Using Prudence to Predict the International Electric Vehicle Market

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Abstract:

In this paper, I study the current international market revolving around electric vehicles (EVs), with an emphasis on the countries of the United States and China. I use a Nash Equilibrium model within a game theoretic framework to assess the outcomes of possible actions taken by these two leading countries. Specifically, I structure this scenario as a multistage game, in which I use a variable I have defined as Prudence to determine the Nash Equilibria of various tariff scenarios by varying the foresightedness levels of the countries towards global needs, rather than short-term economic squabbles. I then provide policy recommendations for a global entity such as the UN to carry out in order to secure international emissions targets best. The outcomes of the model show that there exists a wide range of values for prudence in which the actions of the US and China lead to problematic outcomes for the world. As a result, this paper demonstrates the importance of global action in order to prevent catastrophic outcomes in the realm of the global fight against climate change, specifically regarding Electric Vehicles.

Introduction:

Electric vehicles (EVs), and the transition away from traditional gas vehicles, has the potential to prevent 800 million tons of CO_2 every year by 2040. They are a revolutionary product, one which can help prevent the planet from reaching the terrifying effects of Climate Change forecasted. But on a geopolitical level, whoever can control the creation, proliferation, and innovation of this product is the country who can lead the world into a future of environmentally driven policy and technology, which might be the challenge of our time.

EVs are not a newfound invention; they were well-used in the late 1800s and early 1900s. But with the creation of cost-efficient gas automobiles, such as the Model T of Ford, they took a backseat for the next century. But at the beginning of the new millennium, with projects such as Tesla Motors or the Prius model of Toyota, an electric-gas hybrid vehicle, electric vehicles were back in vogue again (Matulka). And it was of the utmost importance that they were, as oil shortages in the eighties, along with the increasing issue of climate change opened the public up to trying out new things.

However, while EVs have increased in the US the last two decades, the US does not remain at the forefront of the market anymore. Over the last five years, Tesla's dominance has waned, both domestically and abroad, as American customers continue to struggle to make the switch away from traditional vehicles and as prices internationally remain high. In fact, in the first quarter of 2024, Tesla has seen its sales down 20% and its share price decrease by 25% compared to the same period in 2023 (Oxford).

Rather, the new players in the market are Chinese EV companies such as BYD and GAC Aion, as well as other Chinese companies like Xiaomi, originally a phone company, now launching Electric Vehicle models. Chinese EV companies now make up 60% of the worldwide sales of EVs, up from 0.1% at the beginning of the 2010s. Chinese companies now hold three out of the top five global market share spots for EVs (Oxford).

The reason for all of this is, as previously mentioned, the price of the Chinese vehicles. While they are not currently sold in the United States, in other locations, they are much more affordable to the average consumer. For instance, in Mexico, a Dolphin Mini from BYD would cost $21,000, while a Chevrolet Bolt would cost $27,000 (Oxford).

This is a bitter pill for the United States Government to swallow. As a result, two successive presidents have incorporated import tariffs on China. First, President Trump increased the tariff rate on Chinese vehicles from the standard 2.5% to 25%. And in the spring of 2024, President Biden doubled down on this policy, increasing the tariff rate to 100% (Tankersly). To put this into perspective, let's say a car imported from China that a Chinese company is selling is valued at $100. In a perfect *laissez-faire* model, the consumer would be able to buy it at the $100 mark. But under Trump-era policies, that car would now be available to be bought at $125, with the government pocketing the rest. And the new policies of Biden would make this car be sold at no less than $200, with the full 100% tariff.

This becomes interesting when viewing the price of American EVs. Teslas are now the cheaper option compared to the Chinese EVs, despite the lower original market price of the Chinese EVs. As a result, more consumers will buy American vehicles, and the goal of policies like this is to establish a firmer American market and more competitive, both quality and pricewise, American EV companies.

