Modeling Sierra Leone's Investment Flows and Tariff Reforms with Individual Agents

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Abstract

Macroeconomic indicators are important tools for analyzing the implications of potential policy reforms as well as for predicting the future state of an economy given current economic conditions. Standard macro-analysis often yields insights that are difficult and confusing to implement on a micro-scale. Using an individual agent model to simulate Sierra Leone's macroeconomic condition, I show how policy reform can be tested on a more realistic microeconomic level with comprehensive implications of what the outcome would be on a macroeconomic scale. This more accurately captures the nuances of policy decisions (investment and trade restriction decisions) on both the individual agents within an economy, as well as the overall economic health of the country.

1 Introduction

Conventional macroeconomic analysis makes use of broad macroeconomic indicators to tentatively estimate relationships between different economic forces. For instance, when analyzing the implications of a potential policy reform or large investment, economists use aggregate indicators like Gross Domestic Product, or Industry Growth Rates, to find relationships or patterns that would help inform these decisions.

Unfortunately, by using these macro-indicators as proxies for more nuanced and dynamic microeconomic phenomena, many economists may oversimply their analysis, and may not be able to understand the full suggestions of their results. If an economist, using these methods, is trying to estimate the relationship between a country's ability to provide educational services (% of population attending school) to its citizens and the overall Gross Domestic Product (to determine whether the government should invest in a specific sector of education), the economist would inevitably miss all intrinsic dimensions underlying GDP and the country's education system. Moreover, by isolating analysis to prechosen indicators, the economist always runs the risk of omitting unforeseen variables, which would ultimately bias the results.

Given that much of this analysis drives important policy decisions for both government institutions and private actors, it is important that economists are fully able to understand the rippling implications of each major economic action. Failure to do so would lead to unanticipated effects, as well as corresponding anti-progressive, (and even) detrimental, consequences. As a result, in the next few sections I offer a model that may help remedy the curse of oversimplification in customary macroeconomic analysis.

2 Description of Model

The model is structured to initialize a population of firms and a population of individuals in a given country (which in this case is Sierra Leone), some of which are employed by the firms.

Initializing Individuals

I divide the individual population into equal distributions of four income levels: Low, Low-Middle, Middle, and High. Each quartile is characterized by its average daily wage rate, and savings rate, which fortunately, are listed by the World Bank [1] (for the former), and can be extrapolated using United States data [2] (for the latter). These are characterized in the table below:

Income Level	**Average Daily Wage (US Dollars)**	**Savings Rate**
Low	$1.50	1.4%
Low-Middle	$5.75	2%
Middle	$15.75	6%
High	$25.00	12%

For every individual in each quartile, I also specify the consumption rates for products that are characterized by a given firm size. We assume that each population income level corresponds with a given firm size, since empirically, bigger firms are able to offer larger wages, and individuals in higher income quartiles tend to work in more urban regions, which inherently larger corporations. The consumption rates for each income level by each product type are specified below, taken from a study done in Michigan State University specifically about Sierra Leone's consumption levels [3]:

Income Level	**Small Firm**	**Small-Medium Firm**	**Medium Firm**	**Large Firm**
Low	26.6%	53.5%	4.3%	1.9%
Low-Middle	26%	52.2%	5.6%	2%
Middle	25.7%	47.6%	6.2%	2.1%
High	25.4%	50.9%	6.9%	2.1%

Using this data, I can construct a metric for an individual's accumulated wealth per year using the formula below, where *r* is Income Level and *a* is an individual within that income level:

$$Wealth_{r,a} = Wealth_{r,a} + (Wages_{r,a} * DaysWorkedinYear) * (SavingsRate_{r,a})$$

Here, the Wealth of an individual *a* in income level *r* for a given year, is the prior years accumulated wealth added to the total income earned from wages, multiplied by the individual's savings rate.

Initializing Firms

I then construct a population of firms in a theoretical manufacturing sector, which are divided into four income-size types (as mentioned above): *Small*, *Small-Medium*, *Medium*, and *Large*. The size characterizations also serve as proxies for product-type since larger firms tend to produce products for higher income individuals.

Similar to the initialization of individuals, I am able to construct a given firm's income level (profitability) using the wage rates, savings rates, and consumption rates of each individual income level quartile. I also include export levels by firm type, which are based off import export data provided by the Harvard Center for International Development's *Atlas of Economic Complexity* [4]. The formula is specified below:

$$FI_{r,b} = FI_{r,b} + P_r \sum_{n} YW_{r,a}(1 - S)_{r,a} C_r - \sum_{m} YW_{r,a} + X_{r,b}$$

FI is Firm Income in a given year, where *r* is the Firm Type and *b* is the individual firm in Firm Type. *P* is the level of output that each worker is able to produce for a given firm type, approximated using global estimates of factor productivity differences between different firm sizes [5]. The next term is the summation of all customers *n* per year for firm *r,* which is the total domestic revenue that firm *r* brings in. When broken down, this is the product of *YW,* an individual's yearly wages, *(1-S)* a given individual's consumable income (where *S* is that individual's savings rate), and *C*, the proportion of consumable income spent on the product that firm *r* produces. I then subtract out labor costs, which are the yearly wages for each employee *m* in firm *r*. I finally add in *X* which is the total revenue per year from exports out of the country from firm *r*.

