Resilience of Economic Systems to Political and Critical Events

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Abstract

In modern economies, many economic entities are optimized as much as possible, stretching production, minimizing stock levels, and delaying payments. In such optimized settings, flexibility is often sacrificed in favor of speed or cost savings. Given the globalized market and its trends, we are interested in understanding how unpredictable events can impact such systems. With recent events like the COVID-19 pandemic, climate change, and the war in Ukraine, negative impacts on global economies have become more frequent and severe. Reports from the IPCC (Intergovernmental Panel on Climate Change) and other economic studies highlight that these unpredictable events are unlikely to decrease in frequency or intensity [1] [2].

To study these vulnerabilities, we develop a Discrete Event Simulation (DES) model inspired by Hotelling's Law for two main reasons: first, DES fits perfectly with the multi-agent setting of collective intelligence; second, it allows for atomic management of the environment and its components, which is essential for accurately simulating economic systems. By running simulations under different disruption scenarios, we analyze how varying levels of flexibility and redundancy impact system resilience.

Our findings provide insights into strategies for mitigating economic fragility, highlighting the trade-offs between efficiency and robustness in highly optimized systems. This work contributes to the understanding of economic resilience and informs policy and business decisions in an increasingly uncertain global landscape.

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1 Introduction

Modern economies prioritize efficiency through practices such as just-in-time production, minimal stock levels, and delayed payments. While these strategies optimize costs and improve short-term profitability, they also reduce the flexibility and resilience of economic systems. In such an optimized environment, external disruptions—such as geopolitical conflicts, pandemics, and climate-related events—can have severe consequences, propagating through supply chains and financial networks with limited buffering capacity.

Tax policies play a critical role in shaping business strategies, influencing decisions related to investment, production, and market expansion. Corporate tax rates, import-export duties, and government subsidies directly impact cost structures and profit margins. However, rapid or unpredictable changes in tax policies can introduce significant economic stress, particularly for firms operating with tight margins. Given the interconnected nature of global trade and finance, abrupt tax policy shifts can create ripple effects, affecting business viability, market stability, and economic resilience.

Understanding how firms adapt to tax policy changes, especially under conditions of volatility and uncertainty, is essential for designing economic policies that balance efficiency with long-term stability. By studying firm behavior in response to tax adjustments and policy shifts, we aim to provide insights into how economic actors navigate regulatory environments and what factors contribute to their survival and competitiveness.

This study seeks to answer: How do firms adapt to changes in tax policy under conditions of volatility and uncertainty, and what factors influence their resilience and competitiveness in such environments?

2 Related Work

Agent-based modeling (ABM) and discrete event simulation (DES) have been widely used to study economic dynamics, particularly in analyzing policy impacts on firms and markets. One well-known example is Hotelling's Law Simulation, implemented in NetLogo, which models spatial competition between firms and their pricing strategies [3]. While this model captures firm behavior in competitive markets, it does not account for the effects of regulatory and fiscal policies such as taxation or subsidies.

Several studies have explored the role of taxation in economic systems using computational modeling approaches. Wilensky developed an agent-based model to simulate wealth distribution under different taxation schemes [4]. Similarly, the AI Economist framework applies deep reinforcement learning to optimize tax policies for balancing equality and productivity [5]. These approaches provide valuable insights into how tax structures influence economic efficiency but often rely on predefined agent utility functions, limiting their ability to capture emergent behaviors in response to unpredictable policy shifts.

Tax compliance and evasion have also been modeled using agent-based techniques. Bloomquist introduced an ABM that simulates individual tax evasion behavior under different enforcement strategies, highlighting the role of audit probabilities and penalty structures [6]. More recently, microsimulation models have been employed to evaluate tax reforms by simulating their effects on individual and corporate decision-making at a granular level [7].

Despite these advances, existing studies primarily focus on static or predictable policy changes. However, abrupt and volatile tax shifts, such as sudden changes in corporate tax rates, trade tariffs, or subsidy removals, introduce systemic uncertainty that significantly impacts firm survival and market stability. While previous models provide foundational insights, there is a need for a simulation framework that explicitly examines how firms adapt to sudden, extreme tax policy variations. Our work extends the existing literature by developing a Discrete Event Simulation (DES) model to analyze firm behavior under dynamic and unexpected tax policy changes.