Unfortunately, this is not likely to go over very well with policymakers in Beijing. As a result of the actions of the United States, their ability to spread their own EVs is largely diminished. Moreover, the US sanctions increase the possibility of other polities, such as the EU or Japan (Lynch et al.), imposing their own tarrifs. China thus has a difficult choice on whether to respond or not to these sanctions. And depending on China's choice, the United States will also have a decision to make on how to further the situation, which I will discuss more in the following sections of the paper. As a result, there are many scenarios which can occur from the situation in the status quo.

However, it is clear that for the world, the best scenario involves a free and open market for EVs which allows the most amount of innovation and cost-reduction of vehicles, allowing both greater use as well as better vehicles. This would increase the likelihood of meeting necessary emissions targets, as well as minimize the additional carbon footprint caused by gas-powered vehicles. The question my paper thus attempts to ask is how can the UN, or an undefined international body of countries, attempt to keep the market of Electric Vehicles as open as possible, taking into account the variable of how much the US and China are interested in the future?

To answer this, I have developed a sequential and responsive game theoretic model which revolves around a three-form output structure, which incorporates both short term economic desires as well as long-term climate change goals. I run multiple analyses of my model under different weightings of the variable I term Prudence, which I use to represent the value that each country places on the future. Here, P_U and P_C denote the prudence of the US and China, respectively. Under each set of conditions, I solve for the Nash Equilibria, the outcome that results when each player plays the best move given the move of the other player. In particular, as I assign values to describe the outputs of each decision-making tree, the Nash Equilibrium for this model would be where the US and China both maximize their numerical output given what they know about the other's decision making.

While Nash Equilibria are a common tool to utilize in almost all game theoretical models, in this model specifically I will rely on solving for the Subgame Perfect Nash Equilibria or SPNE. In sequential games like this one, to analyze the most likely decision, I will find the most likely play of the US given either of China's actions. Then, if China knows that the US will do one of two possibilities, China will do the action which leads to the US decision which China prefers more. I will find the SPNE of the model under different sets of prudence constants.

Through the results of my study, I have found that at Prudence values of $P_U \geq 0.2$ and $P_C \geq 0.33$, the world's output of EVs is maximized. However, these numbers illustrate that both countries must place high priority on future-oriented thinking, which is far from guaranteed. As a result, the United Nations should attempt to create a form of "positive reinforcement," which essentially means to increase the outputs for the US and China in the situations which are beneficial for international climate change efforts. Possible policy recommendations include instituting leadership positions in committees or reducing contributions in UN dues for the US and China in an effort to increase the numerical benefit for the countries in the situations where they withdraw sanctions Therefore, these recommendations can act as incentives to shift the results of our experiment such that at even lower P_U and P_C values, the countries still choose the world-optimal scenario.

Methods:

I: Set-up

In this game, for both China and the United States, there are short-term consequences, such as jobs created or additional sales that tend to favor one side, as well as long-term consequences, such as preventing climate change emissions that are net-beneficial for the world. As a result, every outcome can be represented in the payoff form (S_U, S_C, L), where S_U is the short-term outcome for the US, S_C is the short-term outcome for China, and L is the long-term outcome for the world. I will refer to this three outcome model as the primitive payoff form.

However, a model with three payoff parts which only corresponds to two actors is challenging to properly analyze. As a result, I use the variables P_U and P_C, which represent the prudence of the United States and China, respectively. P can take on any real value between 0 and 1, and represents the weighting of the actor's preference towards long-term interests rather than a focus on short-term interests. Thus, the payoff for the US, which I will characterize as U, can be determined from the primitive payoff form with the expression:

$$S_U \cdot (1 - P_U)) + L \cdot P_U$$

whereas the payoff form for China, or C can be represented in the form:

$$S_C \cdot (1 - P_C)) + L \cdot P_C$$

We refer to the payoff form of (U, C) as the final payoff form. While we use the same model and the same primitive outcomes for every example, the final payoff forms vary from instance to instance as the Prudence constant of the actors is shifted.

