Problem Chosen
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Summary Sheet

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"Growing" Economic Models for Hunger

Summary

Solving World Hunger is a phrase often used as a more hyperbolic "it's no rocket science/ brain surgery", because as we all know, World Hunger is really complicated. It's estimated that in the USA alone, over 167.5 Billion dollars per year is lost due to food-insecurity-related losses, which is an expense on top of the impossible-to-quantify suffering of the millions of Americans who experience it [1]. Our model seeks to guide policy seeking to address these insecurities by modeling the economics of food distribution in different incentive frameworks at several levels. We model the costs on the side of food production, the incentive structure of the food distribution network, and the wealth inequality that exists within communities to give a framework which can be used to direct policy towards the most impactful parameters of the model and identify which features of the economy are contributing most to food insecurity.

We achieve this model on three levels:

- Supply-side: we examine the factors which influence the cost of producing food and how that impacts the amount of food getting produced.
- Distribution: we examine the impact of infrastructure on the environment as well as on the cost of delivering food. Further, we model several different incentive structures for the distribution network, which determines how much food each community gets. These models include best and worst case capitalism models as well as command economy models. We also model the impact of international trade on food scarcity within rich and poor countries.
- Demand-Side: we examine the effect of various properties of wealth distribution and food-purchasing priorities within communities in rich and poor countries on how many people are food-insecure, how badly they are affected, and who within a population is affected.

The aims of these different pieces of the model are to create a framework which is robust, adaptable and applicable to a great variety of wealth-distributions and agricultural practices, and to be able to use the model to inform policy. While time constraints prevent us from showcasing the complete versatility of the framework to model global economies and a variety of scenarios, we believe our implementation of the framework to the system we're modeling in several interesting scenarios showcases its potential and adaptability. We also believe our policy recommendations based on the model illustrate its ability to inform policy, although we are limited by the number of systems modeled.

Contents

1 Introduction

1.1 Background

Food insecurity has been a major problem in the world for a long period of time, and should seemingly not exist. Every year, there is a surplus of the necessary food made for the entire world, yet there are still many people who go hungry, or do not have enough nutrients to survive. In order to find solutions to this major problem, we modeled the transportation networks and buying/selling markets through the lens of different economic policies. We did this so that we could show if there is a better way to serve not only individual underfed communities, but also the possibilities of malnourished countries.

1.2 What Causes Food Insecurity

While there are many different factors that can go into the cause of food insecurity, they can generally be put into two categories, a national food insecurity or a local one. National food insecurity usually takes place in countries with a lack of infrastructure. These countries may not lack resources themselves or have access to trade for those resources, but instead lack a delivery method. Lack of adequate roadways internally and externally prevents communities from access to external food sources.[2] If there is only local food insecurity, then it is caused by uneven wealth distributions, where people with less wealth have access to food, but not the means to afford it. Even if these local groups can afford food, they might not be able to afford food with adequate nutritional value. [1]

1.3 Finding a Novel Solution

There are many ways to try and end food insecurity, through food banks, welfare, and similar public projects, but none of those get the the heart of the issue. The real issue a lot of the time is either the lack of infrastructure, or the fact that food with adequate nutritional value is more expensive then similar calorie foods. We believe the best way to solve these problems is by viewing it through an economic lens. This allows us to identify what the best system to put in place in order to optimize for no one going hungry.

1.4 Model Overview and Theory

Our different scenarios are all run on the same network model. The model can be split into three main parts: the consumers, which live in "markets", which can be thought of as cities or neighborhoods; the producers, or farmers, which produce food, and the distributor, a decision-maker which 'purchases' food from farms, ships them across the map to markets, and sells the food to consumers. The distributor is the primary decision-making entity and can be thought of the collection of all agents with market power, and its behavior depends on the economy type.

The distributor acts as an optimizer, though what it's optimizing for depends on the type of economy modeled. We model three different economies: a monopoly, a competitive market, and a command economy. The monopoly model assumes there is one distributor which seeks to maximize its profit. It maximizes revenue from selling to markets minus expenses from purchasing from farms and transporting foods, the profit function given in the Utility Optimization section of this report. The competitive market is the opposite extreme, we assume that there is such a perfect competition between distribution firms that they collect no economic profit, and instead optimize number of transactions. This is essentially a trick of imitating the properties of a market without simulating all of the detail, and according to classical economic theory will give the same result. The real world lies between these two extremes, as there exists a small enough number of firms for perfect the competition assumption to be inaccurate, but none has as much market power as a monopoly.

Lastly, we have the command economy, in which some benevolent entity, presumably an exceptionally well-run government is optimizing for outcome, rather than profit. We use a few different utility functions for this: one simply minimizing food insecurity, one maximizing consumer utility, one minimizing damage to the environment, and one optimizing for some combination. Command economies also differ from the capitalism models in that all consumers in a market (one market represents one community) receive exactly the same food. Either everyone is fed or everyone starves.

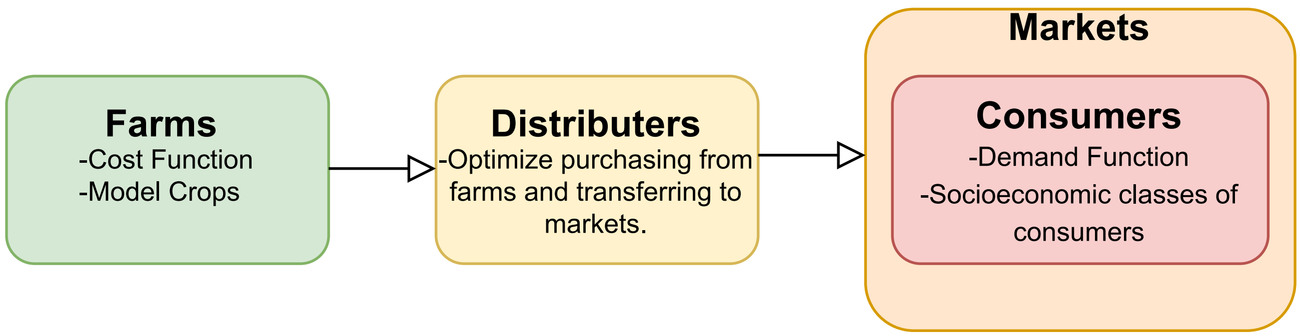

Figure 1: Organization from farm to consumer

2 General Assumptions and Justifications

Some assumptions used throughout the model:

- Food types are interchangeable.
  - This essentially means we don't model the differences between food types nutritionally, or consumer preferences about food types. There would be some non-trivial implications of modeling different food types, such as the ability of a monopoly distributor to price discriminate selling luxury foods to the rich and inferior foods to the poor, which could improve the worst-case (monopoly) scenario a bit. However, the impact this would have on the other scenarios would be fairly small since the purpose of this model is to track means of reducing starvation, and since food is modeled in units of calories, distinguishing between foods does little within the model.
- Farm production is decided by the distributor
  - This is essentially saying, the distributor tells farms how much of a good it's going to purchase from them. This isn't exactly unrealistic, as farms will tend to avoid producing more than will be purchased anyways, but we are also implicitly assuming the farms

themselves have no individual market power. This isn't generally true, but is a reasonable approximation as there are many farms which are on a roughly equal playing field, and modeling optimal behavior of oligopolies is virtually impossible on such a complex system (we spend a lot of time trying).

