Overview, Design Concepts and Details (ODD)

1. Purpose and patterns

- Research Question: How can we predict how tariffs on foreign electric vehicles (EVs) and buyer incentives for domestic EVs will impact the American electric vehicle industry over the projected future (e.g. the next 50 years? Under what conditions (e.g. tariff percentages and domestic incentives) do the interactions between American and foreign policies, companies, consumers, and governments sustain and strengthen the American EV industry's global advantage? How do interactivity and variability in tariff rates, buyer incentives, and prices affect the economics of trading and American and foreign EV sales and market share?
- Purpose of the Model: to predict how best to use tariffs and buyer incentives to protect the domestic American EV industry's market share when there are cheap Chinese and European competitors.
- Function of the Modeled System: all actors and factors (buyers, manufacturers, governments, patterns) in a partitionable open market under national governance produce shifting trade policies and consumer patterns.
- This model focuses on sales, rather than manufacturing.
- It tracks tariffs and government-awarded consumer incentives to make domestic EVs more affordable but omits governmental subsidies for EV manufacturers and manufacturing costs.
- Since this model is intended to be a policymaking tool, it is important for the model to be reflective of real-world, contemporary conditions to explore the range of plausible futures that could emerge, especially ones that are hard for policymakers to imagine or anticipate unaided.
- Because this model uses real-life numbers, using numbers from previous years (e.g. 2022) and running the model to see whether it generates similar results as to what actually occurred that year (e.g. in 2022) helps indicate the model's usefulness for its intended purpose.
- This model also simplifies out the question of scarcity and essentially frees agents/sellers from having to think about hedging against or taking advantage of declining inventory. In other words, the model omits variation in inventory allocation and does not allow experimentation with countries choosing to boost/reduce production or hold inventory in proportion that is not equal to the proportion of buyers. The fundamental assumption is that the car companies plan fixed inventories per sales cycle, which is true in real-life because new models are typically introduced with a limited inventory at a specific time, even during seasonal spikes. Therefore, this model uses a fixed inventory, and cars can be sold out. Therefore, an important benchmark for judging whether the model is realistic enough is if the model attempts to circumvent inventory sell-outs when there are still customers wanting to buy the inventory, so as to accurately model supply and demand.

2. Entities, state variables, and scales

The model has three kinds of entities: governments, electric vehicle companies, and consumers. The governments try to preserve domestic market share, the electric vehicle companies try to preserve profits in the face of tariffs, and the consumers try to purchase the best possible electric vehicle within their budget and preferences. This model shows how these three agent types can simultaneously achieve their respective goals in a dynamic environment with shifting prices, tariffs, and incentives.

- Government bodies
  - There will be three agent variables/characteristics for each actor that, together, denote the general sensitivity to a rise/decline in domestic market share: Slider #1 will denote the minimum percentage of acceptable domestic market share to justify current tariff rate. Slider #2 will denote the maximum percentage of acceptable domestic market share to justify current tariff rate. Slider #3 will denote the percentage increase/decrease in tariffs. For example, if the user inputs 80% for Slider #1, 90% for Slider #2, and 25% for Slider #3, then, if the country does not get 80% of their domestic market share in a run, then they will increase tariffs by 25%. If the country gets more than 90% of its domestic market share in a run, then it will decrease tariffs by 25% to ensure that there is some amount of open market. This creates a potential for a balancing feedback loop to limit or reverse the introduction of tariffs. I will assume that the US, China, and Europe all have equally strong desires for their industries to succeed, so all three will exhibit similar sensitivity to changes in market share rates in the slider.
- Electric Vehicle (EV) companies
  - I chose to illustrate the American EV industry's competition with the Chinese EV industry and the European EV industry. For the sake of this model, all European EV manufacturers have been lumped into the Europe agents, rather than separating them into separate countries (e.g. Germany, Italy).
  - Sellers are composites that are comprised of all sellers of the models in a particular tier in a particular country (e.g. American budget model, Chinese standard model). Because of this, individual sellers emerging and disappearing are implicitly incorporated into this composite model of a seller.
  - The model simulates perfect competition that avoids monopolies, cartels, etc. Consequently, the sellers within each country do not compete for market share or "gang up" against other sellers, and third-country companies do not take advantage of a tariff war between two other countries' companies through price-fixing.
  - All will have a pre-set price range they are willing to sell within, and the price can fluctuate within this range each time the model tics/runs based on whether the company sold an EV during that tic/run. A company's

price has a "basement" and a "ceiling" that it will not cross. This range is allocated based on real-world data on car manufacturer "wiggle" rooms (i.e. 3% for budget cars and 5% for standard cars).