II: Initial Game

As of this writing (July 2024), the United States has already made the first move, increasing the Chinese EV tariff to 100%. As a result, this model begins with China's choice on whether to impose retaliatory sanctions or not. While this might seem like a clearcut decision, China understands that the United States is uniquely in an unstable position, with the forthcoming 2024 election, and as a result, the incumbent party needs to appear tough on China. As a result, the PRC understands that if they get into a tariff battle, there is a strong risk of delving into a trade war. This creates the first stage of the game, as China is forced to weigh its actions to determine the best set of outcomes.

As a result, China has two clear choices: A retaliatory tariff or simply doing nothing. This choice is slightly oversimplified, but the overall decision is a true one: namely, whether China wants to get embroiled in an escalatory situation or whether they prefer to lose money instead.

Let us assume that China does decide to respond with a retaliatory tariff. That would mean the US has three responses to this: the US could raise the stakes even further and get into a full-scale trade battle; the US could do nothing but maintain the original tariff; and finally, the US could lift the sanctions to deescalate the situation.

Alternatively, if China decides to risk going into a trade war and instead takes the loss, the US also has two potential responses. They can increase the tariff further and make it even broader, or they can simply let it be.

It is also important to note that while the US has three responses if China retaliates to the tariff, there are only two logical possibilities if China does not. After all, why would the US back down their tariffs if China does not respond in the first place?

With these sets of choices, the diagram which represents this game is as follows.