- Every urban area has an airport and a railroad.
  - In order to ensure that every continent was reachable by every other continent, we made it so that every urban area had an airport. This is because not all urban areas are coastal, so they wouldn't all be able to have sea ports, but all urban areas have some airline that services them. We assumed that an urban area has sufficient infrastructure to have a rail line, but in future simulations with more detail could leave that as an option.
- Every airport connects to every other airport.
  - In order to make it so every continent was reachable with a relatively small number of areas, we guaranteed that every airport could reach every other without layovers, but if the simulation was expanded, layovers could be an option to more accurately represent air travel. This case is rare to effect the best path, as it would only increase the price of shipping food via air from one continent to another, which the model tries to avoid whenever possible since it is the most expensive and environmentally harmful mode of travel by far.
- All roads within an area have a similar range of costs and environmental impact of traveling on
  - We assumed that local roads and short highways have roughly the same cost of traveling down in order to vastly simplify the model, but it looses relatively little clarity, since in order to account for this, the range of costs for traveling across each path was raised.

3 Notation

Table 1: Symbol Table

Symbol	Definition
t	Metric Tonne
$\{A_{ij}\}$	Matrix Elements of A
$\{C_{ij}\}$	Matrix Elements of C
U_1	Cost Function for Distributor Monopoly in Capitalistic Simulation
U_2	Market Volume for Perfectly Competitive Distributor in Capitalistic Simulation
C_O	Cost of Overhead
C_{MPA}	Maintenance Cost per Acre
L_U	Land Used
L_E	Land Efficiency
Y	Yield

4 Environmental Impact

4.1 Environmental Cost of Growing Crops

For the two crops we modeled, soybeans and corn, we found that growing them released approximately 281 and 283 kg of CO_2/t of crop per year. Around 80% of the CO_2 emissions are caused by the production and use of nitrogen rich fertilizer and the other 20% is from the machinery used to harvest and grow the crops. In producing the fertilizer, a lot of CO_2 gets released into the atmosphere, but is required to grow most commercial crops. The impact of the machines is large, since vast majority of these machines use a diesel fuel. This fuel has a large carbon footprint, and is most likely the best place to cut emissions from the process.[3]

That is just for the CO_2 of growing crops in developed countries, countries with little development, often tropical ones, practice whats known as slash and burn agriculture, where forests are burned down in order to provide fertile soil to grow crops. Not only do these wildfires cause massive amounts of greenhouse gasses to be released into the atmosphere, there are also countless tonnes of CO_2 left in the atmosphere due to the trees being burned down never absorbing. This is massively harmful to the environment, especially since the crops planted in the place of the trees are carbon negative, meaning growing them adds more carbon to the atmosphere then they absorb.[4]

4.2 Greenhouse Gas Emissions Cue to Catching Fish

On a global scale, fisheries produce 2200 kg of CO_2/t of fish per year. These emissions are produced entirely by the fishing vessels used to catch the fish. Similarly to the emissions from producing crops, the emission of CO_2 is due to the fact that most of the boats used run on diesel fuel, which is extremely harmful to the environment. The best place to cut down on emissions in the fishing industry is most likely to identify an alternative diesel fuel with a lower carbon impact, such as a biofuel mix, as well as teaching fisheries more fuel efficient practices.[5]

4.3 CO_2 Released While Transporting Food

For the four methods of transportation that we modeled, we found that airplanes caused around 1.13 kg of CO_2/(t of food shipped*km), cargo ships caused around 0.011 kg of CO_2/(t of food shipped*km), freight trains caused 0.051 kg of CO_2/(t of food shipped*km), and trucks caused kg of 0.20 CO_2/(t of food shipped*km).[6] This meant that shipping food via air caused at least 1 order of magnitude more pollution per trip than any other method, but it is also the most expensive method of transport by far, so it is avoided whenever possible. There is a general correlation between the carbon emission of a mode of transport and the cost of using it, so often times, the cheapest way of shipping a large quantity of food is also the best for the environment.

4.4 Environmental Factors in the Model

The model attempts to account for the sustainability of a system by representing both the environmental cost of traveling from each farm to each market as well as how and what the farm produces. Each connection was assigned a CO_2 emission cost based on what mode of transportation it used. The environmental cost of going the cheapest path from farm to market was calculated for each farm and market. Afterwards, the same system was optimized for the least environmental impact. After the simulation was ran many times, it was found on average, optimizing for the least environmental impact increased the cost of getting from farm to market by 3.01% and decreased the carbon emissions by 0.88%. This means that for most transportation of food, the cheapest path is also the best for the environment.

5 First Order Model

5.1 General Overview

Our model simulates a model subset of the world with two continents. On one, a developing nation with typical income inequality and a mix of big cities and rural areas, such as Brazil or China. Our model farms on this continent are based on the slash and burn agriculture of Brazil and uses parameters based on soy as a model crop.[7][8][9] On the other, a developed country with high income inequality and a mix of big cities and rural areas, such as the US. To model the farms on this continent, we used corn as a model crop and based parameters on data for US corn farms.[10][11][12] It is worth noting that food production was a bit cheaper per yield (measured in calories) in the developing nation.

Each continent contains a two to three rural areas and two to three urban areas, and the two continents are allowed to trade, but trade crossing areas, and especially flying over the oceans, is much more expensive than trade within an area or between adjacent areas (typically). A rural area can be thought of as something of the scale of the Great Plains region of the middle United States, and an urban area can be thought of as something like the New York City and surrounding suburbs and neighborhoods.