        - There will also be three sliders that, together, denote a company's general sensitivity to inventory sell-outs: Slider #1 will denote the minimum percentage of acceptable inventory left to maintain current inventory levels. Slider #2 will denote the maximum percentage of acceptable inventory left to maintain current inventory levels. Slider #3 will denote the percentage increase/decrease in inventory. For example, if the user inputs 75% for Slider #1, 95% for Slider #2, and 15% for Slider #3, then, if the company does not sell at least 75% of its inventory in a run, then it will decrease its next run's inventory by 15%. If the company sells more than 95% of its inventory in a run, then it will increase its next run's inventory by 15%. This creates another possibility for a balancing feedback loop.
        - The companies will consist of:
            - American Standard EV Company
            - American Budget EV Company
            - Chinese Standard EV Company
            - Chinese Budget EV Company
            - European Standard EV Company
            - European Budget EV Company
        - I chose to incorporate two tiers of car models (Standard and Budget). I chose not to include a Luxury car tier because American Luxury EV cars were discontinued in the Chinese market (i.e. they're not sold there anymore). Additionally, the Luxury EV market has a relatively inconsequential amount of sales and has little impact on market share. Budget and standard EVs are the primary makeup of market share even though luxury cars enjoy higher margins. Because my project focuses on market share more than margins, I decided to focus on budget and standard EVs.
    - Consumers
        - My assumption is a finite number of buyers, reflective of real-world buyer data.
        - All consumers are assigned a money amount allocated to purchasing an EV. This amount will be based on real-life market data to account for low-, middle-, and high-budget consumers.
        - Consumers are characterized only by their location, budget, and individual preferences (e.g. preferences for luxury, American-made cars), all characterized using assumed distributions based on real-world data.
- *Environment*. This entails forces that drive the behavior and dynamics of all agents or grid cells.
    - The model illustrates market price/demand and variable tariffs.
    - Global variables track current inventory levels, the number of buyers looking to buy an EV, tariffs, incentives, domestic sales, foreign sales, buyer wealth, and company price changes.

- The environment is simplified to not include inflation and supply chain issues.
- The model assumes that there is still a robust market for EVs in 50 years.