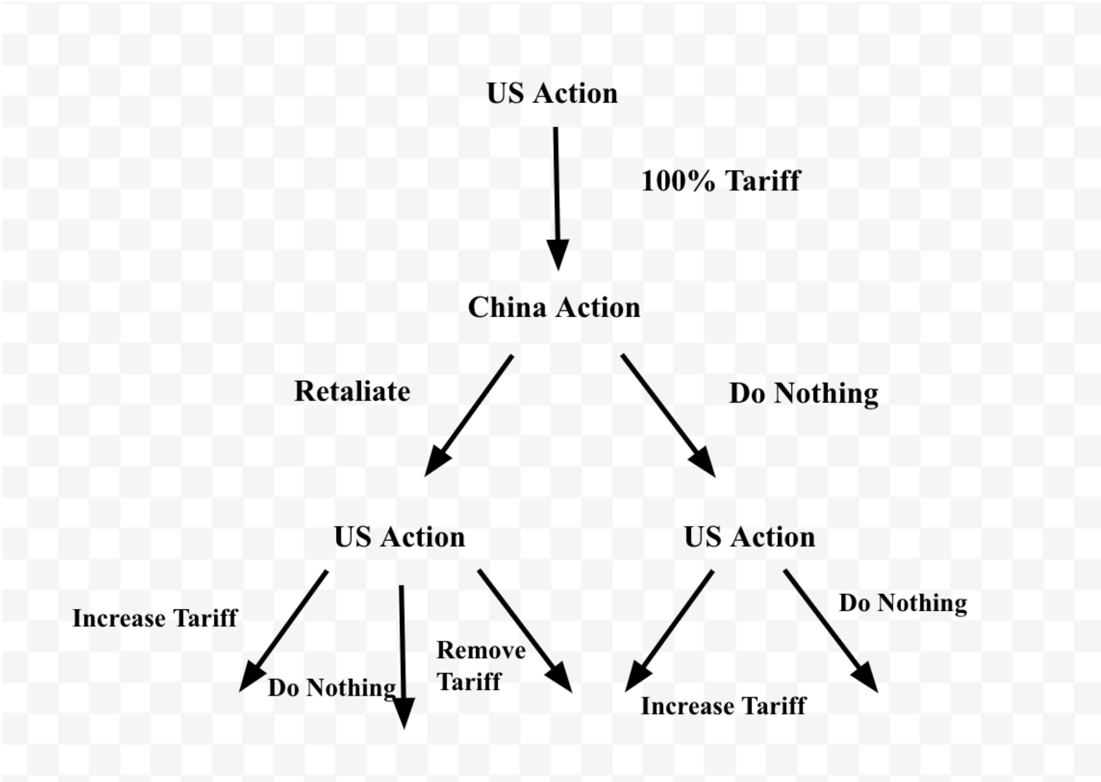

Figure 1: Initial Model Figure

But this model is incomplete at this point. Now, the values in the primitive payoff form need to be determined. Let us examine the outcomes of all five possibilities, determining somewhat arbitrary values for each set. While there is no mathematical reason to state that the long-term coefficient for the both countries' do-nothing scenario is 50, the more important factor at play is the relativity. I will be attempting to assign values such that each output value for each possibility is approximately relative to the others, which means that I will have to make some arbitrary assignments.

Let us start with the possibility that both China and the United States do nothing. This would likely have a neutral effect on the US and a slightly negative economic/short-term effect on China. This would result from the already-imposed tariffs pricing Chinese electric vehicles out of certain markets, but certainly not crippling them. However, the long-term coefficient would have a large positive value. This outcome represents the freest market for EVs in the future, pushing innovation of better EVs and allowing the largest number of people to gain access to EVs (Wagner and Walsh). And because EVs on net in their present state have lower vehicular CO_2 emissions by 43% compared to traditional alternatives (Hausfather), the proliferation of EVs would see a great benefit to the world in terms of reducing the effects of climate change. Thus, if we were to propose an abstract payoff set, which again is arbitrary and attempts to show the relative impacts of the choice towards each player, the values would be (0, -5, 50), in the primitive model structure.

The next possibility that exists is where China does nothing, and the US, sensing a possibility, decides to increase tariffs further. This would hurt China further, while helping the United States standing in the Electric Vehicle Market. However, the global long-term coefficient would also decrease relative to the former scenario as it becomes harder to own Electric Vehicles due to increased pricing. As a result, the values would be something like (10, -20, 0).

Now, we must consider the possibility that China actually retaliates. If the United States attempts to counter, this will harm both countries economically due to the trade war, along with having a hugely detrimental impact on the global long-term coefficient, with the most closed off market and risks to stability further hampering efforts to combat climate change. Thus, I have assigned the payoff matrix being (-10, -10, -50).

A different possibility is the chance that the US does nothing in response to China's retaliatory tariffs. Again, neither country would benefit in a situation like this, although the global coefficient would not be as dramatically reduced. The payoff matrix is (-10, -5, -20).

The final situation for which we must determine payoffs is the one most in China's favor, where they retaliate and the United States responds by backing down and removing their tariff in response. This would also be beneficial for the global coefficient, as it would see a somewhat free market, similar to the first possibility outlined. However, it would also be a stunning loss for the United States' short-term coefficient. The matrix would look like (-15, 10, 20).

As a result, we have the following model for the initial stage.