Each area contains several markets, which can be thought of as communities of consumers which each contain several socioeconomic classes, and several farms. Rural areas have more farms, and urban areas have more markets. Further, urban areas tend to have more infrastructure connecting them to other areas/continents. Additionally, each area contains many highway intersections which are used to generate paths within and between areas as outlined below. Each market and farm within each area is individually modeled.

The farms each produce a cost function, which acts as their supply function relating the quantity produced and the price they would have to be offered to produce that quantity of food. Similarly, each market produces a demand function relating the price at which food is sold to the quantity the market will buy at that price. The distributor connects the two, finding efficient paths from farms to markets and determining the optimal way of bringing food from each farm to each market. The distributor also chooses how much food to buy from each farm and sell to each market along each path depending on what it's optimizing for.

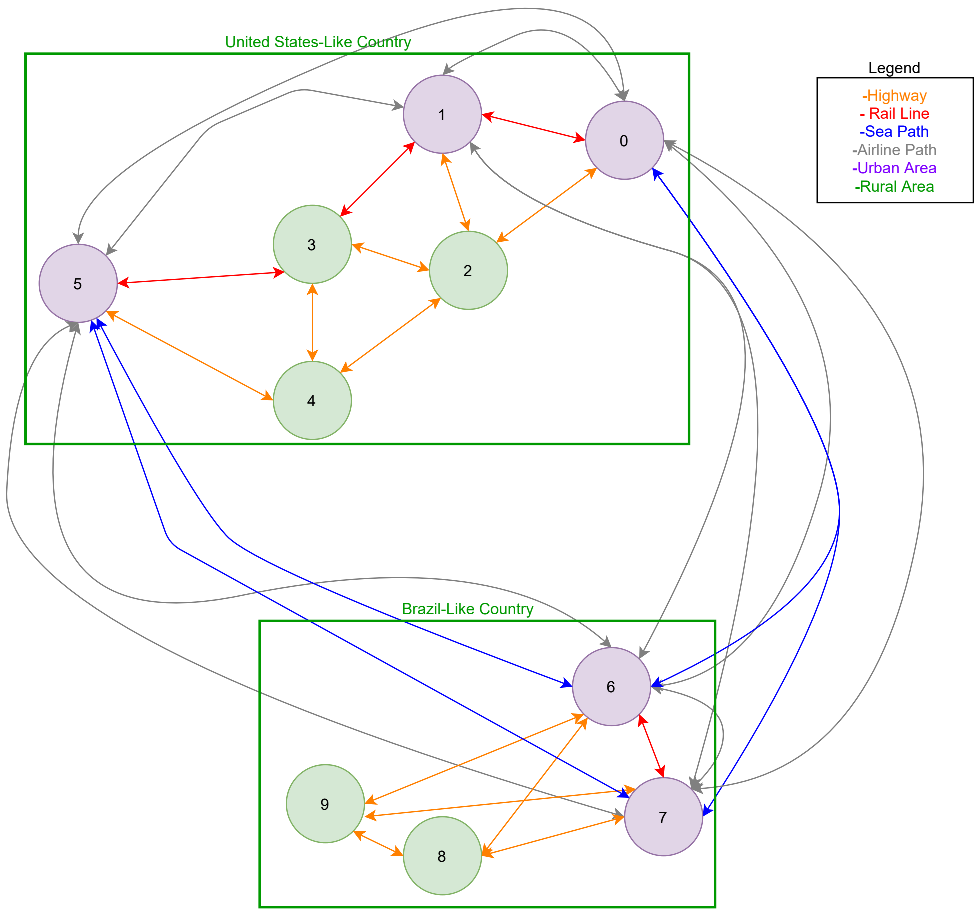

Figure 2: Simulation's estimation of trade between countries with similar structure to United States and Brazil

As seen in figure 2, the model attempts to connect nodes in a realistic way, informed by the cities on each continent, and distances to other areas. The trade routes between a relatively rich country like the United States and a relatively poor country like Brazil are particularly illustrative of the use of the model, since it shows the breadth of options are created by the system of differentiating between many different factors. This also shows how it estimates real life urban populations, such as areas 0, 1, and 5 representing real urban areas in the United States, being New York, Chicago, and Los Angeles respectively. The same goes for the city in the Brazil like country, 6 and 7 representing Salvador and Rio de Janeiro, as well as the rural areas approximately representing the distribution of rural areas in real countries.

5.2 Node Structure

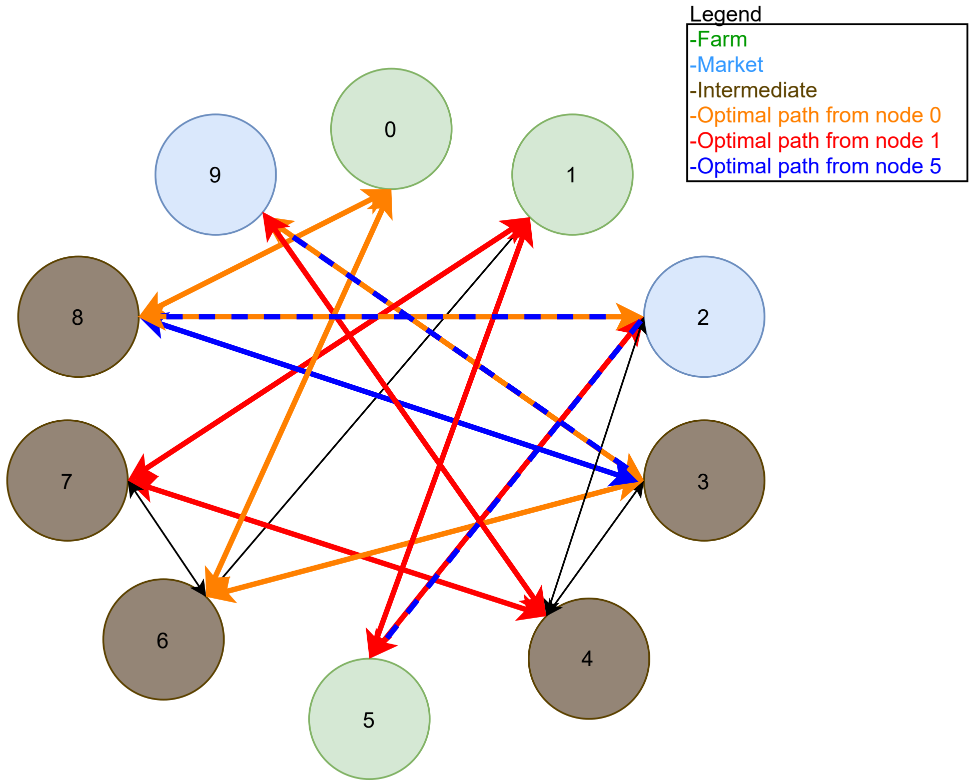

Figure 3: Map of interconnected nodes within an area

To generate the system of nodes and paths, we created subsets of areas, each given a distinction on whether they were rural areas or urban ones, as well as what continent they were on. Rural areas were programmed to have more farms and less markets than urban ones in order to account for groupings of populations in the real world. These areas then had a random number of nodes generated within them, with urban areas containing more nodes to represent their more developed infrastructure. These nodes were then assigned connections in a linked list format, and each link represented a path from one node to another and had an associated monetary and environmental cost of traveling on.