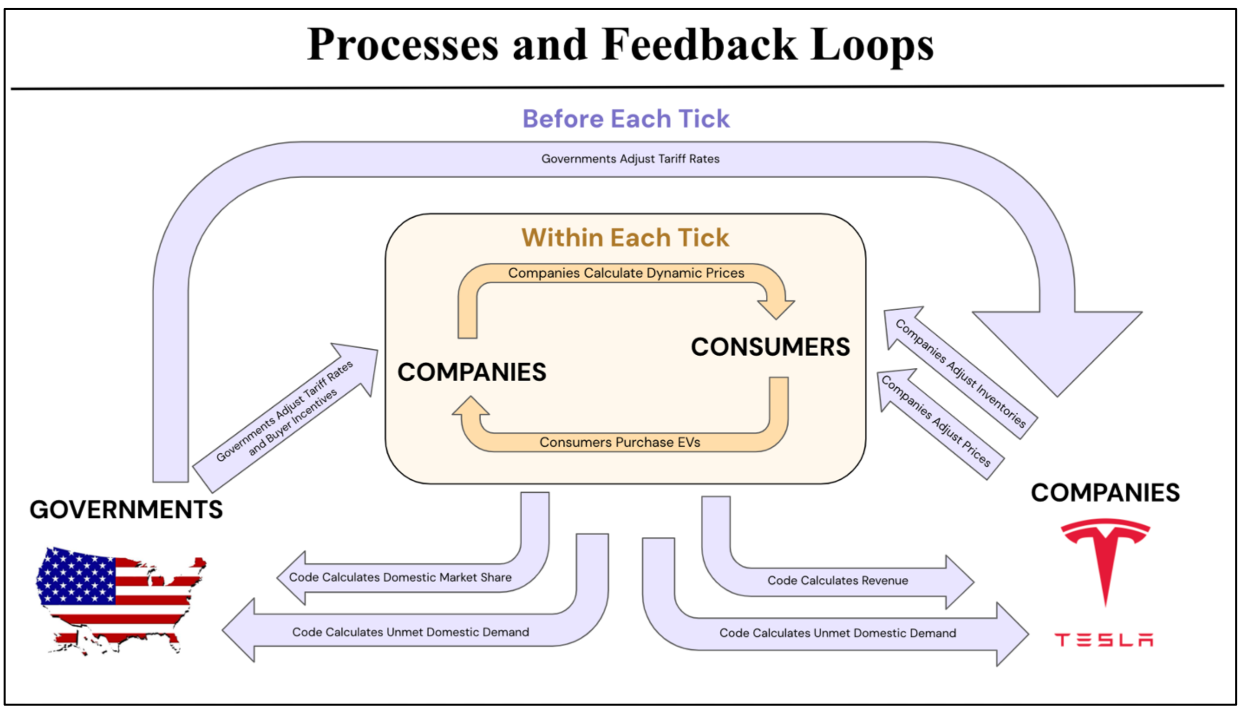
3. Process overview and scheduling

Overall: The agent-level interactions between the companies and consumers dynamically determine the prices and market share within each sales cycle/tick. Then, the regulating agents (governments) and the companies further influence the factors that govern each sales cycle/tick.

Each tick runs for 1 year representing a complete sales cycle. This model assumes that the government tariff policy is also at an annual cycle. In theory, policy can be changed at any time, but it takes time to assess the policy implications of such specific choices of tariffs, and it takes probably more than one sales cycle to see those implications. The effect of tariffs will only become clear after at least several sales and tariffs cycles. Consequently, there is only one set initial tariff value for the first year, inputted through a user slider. Then, governments can change (i.e. continue, increase, or decrease) their annual tariff values during each tick/run based on how the previous year's market share turned out.

During each tick, the number of buyers will be adjusted for population growth every year (0.3% growth for the US, and -0.15% for China, based on real-world data).

This model simulates an adjustable period of say 50 years of EV sales cycles (each tick represents a 1-year sales cycle) because manufacturers follow a yearly sales cycle and set dynamic prices accordingly.



Inner Process in the Diagram Above: This submodel occurs within each 1-year sales cycle. The consumers buy EVs, which influences how the companies calculate dynamic prices. These prices then influence whether the consumers buy EVs. This is a classic supply and demand submodel.

Outer Process in the Diagram Above: This submodel occurs before each 1-year sales cycle. Before the start of the next annual sales cycle, the code calculates domestic market share and the unmet domestic demand, and the governments use that information to adjust tariff rates and buyer incentives. The governments then send that information to the companies ahead of time. Simultaneously, the code calculates the revenue and unmet domestic demand and sends that information to the companies. The companies use the information about revenue, unmet domestic demand, and the upcoming tariff rates to adjust inventories and prices for the next annual sales cycle. Essentially, the governments' actions indirectly affect the next cycle's consumers, and the companies' actions directly affect the next cycle's consumers.

Each tick/run lasts until final equilibrium is achieved/sales stop (i.e. all the consumers have purchased an EV, there are no buyers left that have enough income to buy the brands that are left, or all inventory of all companies is exhausted). The simulation is stopped after 50 years.

Researchers looking to employ this tool can change population and time parameters to analyze the projected field in the future (e.g. in 2050).

State variables are immediately assigned a new value as soon as that value is calculated by a process (asynchronous updating).

Initially, governments institute their initial tariffs using slider input that governs starting tariff values (these values shape the consumers' first round of purchases). The consumers' wealth is assigned based on a randomized Lorenz curve.