Transitioning from Firm to Firm

In order to introduce an element of stochasticity to the model, I integrate into the simulation an employee transition probability matrix, derived empirically from a study done on African labor movements [6]. The matrix is specified below:

$$\begin{pmatrix} 0.66 & 0.21 & 0.08 & 0.04 \\ 0.19 & 0.44 & 0.15 & 0.22 \\ 0.08 & 0.18 & 0.31 & 0.43 \\ 0.01 & 0.01 & 0.08 & 0.90 \end{pmatrix}$$

Each element of the matrix represents the probability that a given employee of a given firm type (small, small-medium, medium, large) transitions to another firm type. For example, the probability that an employee of a small-medium firm moves to a large firm is 22%, which is a lot more likely than an employee of a small firm transitioning to a large firm (4%). By transitioning firms, an individual either bumps up or decreases his or her daily wage, influencing his/her corresponding rate of wealth accumulation.

Finally, with these factors in place, I construct a metric for Sierra Leon's Manufacturing Share of Gross Domestic Product, which is the sum of all individual and firm income.

$$MGDP_i = \sum_{r,a} W_i + \sum_{r',b} FI_i$$

Here, *MGDP* is the Manufacturing Sectors share of GDP for Sierra Leone in year *i, W* is individual wealth in year *i*, where *r,a* is the sum for all individuals in all income levels, and *FI* is firm income in year *i,* where *r',b* is the sum for all firms in all firm types.

3 Analysis

When simulating the base-case economic ecosystem, I assume that all initialized individuals within a given income level consume domestically, meaning that the simulated population only consumes products from the initialized firms. With this base case, I am able to observe the evolution over years of 1) the wealth of individuals in a given income level and 2) the profitability of a given firm type as well as its contribution to Sierra Leone's total Manufacturing GDP.

Though I simulate the ecosystem 1000 times to test the robustness of the results, I inevitably narrow it down to 100 for the sake of visibility. The plot shown in Figure 1 illustrates the growth of wealth for an individual in each income level over 50 years. Quite evidently, we see that the range of wealth accumulation for High Income individuals (in black) far outreaches the range of wealth accumulation for the Low-Medium Income and Low Income individuals (green and blue, respectively). This suggests that while individuals in the High Income Level (and some in the Middle Income Level) are able to significantly increase the accumulation of their assets, the individuals in the Low to Low-Middle Income Level are unable to really move the status of their wealth, even over the span of 50 years.

A recent report by Oxfam studying the growing economic disparity in Africa, corroborates these results in arguing that "the top 10% of society receives half of all wage income while the bottom 50% of the workforce just receive 12% of all wages [7]." Even in an economy with no international competition (no imports), it seems that the combination of savings rates, wage growth, and employment transitions for a given income level, all contribute to the ever increasing growing economic disparity we see not only in Sierra Leone, but many other areas of the globe as well.