After each area had its nodes connected, the areas were connected by a series of airports, seaports, and railways. In the model, every urban area had an airport and a railway station, as well as a chance of being on the coast. If two areas were on different continents, then the only way of connecting them was through either an airport or seaport, and so urban areas were able to connect to each other directly via air or sea, but in order to get from a rural area to a different continent, the path would have to go through urban areas. Every rural area had a chance to be generated with a railway station, and if they were, they would be connected to other areas on the same continent through rail. All areas on a continent were connected by highways or a highway system.

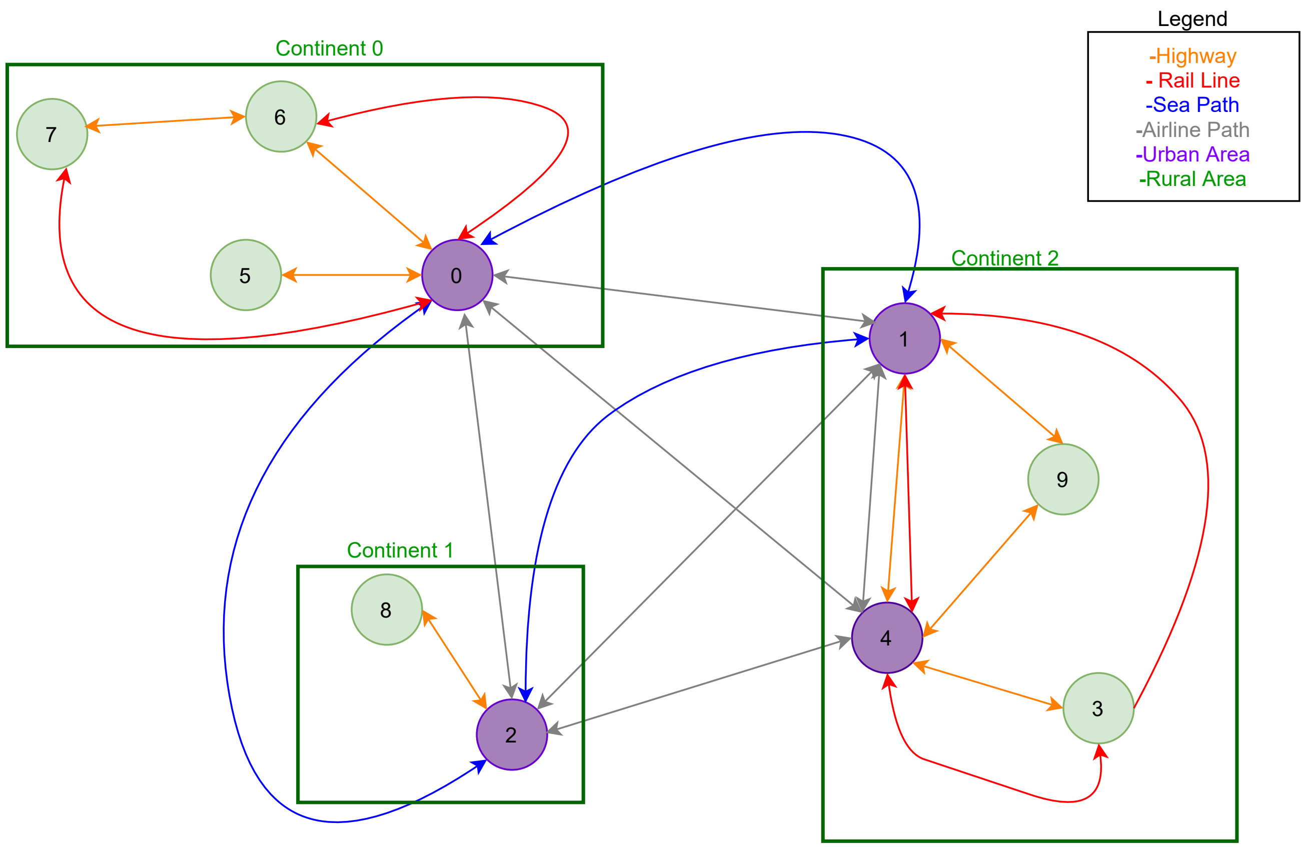

Figure 4: Map of connections between different areas across different continents

Each type of connection was given a narrow range of costs and environmental impact rating, in order from most to least expensive, air, highway, railroad, and sea. This range of costs was used to determine the cost of traveling across each path, and assigned to paths accordingly. In order to find the cheapest path from each farm to each market, we used Dijkstra's shortest path algorithm on the linked list using a priority queue[13], but instead of using path length as the parameter, we used the associated cost of taken a given path.

5.3 Farmers

Because this model focuses on food shortages rather than food diversity, it currently only works in units of 'food', rather than strawberries or corn or meat. However, the parameters of the farms are based on data for the model crop that farm is growing. In this simulation, we have the developed country use parameters for a corn farm in a rich country, temperate climate, and using sustainable (as opposed to slash and burn) agriculture. The developing country uses soy as its model crop, and is based off of data on slash and burn agriculture in Brazil.

Farms produce their cost/supply curves acting on these basic principles. The farm has some given plot of land on which it pays overhead costs (taxes and interest). To meet a given quantity of production, it first sows the least amount of that land that it has to, and pays some amount per acre to do so. If planting on the entire field is not sufficient to meet a given demand, the farm begins fertilizing/ irrigating/ otherwise improving the land which has been sowed and increases the amount of improvement it buys until it has met cost. There is a maximum of improvement, beyond which there is no way of increasing production.