The model action begins with consumers purchasing EVs based on prices, incentives, and individual preferences. Consumers buy in random order.

a. The model uses a function within the code that:
   i. Identifies which EVs are within/below the consumer's budget
   ii. Of those, identifies which EVs satisfy individual preferences (e.g. preferences for luxury, American-made)
   iii. Of those remaining, identifies the most expensive (but still affordable) option
   iv. Each EV's price will take into consideration tariffs and government incentives.

Within each tick, if a company succeeds in selling an EV to a consumer, the company increases its price (within assumed range). If the company fails to sell an EV to the consumer, the company decreases its price (within assumed range).

After the end of each tick/sales cycle, the code calculates domestic market share and unmet domestic demand. Then, the governments use this information – along with user input through sliders governing sensitivity to changes in market share – to update their tariffs and buyer incentives between model runs.

After the end of each tick/sales cycle, the code calculates sales percentages and unmet domestic demand. Then, the companies use this information – along with the updated foreign government tariff values and user input through sliders governing general sensitivity to inventory sell-outs – to update their inventories and prices between model runs.

My assumption is a finite number of sales inventory, reflective of manufacturing constraints.

4. Design concepts

Emergence. All the actors and factors (buyers, manufacturers, governments, patterns) in a partitionable open market under national governance produce emergence, which is the shifting government tariff policies, company inventory and pricing decisions, and consumer buying patterns. An example of a result that is more "built in" is the inventory sell-outs because, while it is dependent on consumer buying patterns, consumers decide to widely over-purchase one model of car because of imposed prices based on real-life data.

Adaptation. Governments adapt their tariff behaviors based on changes in the market share environment. Companies adapt their inventory and pricing behavior based on environment changes like unmet domestic demand, revenue, tariff rates, and whether consumers are buying their model. Customers adapt their purchasing behaviors based on changes to pricings.

Objectives. Governments want to maximize domestic market share (the exact threshold based on user slider input), which is measured through a ratio illustrating successful sales compared to the overall consumer market. Companies want to sell as many cars as possible, which is measured through successful sales compared to their foreign competitors. Consumers want to buy cars, and when there are alternatives, they purchase the most expensive car within their allocated buying budget. If there is a tie, they purchase the car belonging to their home country's companies.

Learning. The model omits domestic politics and the implications of changing administrations, so government agents do not change their domestic market share goals over time. Instead, policy goals are constant.

Prediction. Before each annual sales cycle, the governments inform the companies about the upcoming cycle's tariff rates to inform company decisions on things like prices.

Interaction. "Company-Consumer" interactions are direct interactions. Consumer purchases directly impact company prices. Company prices directly impact consumer purchasing habits. These interactions produce an annual domestic market share and unmet domestic demand that impact government tariff rates and buyer incentives. These government rates and incentives don't directly impact consumer agents in the code; instead, governments directly communicate this information to the companies. The companies use that information – along with revenue information – to inform their pricing and inventories that will be directly imposed on the consumers.

Stochasticity. Consumers' wealth is characterized using a randomized Lorenz function (captures wealth distribution) using real-life GINI values and GDP per capita into NetLogo directly. The randomized Lorenz function is more realistic (reflects the complexity of the real world) for this scenario than the normal, uniform, or power law distributions and should help improve the agent set diversity and account for the "noise" of life. The code calculates the minimum amount of wealth needed to afford any type of EV in any scenario and remove the consumer agents that are not over that minimum threshold.

Observation. Data about the domestic market share after the model finishes running (after 50 ticks) is collected from the ABM. Using Behavior Space is helpful in discovering the optimal parameters for obtaining a specific threshold of domestic market share.

Patterns. The model tracks:

- Revenue of American/Chinese/European sellers in all the Markets (American, Chinese, and European)

- Market share of American/Chinese/European sellers in American/Chinese/European markets
- Charts for the interface to plot available inventory and available buyers. These charts help the user understand when final equilibrium has been achieved.
- Domestic volume sales per country
- Foreign volume sales per country
- Profit per country (country profit = tariffs – incentives) → this will be a global variable
- I decided not to track profit per seller because manufacturing costs are unclear for Chinese EV manufacturers.

