenarios:

No Regulation:

- Firms with higher productivity factors (A) produce more and earn higher profits.
- Optimal production levels are at A/2, which are 5, 10, 15, and 20 for A=10, 20, 30, and 40 respectively.
- Profits without regulation are 25, 100, 225, and 400 respectively.

Command-and-Control (Emission Cap at 10 units):

- All firms except A=10 are restricted by the emission cap and produce at the cap level or below their unregulated optimal level.
- Optimal production levels are 5, 10, 10, and 10 for A=10, 20, 30, and 40 respectively.
- Profits are constrained due to the emission cap.

Tax (t=10 per unit of output):

- Imposition of the tax reduces the optimal production level for all firms compared to the no regulation scenario.
- Optimal production levels are 0, 5, 10, and 15 for A=10, 20, 30, and 40 respectively.
- Profits are reduced due to the tax on each unit of output.

Market for Permits (N=10 permits, p=10):

- The market did not clear at a permit price of p=10 since not all permits were sold.
- Optimal production levels were 0, 5, 10, and 15 for A=10, 20, 30, and 40 respectively.
- At a permit price of p=5, the market clears and firms with A=30 and A=40 would need to buy additional permits, adjusting their production to 12.5 and 17.5 respectively.

The no regulation scenario provides the highest profits as there are no constraints on production or additional costs from taxes or permits.

For costs of different regulation, we see that command-and-control limits profitability for more efficient firms since they cannot produce beyond the cap even if it would be profitable to do so. A tax per unit of output (t=10) makes production less profitable, particularly for less efficient firms (A=10), which cease production altogether. The market for permits allows firms to adjust production according to permit price, potentially allowing more efficient firms to purchase additional permits and produce more than under command-and-control.

Command-and-control and tax scenarios show reduced profits compared to the no regulation scenario. In the permit market case at a permit price of p=5, the market clears, and firms with higher A values can achieve higher production levels by purchasing permits from less efficient firms, leading to higher profits compared to being under the tax scenario.

Firms with higher productivity factors (A=30 and 40) benefit from the permit market because they can buy additional permits to increase production beyond the level that would be profitable under the tax scenario. On the other hand, firms with lower productivity (A=10) benefit as they can sell their permits instead of producing, which would otherwise result in a loss after tax.

Based on the above, we see that regulation impacts firms differently based on the level of productivity. Less efficient firms may stop production under tax scenarios or become sellers of permits in a permit market, while more efficient firms have to reduce production under command-and-control and tax scenarios but can maintain or increase production in a permit market if it is profitable to do so. Hence, the design of regulatory policies can significantly affect the distribution of profits and production within an industry.