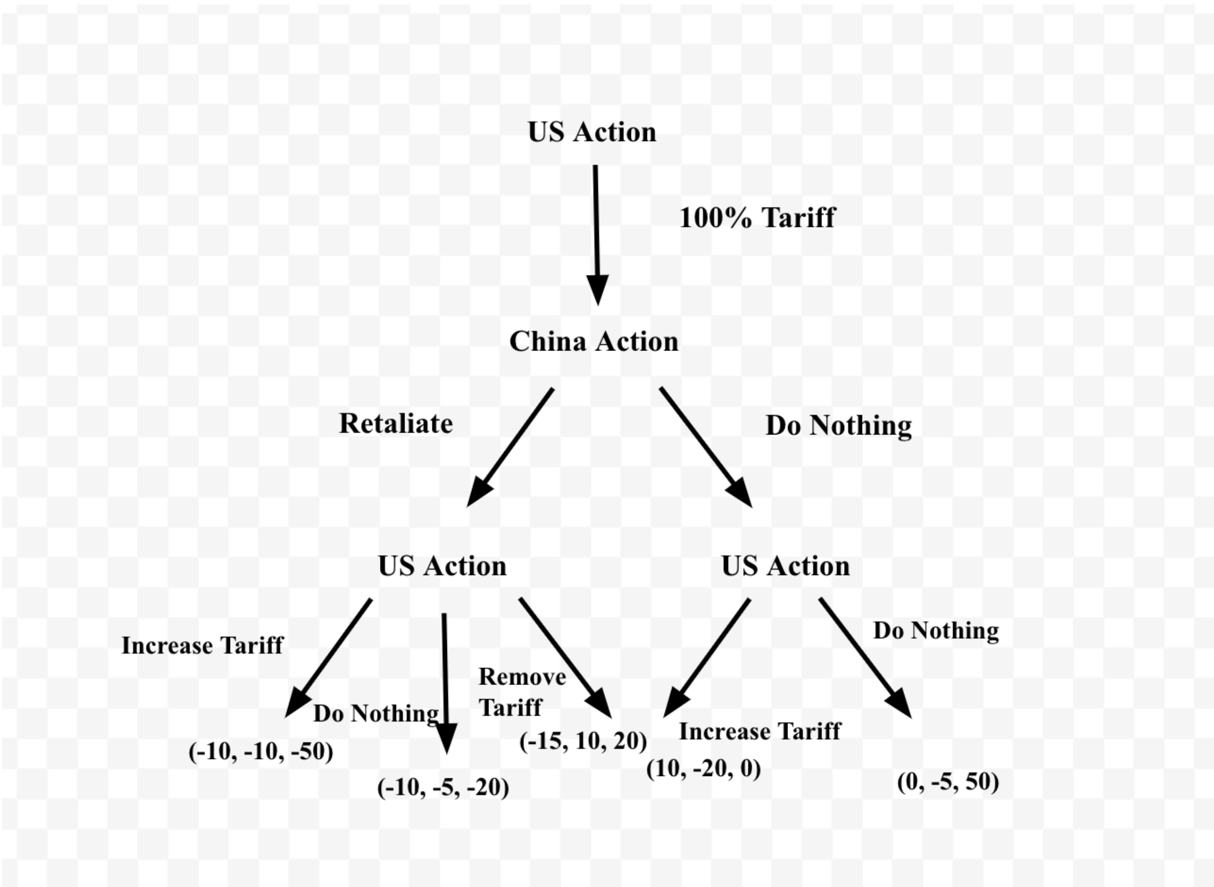

Figure 2: Model Figure with Values

Alternatively, we can look at the possibilities in a table form.

(S_U, S_C, L)	China responds	China does nothing
US increases Tariff	(-10, -10, -50)	(10, -20, 0)
US does nothing	(-10, -5, -20)	(0, -5, 50)
US removes Tariff	(-15, 10, 20)	

Table 1: Model Figure with values in table form

III: Initial Game Prudence Analysis

Let's begin by testing some extreme cases by using the formulae we have previously defined:

$$((S_U \cdot (1 - P_U)) + L \cdot P_U)$$
$$((S_C \cdot (1 - P_C)) + L \cdot P_C)$$

(U, C)	China responds	China does nothing
US increases Tariff	(-10, -10)	(10, -20)
US does nothing	(-10, -5)	(0, -5)
US removes Tariff	(-15, 10)	

Table 2: If $P_U = 0$, $P_C = 0$ (We assume both countries are completely shortsighted)

As this is a sequential game, we should start from the end, and examine what the United States does. If China responds, the US's best course of action is to increase the tariff or do nothing. And if China does not respond, the US's best course of action is to increase the tariff. As a result, China knows that there are three scenarios possible, and the worst scenario for China would be to do nothing as this yields an output of -20. As a result, China will always respond, which means that the subgame perfect Nash Equilibria of this game are China responding and the US increasing the tariff or doing nothing. But for the sake of this simulation, we assume that the US would prefer what China prefers less, meaning that the US increasing the tariff is the most likely scenario.