5. Initialization

Initialization depends on user slider inputs (which could vary across simulations) and publicly available data that has been coded into the model (which will remain the same across simulations).

The initial government tariffs, overall government sensitivities to domestic market share, overall company sensitivities to inventory, and overall consumer percentage of wealth allocated to buying an EV are dependent on user slider inputs. These values can vary across simulations. The interface will have nine sliders where the user can set nine initial tariffs imposed from the US/China/Europe side onto the US/China/Europe. These represent initial tariffs at the beginning of the simulation, as the tariffs will change throughout the simulation. If the user wants to portray the current economic environment for policymakers, they should input the contemporary tariff rates based on current data.

The following values have been coded into the model, so these initializations will remain the same across simulations:

The companies' price and inventory data are not random and instead are based on real-life company websites (the sources are in the next section). The starting price/maximum price is represented by the invoice price (i.e. what the dealer will advertise). The minimum price (i.e. the general retail price or the price that people generally negotiate for) is calculated using the market standard for wiggle room. This is 3% for budget cars and 5% for standard cars, as more expensive cars typically have more wiggle room in price negotiations. These assumptions are based on publicly available information.

- Chinese standard model starting price = \$3,1336

- Chinese budget model starting price = $27,400
- US standard model starting price = $46,630
- US standard model starting price = $40,630

I assumed that the inventory is the number of cars they sold last year because they do not want cars to pile up anymore (this has been the situation for the past couple of years). Also, the inventory variable is general for the entire company and does not split inventory for the US market vs. inventory for the Chinese market. However, this does not account for the coming large-scale shift to EVs as traditional cars are slowly phased out. Modelers can decide to account for this through another growth factor based on market growth projections. The following four numbers are the initial company inventories. These are real-life values that have been scaled down by 100 so the model can run more efficiently. The sources are in the next section.

- Chinese standard model = 1,000 EVs
- Chinese budget model = 1,273 EVs
- US standard model = 8,420 EVs
- US budget model = 3,753 EVs

For this model, 1.2 million individuals are consumers located in America; 600,000 individuals are looking to buy in China; and 3 million individuals are looking to buy in Europe. These numbers are based on real-world data. The code scales down inventory and buyers by 100 so that the model runs efficiently and can be displayed on the interface.

- American consumers looking to buy: 12,000
- Chinese consumers looking to buy: 6,000
- European consumers looking to buy: 30,000
- Annual population growth is 0.3% growth for US, -0.15% for China, and -0.18 for Europe.