3 Methodology

3.1 Model Description

The simulation models a simplified economy in which autonomous agents, represented by Company instances, produce, trade, and consume various commodities. Each company belongs to one of three sectors—primary, secondary, or tertiary—and interacts with other companies or final consumers through contract negotiations, production or extraction processes, and purchasing decisions. These processes are carried out in discrete time steps, or "ticks," during which companies update their financial situation, produce or acquire necessary commodities, and sell their output if demand exists. The ultimate aim of these interactions is to replicate, in basic form, the supply, demand, and price-setting mechanisms that underlie a market.

In this model, each company maintains several attributes and methods that define its behavior in the economy. A company's primary attributes include its sector type (primary, secondary, or tertiary), its initial capital (used to cover production or extraction costs), and its current level of cash flow, stored within a dictionary containing both total available funds and a transaction history. The company also maintains a dictionary of commodities, referred to here as commerce, which maps each resource or product that it trades to an associated CommodityPolicy instance. Additionally, a stock object tracks the current inventory of each commodity, while a ContractManager object manages existing contracts and any ongoing negotiations with other companies. If a company accumulates sufficient capital relative to what it started with, it can expand to add new lines of commerce. Conversely, if its capital remains below zero for too long, the company faces bankruptcy and is removed from the simulation.

Companies evolve dynamically over each simulation tick through several key steps. First, the `update_values()` method is invoked, which checks if the company's capital has been negative for a certain number of ticks. If it has, the company undergoes bankruptcy procedures. Otherwise, the company applies production policies by purchasing needed resources and producing new units of finished goods or raw materials, then proceeds to sell any available commodities to customers under existing contracts. Finally, it updates the status of these contracts to reflect successful or failed deliveries.

Changes to a company's strategies in production, pricing, and negotiations are carried out in `update_policy()`. The policy update begins by processing any new offers in the mailbox through `process_mailbox`, where each company decides whether to accept, reject, or modify contract proposals based on the following formulas:

With $S_f, P_f, E_f, A_f, \text{Rand}_f$ modifiable ponderation factors in the simulation.

- S_f Supply importance factor, represent how much our capacity to correctly supply a client is import (from 0% to 100%).
- P_f Price importance factor, represent how much importance give the company of having profitable contracts (from 0% to 100%).
- E_f Expansion importance factor, represent how much the desire of expansion of the company impacts its decisions (from 0% to 100%, see more bellow).
- A_f Aggressiveness factor, represent how much the policy and decisions of the company will be aggressive (from 0% to 100%).
- Rand_f Randomness factor, allow to add some randomness in the computation in order to simulate unknown factors (from 0% to 100%).

$S_{\%}$ the percent of the sold stock. $P_{\text{avg}}, P_{\text{min}}, P_{\text{max}}$ statistics on the price of other contracts on the same commodity. (if no contract, these values are set at the cost of production / extraction). E represent how much the company wants to expend. C_{price} represent the current price offer from the other company. P_{prod} is the cost of a product only considering the extraction cost of raw materials and the production cost.

- Initial price of negotiation for the supplier

$$P_{\text{init}} = P_{\text{prod}} \times 2^{1+A_f}$$

- Threshold $C_{\text{acceptance}}$ to decide if a supplier should accept a contract:

$$C_{\text{acceptance}} = \frac{1}{S_f + P_f + E_f} \times \left[S_f \times (1 - S_{\%}) + P_f \times \frac{C_{\text{price}} - P_{\text{avg}}}{P_{\max} - P_{\min}} + E_f \times E \right]$$

- The counter offer made by the supplier (a supplier try to maximize the selling price:

Let $\mathbf{X} \sim \mathcal{U}(-0.5, 0.5)$

$$C_{\text{counterprice}} = P_{\text{initial}} + (0.5 - S_{\%}) \times (P_{\text{avg}} - P_{\min}) + N_f \times (C_{\text{price}} - P_{\text{avg}}) + \\ E_f \times E \times (P_{\text{avg}} - P_{\min}) + \text{Rand}_f \times \mathbf{X}$$

We find similar formulas on the client side, with some differences to minimize the cost of resources.

If relevant, a company will also adjust its production rate or final-customer pricing to align with recent supply-and-demand observations in its stock. Furthermore, if the company's capital surpasses a threshold, it may choose to invest and begin selling another commodity, reflecting expansion. The desire for expansion increases when the company has enough money to invest in a new business.