We model the production as a function of land used and improvements purchased by the equation

$$Q = Y \cdot L_U \cdot \sqrt{E_L} \tag{1}$$

and the expense as a function of the same by

$$C = C_O + C_{MPA} \cdot L_U \left(Y \cdot \sqrt{E_L}\right)^{-1} \tag{2}$$

Holding improvement used at 0 and solving the cost function in terms of Q gives

$$C = C_O + Q \cdot C_{MPA} \left(Y \cdot \sqrt{E_L}\right)^{-1} \tag{3}$$

, and setting land used at max land and solving for C in terms of Q gives

$$C = C_O + L \cdot \left(C_{MPA} + \left(Q^2 - L^2\right)\left(L_E \cdot L_E^2\right)\right)^2 \tag{4}$$

. See figure 4 for an example graph.

The nature of the dependencies is justified as follows: Supply (Quantity) is linear in land used

5.4 Distributors

The distributors are the ones who buy crops from the farms and ship it to markets, optimizing for the lowest cost of shipping the product to the market. This is modeled in our simulation by Dijkstra's shortest path algorithm. This algorithm calculates the shortest possible distance from one node in a system to all others. [13]This allows for finding the path from one farm to every market. The model then performs the algorithm on every farm in the system, that way it finds the most efficient path from every farm to every market.

In each variant of our model, we are faced with the task of optimizing an objective function, under specific constraints. In the case of the Distributor-Monopoly Capitalist model, we are tasked with optimizing an objective function U, representing the utility, or profit of the single distributor agent. In

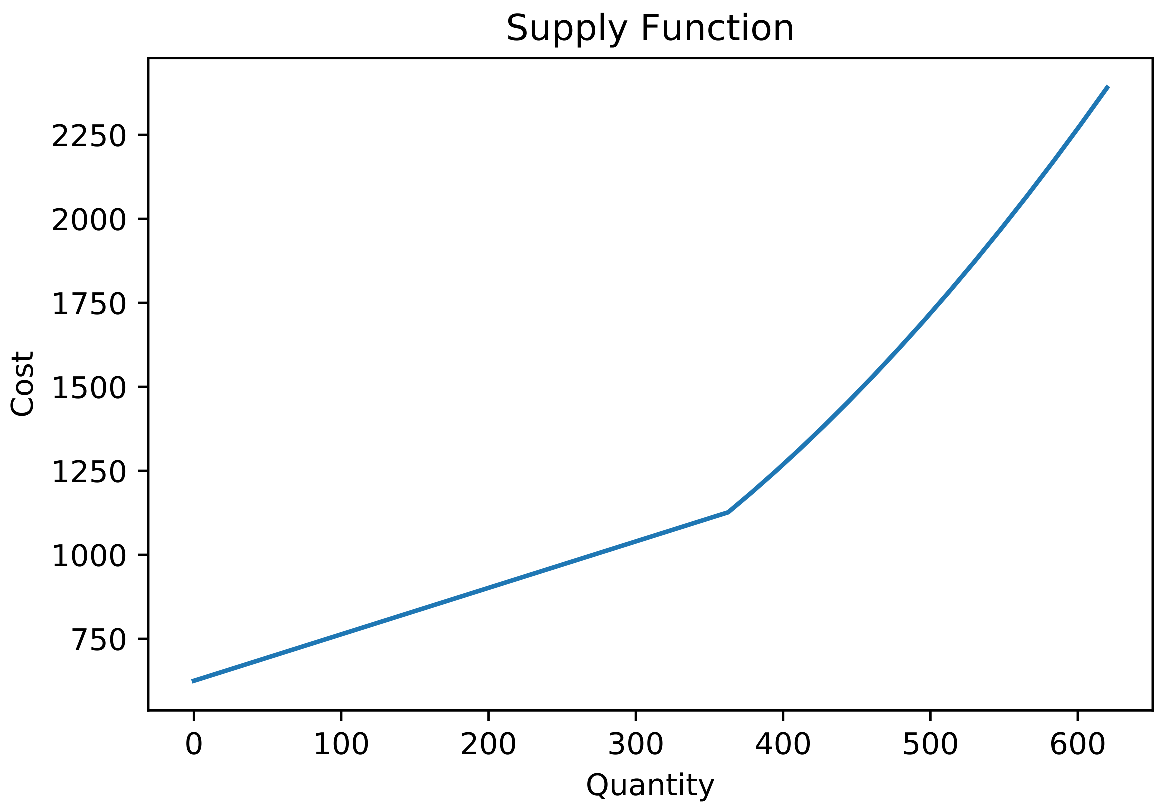

Figure 5: Cost/Supply function for a farm

this case, the single distributor agent seeks to find the matrix A which gives the maximum profit U. The computational approach we have employed to find this matrix A is a simulated annealing process.

Simulated annealing is a process for approximating the global optimum for a function. The simulated annealing algorithm employed to find the A which maximizes the cost function of interest. In the previous example, the cost function being maximized is U. The simulated annealing algorithm is comprised of a **Metropolis algorithm**[14], which is a Markov Chain Monte Carlo method.[15]

The Metropolis Algorithm portion of our code operates by:

1. Choose an initial Matrix A_{ij}
2. Choose a random element A_{ij} of our matrix A
3. Calculate the change ΔU in our cost function U, if element A_{ij} is slightly changed, (increased or decreased by a small value). Note: If the change violates any constraints on the system, go back to step 2.
4. If ΔU is positive, accept the change to A_{ij}.
Else: Generate a random number $0 < r < 1$, and accept the change if $r < e^{-\Delta U/T}$, were T is a parameter that dictates the probability of accepting a change which decreases U.

The $e^{-\Delta U/T}$ term gives a non-zero probability of editing A such that U takes on a lower value. This strategy is employed to avoid getting trapped in a local maxima, and aid in exploring more of the landscape in the configuration space of A.

What makes the Metropolis algorithm used a simulated annealing process, is that the parameter T,[1] is gradually decreased, which makes large decreases in our cost function less likely to occur as the algorithm progresses.[16]

5.5 Markets/Consumers

Within each market, we model 5 types of consumers. The rich, with wealth 10 deviations (not exactly standard deviations, but proportional to a standard deviation) above average, the wealthy, with wealth one deviation above average, the average consumer, with average wealth, the poor consumer, with wealth one deviation below average, and the desperate/homeless/unemployed, with wealth determined by the market's welfare program (a parameter determined by country type).

For each rich person in a market, there are three wealthy people, 10 people of average wealth, five poor people, and 3 welfare-dependent people.