6. Input data

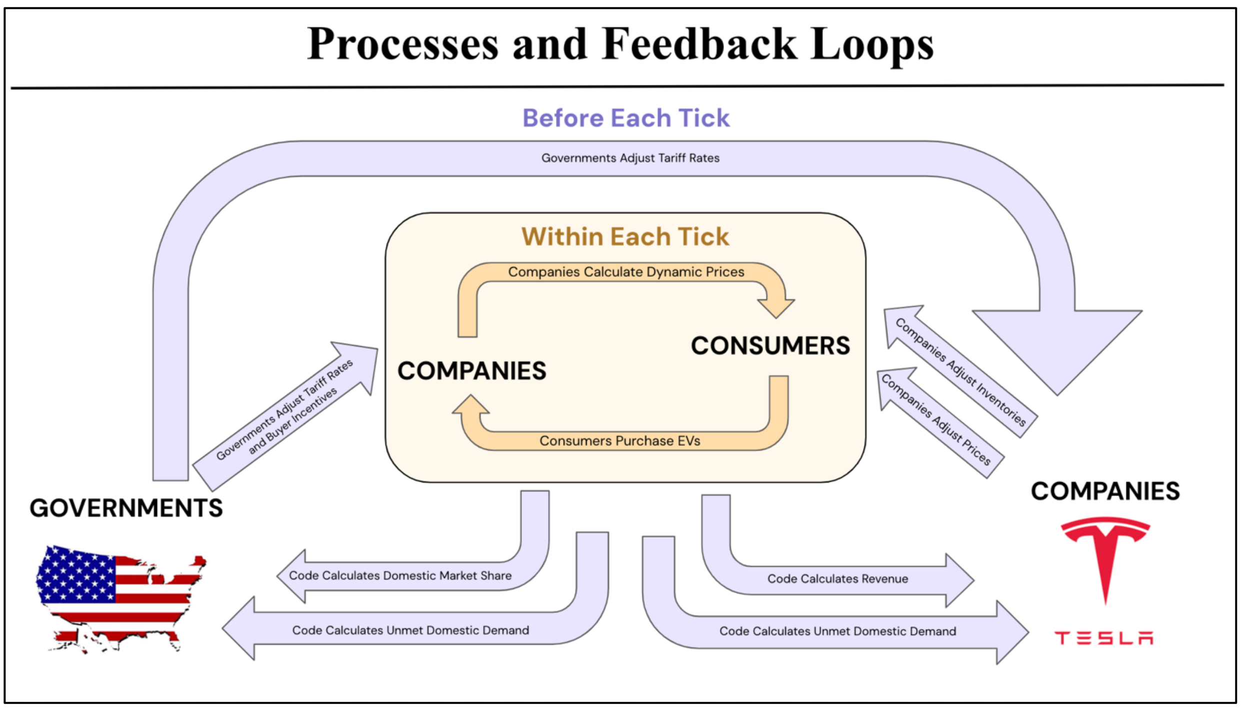
Instead of drawing from data files, I used publicly available data to compile my own information on company prices and inventory that I injected into my NetLogo "world."

The model draws on values for 2023 company prices and inventories. Because data about Chinese companies is hard to find, the inventory is calculated using overall sales worldwide. For Tesla, I was able to find US sales and China sales, so I added those together to get the inventory since I have not incorporated the European market yet.

BYD Seal inventory	https://cnevpost.com/2024/01/01/byd-dec-2023-sales-breakdown/#
BYD Seal invoice price	https://carnewschina.com/2023/05/10/2023-byd-seal-launched-starting-at-27400-usd-with-550-km-range/
BYD Atto 3 inventory	https://carnewschina.com/2024/01/11/byd-overseas-model-sales-review-in-2023-atto-3-best-selling/#

BYD Atto 3 invoice price	https://www.reuters.com/business/autos-transportation/chinas-byd-prices-new-version-best-selling-ev-lower-than-predecessor-2024-03-04/
Tesla Model 3 inventory	https://worldpopulationreview.com/country-rankings/tesla-sales-by-country
Tesla Model 3 invoice price	https://www.kbb.com/tesla/model-3/2023/standard/
Tesla Model Y inventory	https://worldpopulationreview.com/country-rankings/tesla-sales-by-country
Tesla Model Y invoice price	https://www.caranddriver.com/tesla/model-y-2023

7. Submodels



The government parameters about market share thresholds, the company parameters about inventory thresholds, and the consumer parameter about the percentage of wealth allocated to an EV purchase (typically not more than 30% based on real-life research) all come from user slider inputs.

The consumer parameter about assigned wealth comes from a randomized Lorenz function using real-life GINI values and GDP per capita. I created the following function to be called for each consumer:

```
to-report random-wealth [ GINI total-wealth-var count-buyers ]
  let wealth-share random-float 1
```

```
let scaled-share (1 - GINI) * wealth-share + GINI * (wealth-share ^ 2)
report scaled-share * total-wealth-var / count-buyers
```

Additionally, on the interface, consumer agents do not move grid squares but instead change colors to represent which country's car they have purchased (or if they failed to purchase at all). In the current code, red indicates buying a Chinese EV and green indicates buying an American EV.