The logic of a company's behavior for each specific commodity is encapsulated within the `CommodityPolicy` class. Each company's commerce dictionary associates a given commodity with a corresponding `CommodityPolicy`. If the company belongs to the primary sector, the policy simply extracts raw materials and deducts the relevant extraction costs. Secondary-sector policies account for the procurement of necessary input resources and the consequent production of finished goods. Tertiary-sector policies handle purchasing finished products from secondary suppliers. In all cases, the policy also manages a production rate, which is periodically recalculated based on the disparity between how much a company sold, how much was demanded, and how much inventory the firm maintained. In addition, tertiary-sector companies can update final selling prices to consumers in response to under- or over-supply signals. The production rate is calculated as follow:

With $Q_{\text{asked}}, Q_{\text{sold}}$ the quantity of product ordered and sold since the last update. Stock the current amount of stock of the focus commodity. Stock_{A_f} the stock adjustment factor, represent how much we try keep a constant amount of stock. R_f the responsiveness factor of the production rate.

$$\text{Prod}_{\text{rate}} = \text{Prod}_{\text{rate}} \times \left[\frac{Q_{\text{asked}} + 0.5}{Q_{\text{sold}} + 1} \right]^{R_f} + (\text{Stock}_{t-1} - \text{Stock}_t) \times \text{Stock}_{A_f}$$

We define the quantity of resources that a company can purchase without putting itself at risk as follows, with P_a represent the price of the product a, Q_a the quantity of product a we want to buy, which can be define as the production rate multiplied by the quantity of resource required r_a to produce the desired product. If the total cost of the operation is higher than $D_{\max}$, the max amount of money that we are willing to spend. We need to find the right quantity of resource to buy in order to be as close as possible to the maximum allowed amount of money:

$$\begin{aligned} P_a \times Q_a + P_b \times Q_b + ... + P_n \times Q_n \leq D_{\max}, Q_i \to \text{Prod}_{\text{rate}} \\ \iff Q \times (P_a \times r_a + P_b \times r_b + ... + P_n \times r_n) \leq D_{\max} \\ \iff Q = \frac{D_{\max}}{(P_a \times r_a + P_b \times r_b + ... + P_n \times r_n)} \end{aligned}$$

To take into account the current amount in stock of each resources, with the aim of buying more of the missing resources we replace r_a by $\Sigma_i^P(\text{Stock}_{P_i}) \times r_a - \text{Stock}_{P_a}$

To account for final consumer needs, the simulation introduces chunks of population that periodically regenerate demand for specific products and trigger purchases if a suitable company is identified.

Each chunk holds a dictionary of current needs {current_quantity, depletion_rate, regeneration_rate} for every product. At every tick, the chunk's "current quantity" of needed goods is incremented by its regeneration_rate, up to a fixed cap. Formally, for a product p in chunk c:

$$\text{Need}c, p(t+1) \; = \; \min\Big(\text{Need}c, p(t) \; + \; \text{regeneration\_rate}_p, \; \text{Cap}_p\Big).$$

Once updated, these individual needs are aggregated to different scales—local, regional, or global—by taking averages across all chunks in a relevant area. Specifically, a function `average_needs(...)` is applied to a set of chunks $\{c_1, ..., c_n\}$ to compute, for each product p, the mean demand:

$$\text{Needs}_{p(scale)} = \frac{1}{n}\sum_{i=1}^{n}\text{Need}_{c_i,p}(t)$$

This aggregate result is then used to determine how strongly the market is undersupplied or oversupplied in that product at a given scale. Companies—particularly those in the tertiary sector—can factor these needs into their decision-making, including whether to produce (or purchase) additional goods in anticipation of a strong local or regional demand. By combining the per-chunk demand profiles, which increase predictably via a regeneration rate, with per-company production decisions, the model simulates how consumers interact with the market over time and how companies adapt to variations in aggregate demand.

Each company's inventory is tracked and adjusted by its `Stock` instance. This `Stock` object's main responsibilities include storing quantities of each commodity, as well as maintaining counters for how many units of each commodity were requested (demand side) or sold within the last tick. These counters inform subsequent production-rate updates and help assess whether the company needs additional suppliers. The stock object also provides convenience methods to retrieve or modify quantities of commodities, perform partial consumption of the inventory, and record sold units.