Each consumer in the market determines how much of a good to buy at a given price by the following procedure:

- I have a minimum food requirement. I value excess food above that requirement by an amount related to the square root of excess, and will purchase excess food until the marginal utility of that extra food equals one dollar's worth.
- If this means purchasing more than 40 units of food, I will instead purchase only 40 units of food.
- If this means spending more money than my wealth permits, I will instead spend as much as I can afford.
- If I cannot afford to meet my basic food needs, I will 'borrow' what it takes to meet my basic needs. I cannot borrow more than the parameter borrowLimit, which depends on the wealth of my community.

    .Borrowing could mean literally borrowing money, or can be thought of as taking advantage of charity available, or coming up with additional funds by some other means.

- If I have to exceed borrowLimit to meet my basic food needs, I will by what I can as long as I'm still within 'Starvation Tolerance' of my basic need.
- If I'm more than starvation tolerance below my basic needs, I exit the market. This may mean becoming a refugee, or some other desperate measure. The rich do not tolerate any starvation and will immediately exit the market if they start to solve.

In terms of the math behind this, the consumer sets price along the 'preference-determined' part of the curve by setting price equal to the derivative of the extra food utility function and solving for quantity. The result is <>. This part of the curve is only seen when it is below the curve determined by what the consumer can afford and below 40 units of food, which for poor consumers tends to mean

[1] In thermodynamics and statistical mechanics this parameter is temperature.

this curve is entirely absent. When the consumer becomes limited by what they can afford, they move off the asymptote toward base need and follow the 1/P curve (P being price) until they reach their base need. Here they borrow money until they can't anymore then go below their base need until they leave the market. This process is illustrated in figure 5. The sum of the plots from 5, weighted by the proportion of the population each class makes up is given in figure 6. Figure 6 is the demand function seen by the distributor. [2]

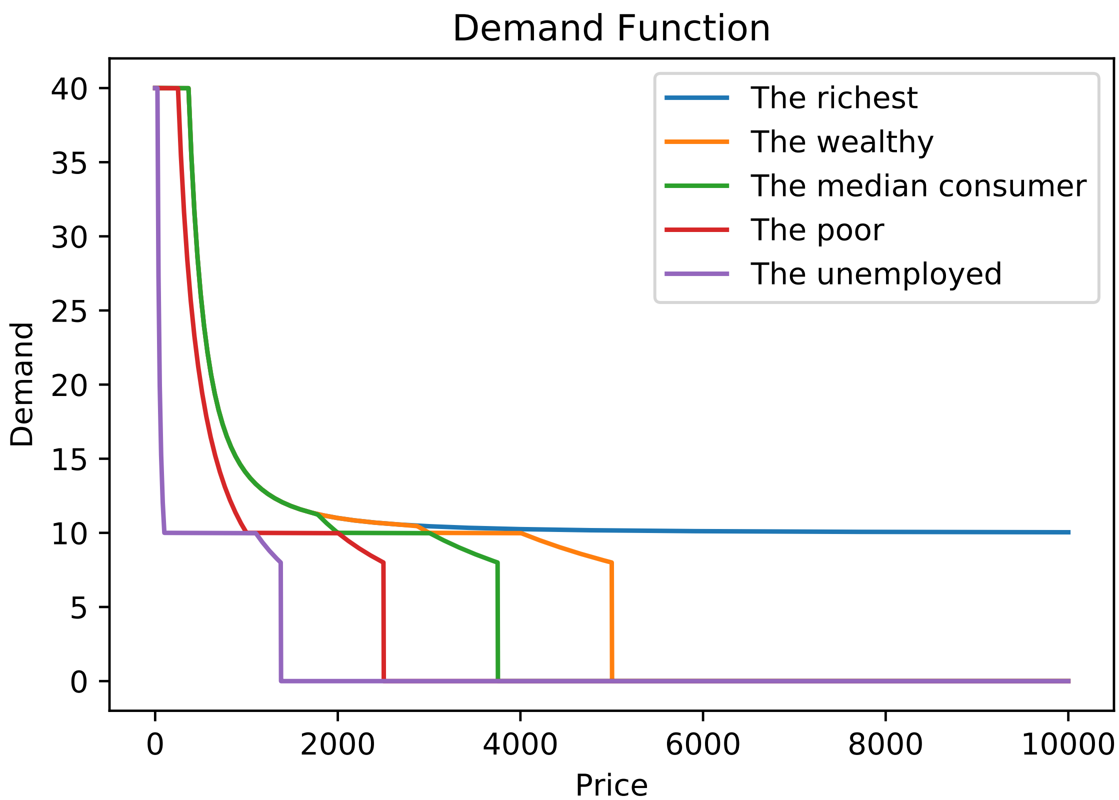

Figure 6: Demand Curve Example: USA-type country (rich but highly unequal) 5 types of consumers

[2]Technically the distributor reads the inverse of the demand function rather than the demand function. Because this is not an invertible function, this had to be done in a convoluted way which requires integerality of the demand function, which leads to some loss of precision. This probably had minimal impact on the data itself, but is the reason the sensitivity analysis data looks so rough.