(U, C)	China responds	China does nothing
US increases Tariff	(-50, -50)	(0, 0)
US does nothing	(-20, -20)	(50, 50)
US removes Tariff	(20, 20)	

Table 3: If $P_U = 1$, $P_C = 1$ (We assume both countries are completely farsighted)

By the same process, solving backwards, we see that the US prefers to remove the tariff if China responds, and does nothing if China does nothing. The best scenario for China would be to do nothing: (50, 50).

(U, C)	China responds	China does nothing
US increases Tariff	(-50, -10)	(0, -20)

US does nothing	(-20, -5)	(50, -5)
US removes Tariff	(20, 10)	

Table 4: If $P_U = 1$, $P_C = 0$ (We assume the US is completely farsighted and China is completely shortsighted)

There are only two possibilities (20,10) and (50, -5), by the same process for the US. China looks and sees the best for them is (20, 10).

(U, C)	China responds	China does nothing
US increases Tariff	(-10, -50)	(10, 0)
US does nothing	(-10, -20)	(0, 50)
US removes Tariff	(-15, 20)	

Table 5: If $P_U = 0$, $P_C = 1$ (We assume the US is completely shortsighted and China is completely farsighted)

Now, we can proceed ahead and start checking intermediate cases, again using the same process to find the Subgame Perfect Nash Equilibriums.

(U, C)	China responds	China does nothing
US increases Tariff	(-18, -18)	(8, -16)
US does nothing	(-12, -8)	(10, 6)
US removes Tariff	(-8, 12)	

Table 6: If $P_U = 0.2$, $P_C = 0.2$

(U, C)	China responds	China does nothing
US increases Tariff	(-26, -26)	(6, -12)
US does nothing	(-14, -11)	(20, 17)
US removes Tariff	(-1, 14)	

Table 7: If $P_U = 0.4$, $P_C = 0.4$

(U, C)	China responds	China does nothing
US increases Tariff	(-34, -34)	(4, -8)
US does nothing	(-16, -14)	(30, 28)
US removes Tariff	(6, 16)	

Table 8: If $P_U = 0.6$, $P_C = 0.6$

(U, C)	China responds	China does nothing
US increases Tariff	(-42, -42)	(2, -4)
US does nothing	(-18, -17)	(40, 39)
US removes Tariff	(13, 18)	

Table 9: If $P_U = 0.8$, $P_C = 0.8$

We can clearly see at higher prudence levels that the Nash Equilibrium results in the US doing nothing and China doing nothing. Moreover, this change occurs between the P levels of 0.2 and 0.4. If we view this from the world's perspective, this is clearly the optimal outcome for global emissions rates; as a result, I will refer to it as optimal from now on. Consequently, let us examine some asymmetric intermediate cases, where the US and China have different P levels, to further make observations.

(U, C)	China responds	China does nothing
US increases Tariff	(-10, -10)	(10, -20)
US does nothing	(-10, -5)	(0, -5)
US removes Tariff	(-15, 10)	

Table 10: If $P_U = 0$, $P_C = 0$

(U, C)	China responds	China does nothing
US increases Tariff	(-10, -18)	(10, -16)
US does nothing	(-10, -8)	(0, 6)

US removes Tariff	(-15, 12)	

Table 11: If $P_U = 0, P_C = 0.2$

This condition is unique. Off the bat, the US prefers either (-10, -18), (-10, -8) if China responds, and (10, -16) if China does nothing. However, China does not know whether the US will select (-10, -18) or (-10, -8), so its best strategy is to play (10, -16).

(U, C)	China responds	China does nothing
US increases Tariff	(-10, -26)	(10, -12)
US does nothing	(-10, -11)	(0, 17)
US removes Tariff	(-15, 14)	

Table 12: If $P_U = 0, P_C = 0.4$

The same process holds true for this model as well.