Coordination of trade between two companies occurs through the `Contract` and `ContractManager` classes. A `Contract` object binds a client with a supplier over a specific commodity and includes the last agreed-upon unit price, a record of all offers exchanged, and a state indicating whether the contract has been accepted. The distance between the two companies is factored into an additional transport cost imposed on deliveries. Accepted contracts then allow buyers to send quantity requests, which the supplier attempts to fulfill depending on its stock. The `ContractManager` on each company's side collects all contracts in which the company participates and supports the sending of proposals and counteroffers to other companies' mailboxes. The manager also processes every contract request in order of demand and price so that suppliers prioritize large or better-priced orders first.

In addition to inter-company commerce, tertiary-sector companies also sell to "chunks," which represent groups of final consumers distributed across a geographical map. When a chunk needs a certain amount of a product, a tertiary company fulfilling that need deducts the corresponding quantity from its stock, adds the income to its cash flow, and registers a corresponding transaction. A chunk choose a company to buy products base on the price of the product set by the company as well as the distance from the company.

These classes and methods together implement a cyclical market mechanism. Over time, companies with consistently negative capital fail and exit the market, while financially successful companies expand by starting trade in additional commodities. This process of negotiation, production, and consumption serves to illustrate, at a simplified level, how supply and demand forces determine trade volume and prices in an evolving market.

A complete simulation cycle is carried out in the `Simulation` class through its `update` method, which advances the simulation by one tick each time it is called. During every call of this method, the model updates a variety of elements, including the capital status of each company, production output, and the handling of any pending contracts. These updates occur on every tick because they are relatively inexpensive to compute. By contrast, a number of additional computations—such as generating new companies, scanning global needs for commodities, and producing some of the detailed numerical summaries—are significantly more computationally intensive. In order to avoid causing buffering issues and slowdowns, the code confines these heavier computations to every 50^{th} tick (tracked by the parameter `self.ticks_after_update`, set to 50 in `simulation.py`). This approach allows normal per-tick operations to run quickly while limiting the performance impact of more exhaustive data processing.

The update function in simulation.py also triggers the gathering of data for various visualizations. Whenever the heavier computations are performed, aggregated statistics are collected and passed to chart-rendering routines. These include line charts representing the number of active companies over time, charts quantifying the volume of resource needed, and plots tracking the number of contract proposals or acceptances at each relevant tick interval. In addition, bar plots are produced to illustrate final consumer needs per product category, updating whenever new data becomes available. By periodically transmitting these aggregated measures, the simulation provides insight into how the number and distribution of companies evolve, how resources flow through different sectors, and how the overall supply-and-demand balance changes from one phase of the simulation to the next. This combination of high-frequency market updates with less frequent but more detailed analytics and plots ensures that participants can observe both the micro-level interactions of companies at each tick and the macro-level trends over the entire simulation run.

The different countries on the map give access to an interface that allows you to modify their policy. The first element to have an impact is business tax. This is levied every 50 ticks (if the company can afford to pay it). In addition to this tax, there is a system of taxation on imports and exports, enabling you to customise your policy in more detail. Import/export taxes are a key issue in the globalised economy. They are applied realistically, i.e. the customer pays all the taxes (the import tax in his country and the export tax in the country of origin). Companies will update their contracts to absorb as much of the tax as possible (so that in the end it is the individuals who pay it, as is the case in our economic systems). This notion of import-export tax can also be used to model events that hamper the economy, thereby increasing prices. Then there is the notion of subsidy, which is a percentage of money added when a business is set up in the country (depending on its initial capital). This tool can be used to simulate job preservation policies, or simply to help new businesses. The last tool can be used to simulate disasters that paralyse the entire country: withdrawing all imports, or all exports, or even both. These events can occur in the event of war or other, more or less punctually. Finally, the country screen can also be used to display all monetary import, export and local flows (reset each 50 ticks), broken down by primary, secondary and tertiary markets.

Lastly, we have provided 4 graphs in addition to the map, the country information panel and the company information panels. The first shows the evolution of the number of companies over time. We've kept the same colour code throughout: blue represents primary businesses, green secondary and red tertiary. The second graph shows the evolution of raw material requirements over time (information obtained from a sample of companies). The third graph shows the percentage of the population's needs for each product (information obtained from a sample of the population). Finally, the last graph represents the number of contracts offered by companies (to other companies) versus the number of contracts accepted. Note that a contract is never accepted directly; companies will negotiate it, as explained above, over several ticks.