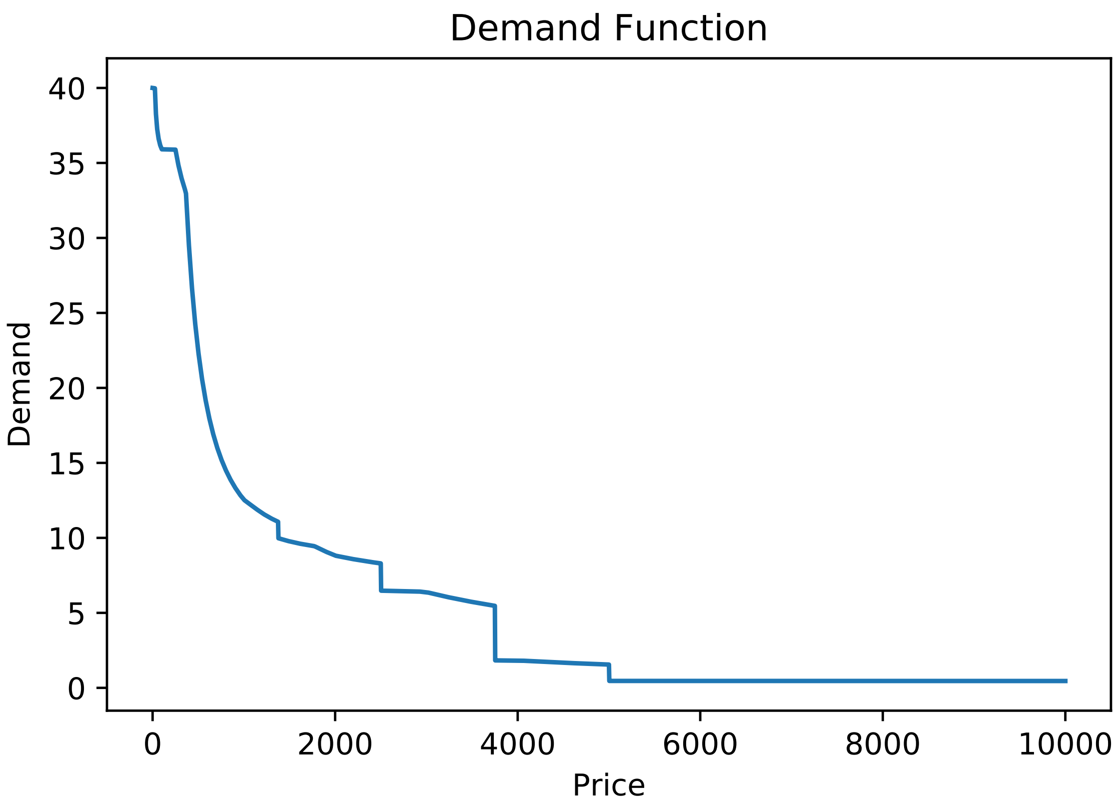

Figure 7: Demand Curve Example: USA-type country (rich but highly unequal)Total demand curve

6 Sensitivity Analysis

6.1 Rich Consumers

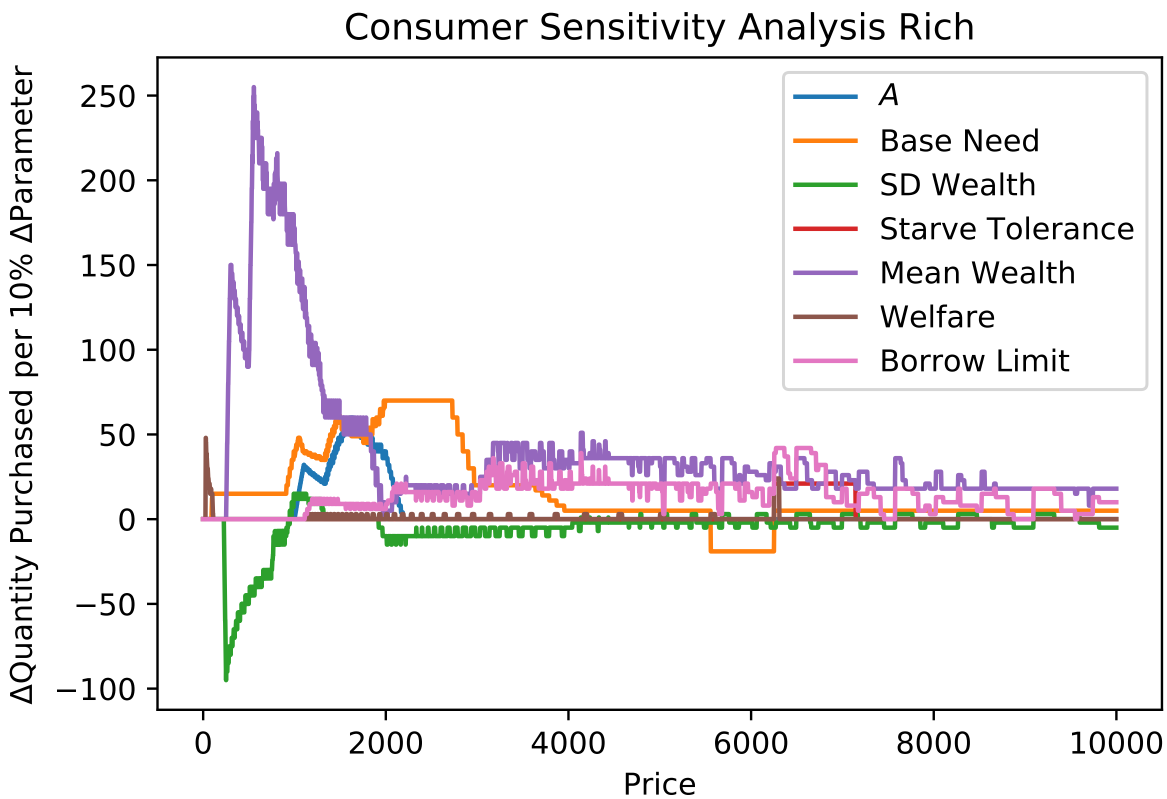

Figure 8: Change in price due to varying parameters by 10% for a wealthy consumer

In order to test the sensitivity of the parameters that go into modeling the consumers, we varied all of the parameters associated with the generation of a consumer, and increased their value by 10% for both a poor consumer and a rich consumer. As seen in Figure 8, a wealthy consumer is most affected by the mean wealth as well as the deviation in wealth, in order to determine how much they are willing to pay for a given quantity of food for cheaper prices. Base need stays a moderate factor no matter the price, and mean wealth and the borrow limit become stronger than other factors for most medium-high price ranges.