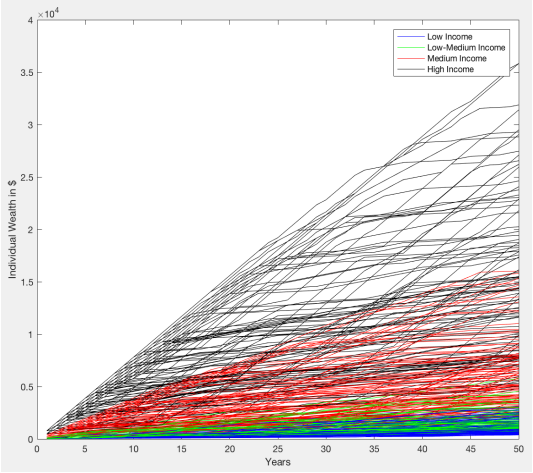

Figure 1

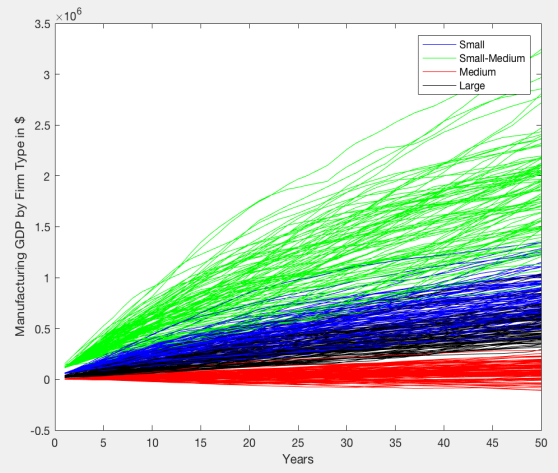

Figure 2

The plot shown in Figure 2 illustrates the evolution of the share of income that a particular firm type contributes to overall manufacturing GDP within the country (also over 50 years). Here, it is evident that Small Firm types (green) and Small-Medium Firm types (blue) contribute most positively to the overall Manufacturing GDP in Sierra Leone, while Medium Firm (red) and Large Firm types (black) are quite negligible in their contribution to the country's aggregate income growth.

Data by Enterprise Surveys on Sierra Leone's business environment in 2017 corroborates that the contribution of large firms to the country's aggregate income are far outweighed by the contribution of small and medium sized firms in the country. More specifically, while large firms only make up roughly 11% of Sierra Leone's economy, small and medium sized firms make up 88% of the country's

business environment [8]. Despite the myriad other relevant conditions of Sierra Leone's political-economic context, this example reveals that the domestic consumption patterns of a country's demographic and the corresponding profit structure of a given firm type are important factors of enterprise survivability and prevalence.

3.2 Sensitivity Analysis

Now using this model, we observe the sensitivity of Sierra Leone's economic condition to introductions of two types of exogenous shocks: 1) tariffs and 2) injections of capital investments.

Tariffs

Changing tariff levels are programmed into the pre-described consumption rates of individuals within each income level. Using explicit measures for the percent of imported products consumed within the population [3], I construct a measure of tariff enforcement by restricting the percentage of imported products consumed and replacing it with added consumption rates for domestic products. The intuition here is that since the domestic population can no longer consume imported products at the same level (depending on the type of tariff enforcement), the domestic population will resort to domestic products as a substitute. Consequently, using this method I create a range of tariff levels to test which restriction magnitude yields the largest growth in domestic income. The plot shown in Figure 3 illustrates the evolution of Sierra Leone's aggregate Manufacturing GDP for each tariff magnitude level, for 5 simulations (narrowed down for the sake of visibility, but results relatively consistent with 100 simulations), T1 being the lowest level (no tariffs), and T15 being the highest tariff level (where no products are imported).

Interestingly, the tariff level that optimizes Sierra Leone's income is neither having no tariffs (*T1*), as many free market capitalists would believe, nor having highly restrictive tariffs (*T15*), as many economic protectionists would believe, but rather having a relatively moderate tariff level (*T8, T9*). Since most imports are high-income level goods that are manufactured by larger companies [4], it is possible that a moderate amount of international competition for the domestic Large Firm types gives the smaller firms (which as mentioned above, contribute significantly more to national income) more opportunity to capture market share. Residing in the absolutes of having no tariff restrictions (*T1*), or having complete tariff restrictions(*T15*), however, seem to be similarly detrimental to the prospective income potential of Sierra Leone.

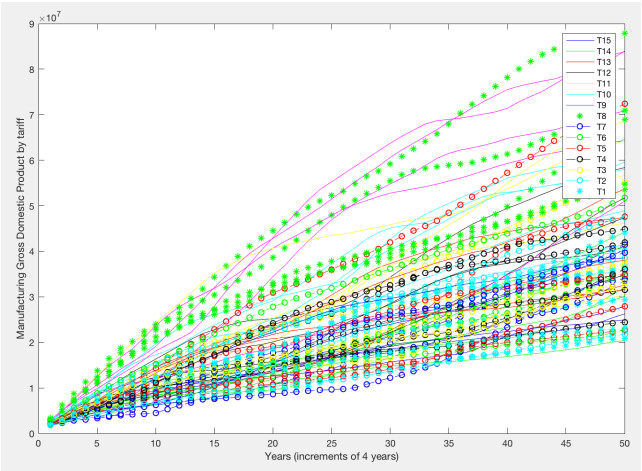

Figure 3

Investments

Investment shocks are programmed into the model by increasing the productivity of a given firm type. I differentiate each investment shock by isolating the increase in productivity to one firm type at a time. The intuition in using productivity as a proxy for investment is that when an investor injects money into a given firm, the presumably rational firm would use that money to invest in productive capital that would enable the firm to produce more for a given unit of labor. By using this proxy for investment, I can measure the difference in domestic output for each investment shock by comparing the results of the simulation when investing in Small Firms (Low-Income Firm), Small-Medium Firms (Low-Mid Income Firms), Medium Firms (Mid-Income Firms), or Large Firms (High Income Firms).