3.2 Implementation

To facilitate an interactive and scalable simulation environment, we implemented the proposed model as a server-based web application that communicates with a Python backend responsible for running the simulation. The architecture consists of three main components:

- Frontend Interface: A web-based graphical interface allows users to configure simulation parameters, define tax policies, and visualize the results in real-time. The frontend is developed using JavaScript and HTML, utilizing `d3.js` frameworks to ensure responsiveness and usability.
- Backend Computation Engine: The core computational logic is implemented in Python, leveraging Discrete Event Simulation (DES) frameworks to model firm behavior, tax policy changes, and market dynamics. The backend receives user inputs from the frontend, executes the simulations, and returns the computed results.
- Client-Server Communication: The communication between the web frontend and the Python backend is established using a server socket with a designated port number. The backend operates as a socket server, continuously listening for incoming connections from

the web client. When a request is received, the backend processes the request, executes the computations, and sends back structured responses in JSON format.

The modular implementation ensures scalability, allowing for the integration of additional economic parameters or alternative taxation models. The server-side execution of simulations enables complex computations without overloading the client's hardware, making the system accessible across different devices. Additionally, real-time visualization components facilitate the analysis of firm behavior under various tax policy scenarios, supporting comparative studies on economic resilience.

Python was selected as the primary implementation language due to its versatile networking capabilities which allowed for seamless integration of a server-socket communication system, ensuring real-time data exchange between the frontend and backend.

Furthermore, given our prior experience and proficiency with Python, it provided an optimal balance between development efficiency and implementation accuracy. Since the focus of this work is on economic modeling rather than software development, using a familiar and well-supported language allowed us to allocate more time to refining the simulation framework rather than overcoming language-related learning curves.

4 Experimental Setup and Result Analysis

In this work, we investigate how different tax policies affect the simulated market's overall behavior in terms of company growth, bankruptcy rates, and resource circulation. We aim to show that altering taxation parameters at either regular intervals or leaving them fixed leads to varying market equilibria and different distributions of company success. By comparing outcomes across multiple scenarios, we aim to identify which policy approach best fosters economic stability.

Three primary experiments are conducted. In the first Figure 5, each country's tax rates are automatically adjusted every 50 ticks according to an internal routine that tries to optimize tax revenue without undermining the local economy. This approach reflects a scenario in which governments periodically revise their policies in light of observed economic conditions.

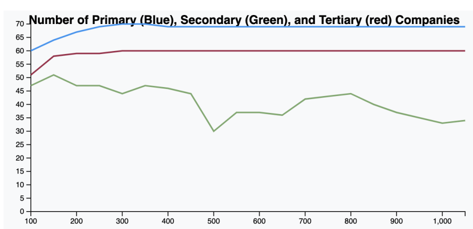

Figure 1: Total number of companies per sector

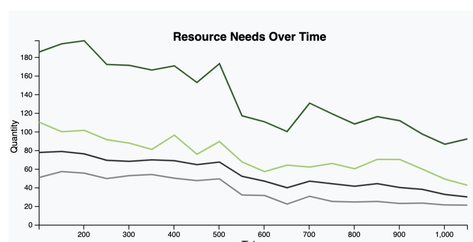

Figure 2: Needs per resource

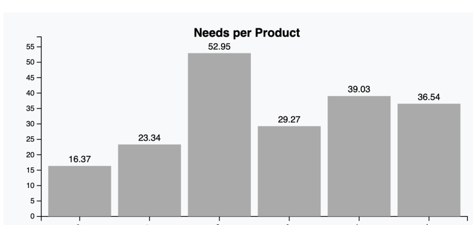

Figure 3: Percentage of needs per product

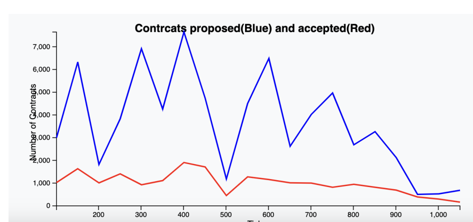

Figure 4: Evolution of proposed vs. accepted contracts

Figure 5: Results for Experiment 1

Figure 5 summarizes the outcome when each country's tax policy is updated every 50 ticks. In Figure 1, both primary and tertiary companies remain relatively stable, while the secondary sector experiences more frequent fluctuations in the number of active firms. This indicates that secondary companies may be more sensitive to variable input costs and downstream market conditions. In

Figure 2, the overall resource needs decrease over time, suggesting that supply tends to catch up with or exceed demand as the simulation progresses. Figure 3 shows that the percentage of unmet needs per product moves downward, which is consistent with growing production and decreasing consumer scarcity. Meanwhile, Figure 4 tracks contract activity, revealing oscillations in the number of proposed contracts and a decline in accepted contracts over time. These observations imply that frequent tax adjustments can create a dynamic environment in which companies continually seek more favorable arrangements, yet ultimately converge on fewer long-term contractual relationships.