6.2 Poor Consumers

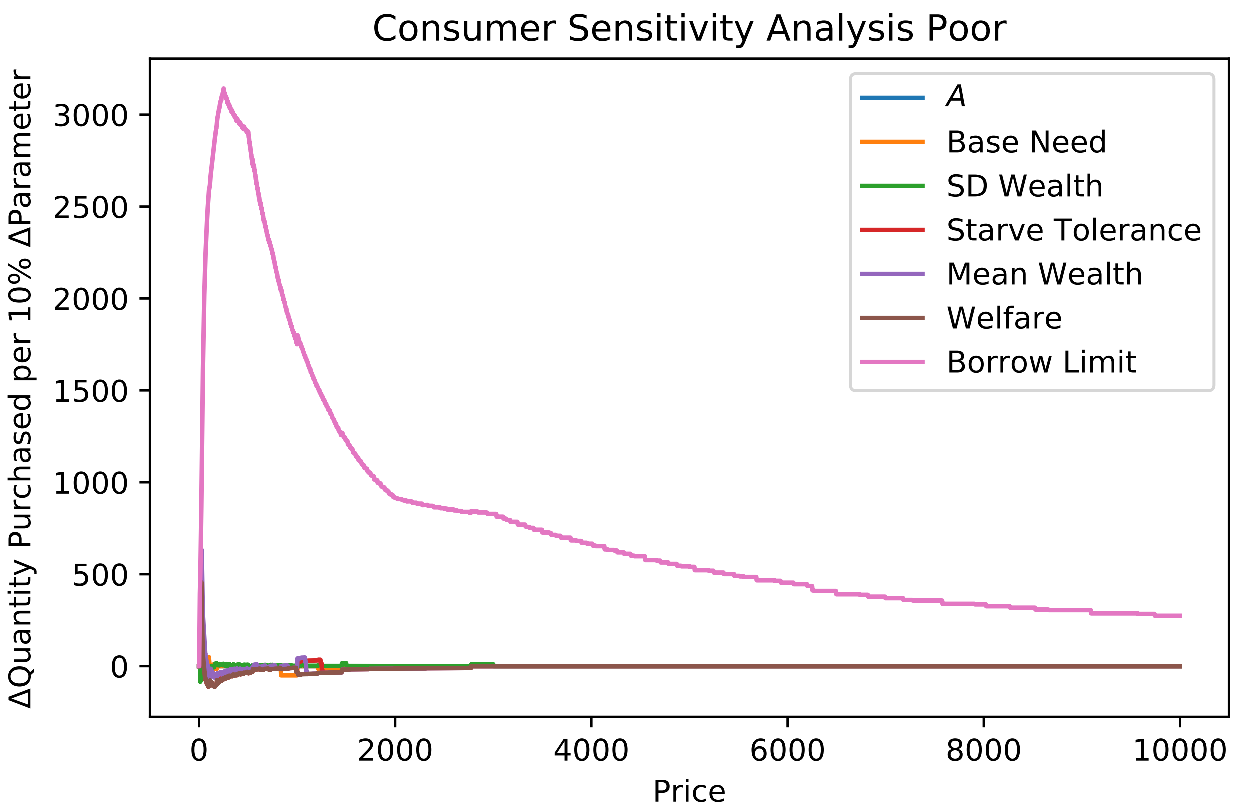

Figure 9: Change in price due to varying parameters by10% for a poor customer

When the parameters are changed by 10% for the poor, the borrow limit becomes a much bigger factor in determining how much a consumer can afford as shown in Figure 9. The borrow limit completely takes over all other factors, which makes sense, considering the fact that these are the people that can lack the funds to adequately feed themselves, that if they can borrow more for food, then they will be able to get more food. Out of the remaining parameters, the most major one is welfare given to the consumer, but it is a small fraction of the impact the borrow limit has on the difference in quantity purchased at each price.

7 Strengths and Weaknesses

7.1 Scalability and Adaptability

This model can easily be scaled to model different size areas, from a single city area to the entire globe, given enough runtime. Since the model is based on predicting trade of food within an economic system, this means as long as you accurately add areas to the system, you can scale the model as far as there is data for. The model specifically allows for an increase in nodes, as well as total areas, continents, and number and type of connections, so you can always increase the resolution of the model until it is optimal for the specific needs of the simulation.

The versatility of the model doesn't stop at the size, it also extends to the ability to not only model different types of economies, it can also be used to model different types of groups simultaneously. The ranges of people it can model go all the way from well of individuals who live in large urban areas to impoverished people living in a tropical, rural area. This flexibility of the model makes it a robust simulation of real world events.

The model can also be easily adapted to model different areas, given that data on the crops grown is given, as well as the level of development in the area. This model is able to model tropical areas just as easily as arid ones, as long as there is food being grown somewhere in the system and there are people looking to eat said food.

7.2 Weaknesses

The largest weakness in the model that we created is the lack of diversity in modeling different food products. Livestock and fish have very different associated costs, as well as different environmental impacts. Unfortunately, in order to limit the complexity of the model because of the time limit, we were unable to model these effects on our model. Based on the results of the model, it seems that it would still remain a good predictor without this added detail. The numbers associated with the cost and revenue might not be exact due to only modeling 2 similar crops, but the trends created by the data would remain correct. This is important to note, since the exact values were never the intention of creating this model, but instead to predict the trends.

8 Results

Table 2: Impact of Competition

	Utility Improvement	Food Insecurity Reduction	Starvation Reduction	Malnutrition Reduction	Equity Improvement
Developing Country	36%	36 %	35%	33%	73%
Developed Country	53%	39%	52%	37%	91%

Table 3: Command Economy Impact Increasing Budge

Equity Improvement Budget = 26 Million	Equity Improvement Budget = 45 Million	Starvation Improvement Budget = 26 Million	Starvation Improvement Budget = 45 Million
40322	44316	200200	500600
30351	37570	-299800	400

Developing Country is ordered above Developed Country in Table 3

9 Conclusion

9.1 Effect of Competition

When comparing the data on the outcomes of a monopoly distributor versus a competitive market distributor we see substantial reductions in starvation, malnutrition and food insecurity, as measured in Table 2: Impact of Competition, as well as a significant increase to the equity function which tracks food excess minus 10 times food deficit (which is what the command economy is optimizing to improve), as well as utility, which is a score combining equity and the starvation through malnutrition factors. These impacts were especially significant in the poorer developing nation. When comparing the impact of increasing budget in a command economy optimizing for the equity score, there is, as expected, and indication that increasing budget improves the outcomes. However, this is not universally true, especially in the poorer country. It appears that increasing the budget allotted to the distributor funneled resources into the rich country- an interesting and unexpected result, possibly due to a degeneracy of the optimal solution, or perhaps a symptom of the tendency of this type of optimizer to extract resources from the cheapest, least sustainable slash and burn plantations in the poor country to increase the equity of the larger rich country, a pattern which perhaps isn't dissimilar to the interaction of command economies in the real world.

9.2 Further Notes on the Sensitivity Analysis

It appears that in the poor country, the most significant parameter by a large margin is the borrow limit. This borrowing limit can be seen as the capacity of banking, charity, social safety nets, and other systems which influence the ability of a person to temporarily exceed their means. Since a change by 10 percent in this value had by far the greatest impact, it may be safe to assume this points to a potential area for policy makers to focus for decreasing starvation and food insecurity in developing nations. It should be noted that the dependent variable in the sensitivity analysis is not linearly related to outcome, but both theory and our data indicates that this quantity, related to the purchasing capacity of a community, is positively related to outcome and should be increased where possible.

9.3 Environmental suggestions

As it stands now, the current system is fairly well optimized for the lowest possible amount of carbon emissions for long haul trips, but is relatively inefficient for shorter ones. Improvements can be made by establishing more rail lines in areas that don't currently have any. We thoroughly recommend stopping the practice of slash and burn agriculture due to its immense harm on the environment. Slash and burn agriculture also is only provides a short term benefit to the countries using the practice, but comes out to be a long term loss for them.

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