(U, C)	China responds	China does nothing
US increases Tariff	(-10, -34)	(10, -8)
US does nothing	(-10, -14)	(0, 28)
US removes Tariff	(-15, 16)	

Table 13: If $P_U = 0, P_C = 0.6$

(U, C)	China responds	China does nothing
US increases Tariff	(-10, -42)	(10,)
US does nothing	(-10, -17)	(0,)
US removes Tariff	(-15, 18)	

Table 14: If $P_U = 0, P_C = 0.8$

(U, C)	China responds	China does nothing
US increases Tariff	(-18, -10)	(8, -20)

US does nothing	(-12, -5)	(10, -5)
US removes Tariff	(-8, 10)	

Table 15: If P_U = 0.2, P_C = 0

(U, C)	China responds	China does nothing
US increases Tariff	(-18, -18)	(8, -16)
US does nothing	(-12, -8)	(10, 6)
US removes Tariff	(-8, 12)	

Table 16: If P_U = 0.2, P_C = 0.2

(U, C)	China responds	China does nothing
US increases Tariff	(-18, -26)	(8, -12)
US does nothing	(-12, -11)	(10, 17)
US removes Tariff	(-8, 14)	

Table 17: If P_U = 0.2, P_C = 0.4

(U, C)	China responds	China does nothing
US increases Tariff	(-18, -34)	(8, -8)
US does nothing	(-12, -14)	(10, 28)
US removes Tariff	(-8, 16)	

Table 18: If P_U = 0.2, P_C = 0.6

There is no need to continue checking scenarios; we can see that the prudence-level checkmark for China to change its decision making towards optimal is again between 0.2 and 0.4. Now, we can move on to the 0.4 threshold.

(U, C)	China responds	China does nothing
US increases Tariff	(-26, -10)	(6, -20)

US does nothing	(-14, -5)	(20, -5)
US removes Tariff	(-1, 10)	

Table 19: If P_U = 0.4, P_C = 0

(U, C)	China responds	China does nothing
US increases Tariff	(-26, -18)	(6, -16)
US does nothing	(-14, -8)	(20, 6)
US removes Tariff	(-1, 12)	

Table 20: If P_U = 0.4, P_C = 0.2

(U, C)	China responds	China does nothing
US increases Tariff	(-26, -26)	(6, -12)
US does nothing	(-14, -11)	(20, 17)
US removes Tariff	(-1, 14)	

Table 21: If P_U = 0.4, P_C = 0.4

Again, there is no need to continue checking; we can clearly see that between 0.2 and 0.4, China begins to prefer the optimal scenario. A pattern has begun to emerge, but we verify it with an additional set of cases.

(U, C)	China responds	China does nothing
US increases Tariff	(-34, -10)	(4, -20)
US does nothing	(-16, -5)	(30, -5)
US removes Tariff	(-6, 10)	

Table 22: If P_U = 0.6, P_C = 0

(U, C)	China responds	China does nothing
US increases Tariff	(-34, -18)	(4, -16)

US does nothing	(-16, -8)	(30, 6)
US removes Tariff	(-6, 12)	

Table 23: If $P_U = 0.6$, $P_C = 0.2$

(U, C)	China responds	China does nothing
US increases Tariff	(-34, -26)	(4, -12)
US does nothing	(-16, -11)	(30, 17)
US removes Tariff	(-6, 14)	

Table 24: If $P_U = 0.6$, $P_C = 0.4$

We see a pattern forming that $P_U \in \{0.2, 0.4, 0.6\ldots\}$, if $P_C = 0$ or 0.2 then we see the China responding and US removing scenario, whereas at $P_C > 0.4$, the optimal scenario occurs. The same holds true for $P_U = 0.8$.