In the second experiment Figure 10, tax rates remain static at randomly determined values set at the beginning of the run. This setup captures a situation where fiscal policy is locked in from the outset, regardless of how the economic environment evolves.

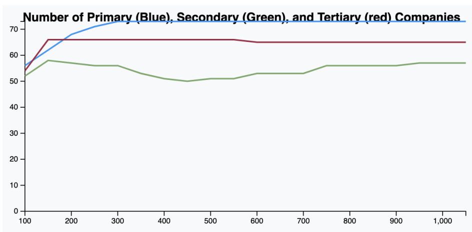

Figure 6: Total number of companies per sector

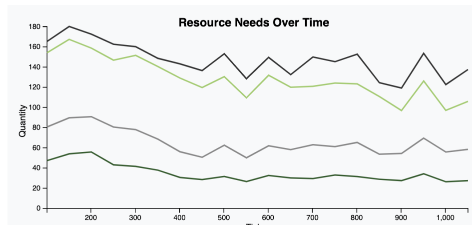

Figure 7: Needs per resource

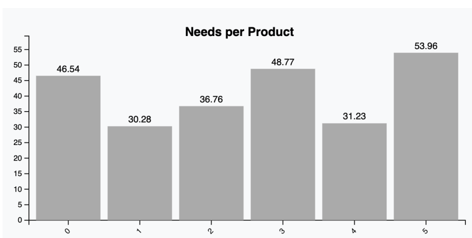

Figure 8: Percentage of needs per product

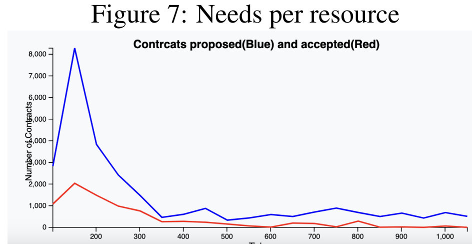

Figure 9: Evolution of proposed vs. accepted contracts

Figure 10: Results for Experiment 2

Figure 10 illustrates the effect of using a static tax policy set at the simulation's start. As shown in Figure 6, the number of companies in both the primary and tertiary sectors remains largely stable, whereas the secondary sector exhibits moderate variability. This pattern suggests that fixed tax rates can still lead to moderate fluctuations in industrial intermediaries without destabilizing resource extraction or final consumer sectors. In Figure 7, resource needs have a downward trend, although they remain at non-negligible levels over a longer timescale compared to Figure 5. Lastly, Figure 9 demonstrates that proposed and accepted contracts converge toward low levels, suggesting reduced negotiation over time. This outcome may reflect how unchanging fiscal policy leads companies to finding a relatively stable operating point without continuous searching for improved contract terms.

Finally, the third experiment Figure 15 uses a zero-tax policy throughout, representing a fully free-market scenario with no governmental revenue collection. These three simulations are executed under otherwise identical parameters to isolate the impact of taxation strategies on the market trajectory.