The results of the simulation in Figure 4 below illustrate the evolution of Manufacturing Gross Domestic Product for Sierra Leone given an investment shock in a particular firm type. What is shown is the result of 5 simulations which have similarly been narrowed down for the sake of analytical visibility (still consistent with the output of far more simulations). Here, we find that investing in Small Firm types (blue), as well as Small-Medium Firm types (green), yield higher aggregate outputs compared to investments in Medium (red) and Large (black) Firm types. One potential reason behind this result is that since Small and Small-Medium Firm types are the main contributors to the domestic economy, investing in these firms to increase the productivity, as well as the corresponding wages for the employees of these firms, would not only jolt the output of each firm, but also increase the monetary capacity of the market base for such firms (higher wages mean higher individual incomes).

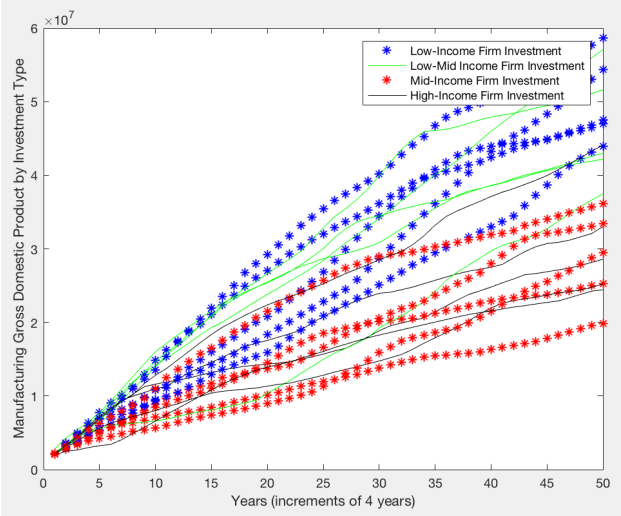

Figure 4

4 Discussion

Analysis of the individual agent model in the context of a simulation of Sierra Leone's macroeconomic condition demonstrates on an individual level, that one's initial income may determine one's ability to aggregate wealth over the years, and on a firm level, that the country's specified domestic consumption and savings behavior contribute to an environment that encourages the prevalence of small firm types yet deters the establishment of large firm types—correspondingly suggested by real scenarios observed in Sierra Leone today.

The analysis also demonstrates how a particular tariff level or investment type influences the country's macro-economy; namely, that mid-level tariffs and small firm investments yield the greatest output potential. Observably, the benefit of using an individual agent model for this analysis is that we can shock a micro-economic factor of the model, and see the aggregate impact not only upon the other actors of the ecosystem, but also upon macro-economic indicators like a country's Manufacturing Sector's Share of Gross Domestic Product.

The simulations of the model make the following assumptions:

- Although the individuals in each income level have a non-zero probability of transitioning to a firm that pays them a wage for another income level, the consumption rates prescribed during initialization remain constant. This means that although individual *i* moves from a firm that pays him/her *x* to a firm that pays him/her *y*, he/she will still consume as if he/she is a part of firm *x*.
- There are an equal number of firms within each firm type, and there are an equal number of employees from a given income level within each firm. In other words, all small firms employ an equal number of individuals from the low-income level.
- Similarly, during initialization, each income level is matched with a firm type
- The economy is composed only of firms and individuals that are either employed by those firms, or is part of a family that has an individual employed by a firm.

Moreover, by nature of being an individual agent model (in addition to the described assumptions above), the simulations are constrained by certain limitations. First, it is very difficult for the model to be formally analyzed. Since the individual agent model programs each individual agent within a more complex ecosystem, parsing out formalized relationships between two agents is practically nonviable. Second, by prescribing a given agent's behavior *before* the evolution of the system, it is hard to program changes in behaviors that are contingent upon the output of other agents within the ecosystem. Despite these limitations however, we see that this model *does* offer unique advantages to other current tools used in macroeconomic analysis.

5 Conclusion

With increasing conditions of economic disparity in many parts of the world, understanding how different types of policy reform and other economic phenomena impact the resilient poverty rates of many countries is essential. As our model suggests, productive analysis of economic ecosystems require that the entire system be wholly observable. Quite evidently, macroeconomic indicators are aggregates of complex and interrelated micro-phenomena, meaning that adequate assessment of a given policy to, for instance, eradicate major forms of poverty within a country, demands that micro-phenomena be accounted for. As a result, using an individual agent model offers a way to somewhat integrate such micro-phenomena with more aggregate outputs. Possible extensions of this model would be to program the simulation such that each individual's consumptive behavior is dynamically contingent on the amount of wealth he/she is able to accumulate over time. Moreover, integrating other sectors into the model (i.e. agriculture and services), as well as migratory behavior into these different sectors, would provide a more realistic view of Sierra Leone's labor market.

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