We can thus create the following table to demonstrate our findings, where the values of the US are demonstrated on the left column and the values of China are demonstrated on the top row. Moreover, we can represent the outcomes in terms of global benefit through a color gradient in the following manner, where the greener colors are more beneficial for the world and the redder colors are the least beneficial for the world. The map gives the colors that correspond to outcomes in the following table.

(S_U, S_C, L)	China responds	China does nothing
US increases Tariff		
US does nothing		
US removes Tariff		

Table 25: Color-coordinated map of possibilities

	$P_C = 0$	$P_C = 0.2$	$P_C = 0.4$	$P_C = 0.6$	$P_C = 0.8$	$P_C = 1$
$P_U = 0$						
$P_U = 0.2$						

$P_U = 0.4$						
$P_U = 0.6$						
$P_U = 0.8$						
$P_U = 1$						

Table 26: Nash Equilibrium at all possibilities

This table of tables confirms the trend we have been witnessing. As long as the US has a P_U value of 0.2 or more, the P_C value determines whether we will see the light green scenario in the table or the optimal scenario. Moreover, we see that there is some threshold of P_C between 0.2 and 0.4, where, before the threshold is passed, the former scenario plays out, and after the threshold is passed, the latter scenario plays out.

Further calculations isolate the true value for this threshold where optimal is reached. With the equation

$$10(1-P_C) + 20P_C = -5(1-P_C) + 50P_C$$

When we attempt to solve this, we find that the threshold (the one we know to be between 0.2 and 0.4) is exactly $\frac{1}{3}$.

We can also find the P_U threshold value, all though it is not as abundantly clear as the P_C value. However, we can see that if P_C is sufficiently high, that there is a P_U value between 0 and 0.2 where the Nash Equilibrium goes from being the yellow scenario or the optimal scenario. We can again set an equation.

$$10(1-P_U) = 50P_U$$

Solving this, we find that the threshold for P_U is $\frac{1}{6}$.

As a result, we have solved the model. The United Nations should know that only if $P_U > 0.1\overline{6}$ and $P_C > 0.\overline{33}$ hold true does the optimal scenario occur.

Conclusion and Policy Recommendation:

We have solved all quintile possibilities. We have determined the levels at which the United States and China have preference angling towards the outcome which is best for the world. Now, it is critical to reflect on how it would be possible, as an international body, to angle the US and China into this scenario.

I have thought of two possibilities. The first would be to guarantee that both the United States and China have P-values above their thresholds of $P_U > 0.1\overline{6}$ and $P_C > 0.\overline{33}$. Unfortunately, this would be rather hard to do. International bodies are notoriously inefficient at directly being able to influence countries in this manner (Crisis Group). Moreover, this process would raise further questions of this model in particular. The values are not perfectly relative to the actual outcomes in the real world, nor do they strive to be. As a result, this path would not be very feasible, given that this paper serves more abstract purposes when creating the model than perfectly specific ones.

The other possibility would be for the United Nations to attempt to affect the values associated with the game. For instance, finding a way to decrease the short-term coefficients further in the suboptimal scenarios is one potential path to effectively shift the game. This could look like sanctions or tariffs to the United States or China in scenarios where either or both decide to further continue this trade battle. Unfortunately however, this would also be unlikely to occur in the real world, given the United States and China's power and prestige on the five permanent members of the Security Council, and their ability to veto any measures they find hard to stomach (Security Council Report). This form of compulsion, of attempting to decrease certain values, would likely fall flat on its head.

As a result, the only possibility left standing is what can be described as a type of positive reinforcement. Increasing the short-term outputs of the US and China in the optimal conditions, is the most feasible of the scenarios. An idea to consider includes incentivizing cooperation by offering incentives for the US and China if they withdraw sanctions. For example, if the UN were to offer leadership roles on committees or initiatives, or by decreasing the contributions that the countries have to provide to the UN (Council on Foreign Relations), in exchange for the countries removing sanctions on the UN, this might promote the countries to follow the optimal scenario, which would undoubtedly be the best for emissions efforts.

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Notes

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