Below are submodel overviews illustrating how the government and company agents interact with each other:

a. Governments decide to increase tariffs by A if domestic market share > B
b. Governments decide to decrease tariffs by A if domestic market share < C
c. Governments decide to increase buyer incentives by D if domestic demand > E
d. Governments decide to decrease buyer incentives by D if domestic demand < F
e. If American/European government has decided to increase tariff rates on Chinese cars by A and domestic market share is > K, Chinese companies decide to increase their price range proportionately to A (because companies want to maximize profits)
f. If American/Chinese government has decided to increase tariff rates on European cars by A and domestic market share is > K, European companies decide to increase their price range proportionately to A (because companies want to maximize profits)
g. If Chinese/European government has decided to increase tariff rates on American cars by A and domestic market share is > K, American companies decide to increase their price range proportionately to A (because companies want to maximize profits)
h. If American/European government has decided to increase tariff rates on Chinese cars by A and domestic market share is < L, Chinese companies decide to increase their price range by a fraction of A (for this model, let's say arbitrary 0.5*A) (this is because companies still need to fight to maintain market share)
i. If American/Chinese government has decided to increase tariff rates on European cars by A and domestic market share is < L, European companies decide to increase their price range by a fraction of A (for this model, let's say arbitrary 0.5*A) (this is because companies still need to fight to maintain market share)
j. If Chinese/European government has decided to increase tariff rates on American cars by A and domestic market share is < L, American companies decide to increase their price range by a fraction of A (for this model, let's say arbitrary 0.5*A) (this is because companies still need to fight to maintain market share)
k. Companies decide to increase its price range by M if revenue (i.e. sum of each price the car was sold at) > N
l. Companies decide to decrease its price range by M if revenue (i.e. sum of each price the car was sold at) < P
m. Companies decide to increase inventory by G if domestic demand > H

n. Companies decide to decrease inventory by G if domestic demand < J

8. Appendix

If – after accounting for tariffs, incentives, and preferences – there was both a domestic EV and a foreign EV that had the same price and fulfilled the same consumer preferences, I assumed that the consumer would choose to purchase the domestic EV to support their own country's economy. Additionally, the model is scoped to exclude people who are unable to purchase an EV for financial reasons and have people who are wealthy enough to buy multiple EVs use an individual proxy (i.e. still only one car per person).

Additionally, inflation and shifts in global transportation have been simplified out of this model.

This model assumes that customers will only attempt to buy one car each (instead of purchasing multiple cars if they have the funds). The percentage of wealth allocated to buying a car is standardized across all consumers and countries and is based on user slider input.

The model uses a rectangular grid, using x- and y-coordinates. The model shows the density of domestic and foreign purchases in each country visually. The grid will be split into the top left (US), top right (China), and bottom half (Europe) because Europe has almost three times as many EV buyers as the US, according to current data.

Additionally, this model assumes that all unsold inventory goes to bargain sales, in which revenue is negligible.

This model focuses on market share as a driving factor of government decisions, rather than margins. A more complex policy could take into account margins, as well, but data on margins is hard to estimate from Chinese companies because these companies often swallow margins for the sake of market share. Therefore, I chose to use market share because the data is more easily verifiable.

This model does not track Deadweight Loss [deadweight loss = (new price - old price) x (original quantity - new quantity) / 2]. However, modelers can always code in a Deadweight Loss tracker if they want to see how much the consumer is being impacted by the tariffs and buying incentives.

This model does not program in companies that decide to be "loss leaders." "Loss leaders" occur when a manufacturer purposefully sells a vehicle at a loss to achieve market share. This is sometimes the case with Chinese manufacturers, so this should be factored into their real-life prices to some extent. This model instead codes in that all companies should not "dump" cars and swallow profits to gain market share (instead, companies want both to increase).

Company price increments are standardized across all companies and countries and are based on input through a user slider on the interface.

This model also omits the threshold of EVs that contain parts manufactured outside of their domestic home country. For example, despite China considering expanding production into Mexico to circumvent US tariffs through NAFTA, the US and Mexico have already cooperated on combating Chinese tariff circumvention. Consequently, this model considers China a lone importer/exporter.

This model assumes that these governments are **not** non-interventionist and that all political parties have the same tariff policy platform, thereby omitting domestic politics as a parameter.

This model omits currency depreciation as a government agent choice. In the real world, the CCP might depreciate currency in response to increased tariff rates from the US.