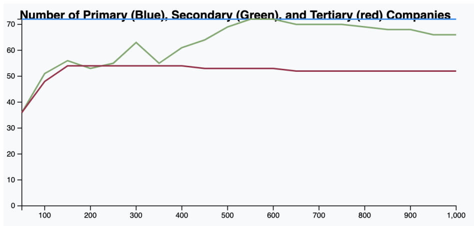

Figure 11: Total number of companies per sector

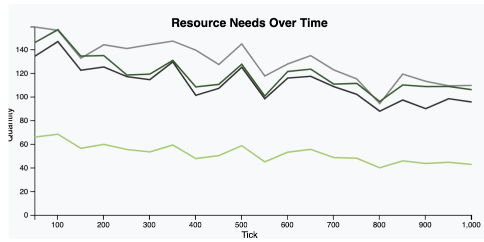

Figure 12: Needs per resource

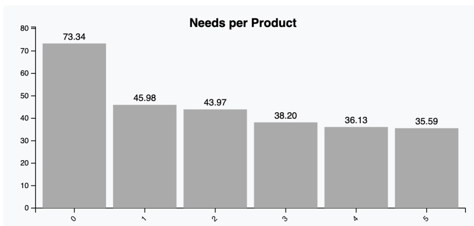

Figure 13: Percentage of needs per product

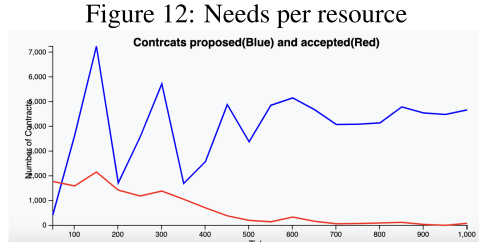

Figure 14: Evolution of proposed vs. accepted contracts

Figure 15: Results for Experiment 3

The results in Figure 15 show how the market develops when no taxes are collected. From Figure 11, both primary and tertiary companies persist at nearly constant numbers, whereas secondary firms remain more volatile, indicating that the absence of taxes does not eliminate the inherent challenges faced by mid-supply-chain companies. As seen in Figure 12, resource needs decrease over time but stay comparatively high relative to the duration of the simulation. Figure 13 reveals that consumer demand for certain products remains partially unmet. Meanwhile, Figure 14 shows that contracts proposed oscillate around a relatively large volume and gradually stabilize, while the number of accepted contracts steadily decreases toward zero. This contrast suggests that a zero-tax environment promotes frequent offers but does not guarantee steady, long-term agreements among firms.

Across all three experiments, a consistent observation emerges that secondary companies exhibit greater fragility than primary and tertiary companies, underscoring their dependence on reliable upstream supply and predictable downstream demand.

We conduct a further experiment in which the environment runs for 500 ticks under fixed taxes (randomly determined at the beginning), then automatically switches to an adaptive tax policy at tick 501. This setup is designed to investigate whether late adjustments to taxation can alter the market's dynamics when companies have already established their contractual and production routines. Figure20 shows the resulting data:

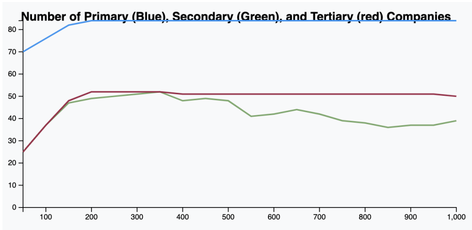

Figure 16: Total number of companies per sector

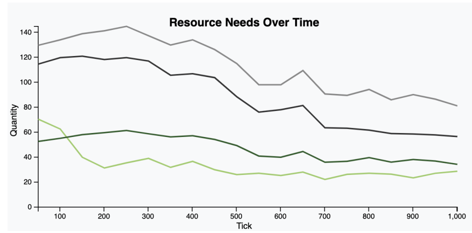

Figure 17: Needs per resource

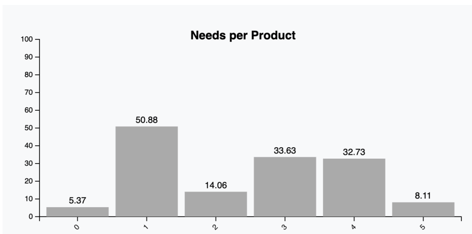

Figure 18: Percentage of needs per product

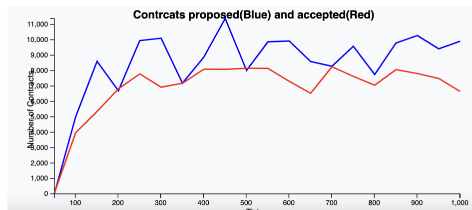

Figure 19: Evolution of proposed vs. accepted contracts

Figure 20: Results for the hybrid experiment with fixed taxes until tick 500, then automatic updates from tick 501 onward.

The primary and tertiary sectors remain relatively stable in terms of the total number of companies, while secondary-sector firms once again exhibit higher volatility. Needs for raw resources display a general downward trend over time, and the proportions of met product demands increase so that most product needs are eventually satisfied. Unlike some previous experiments, the number of proposed and accepted contracts does not converge to a single stable value, nor does it diverge entirely; instead, it continues to oscillate within a moderate range, suggesting that companies frequently negotiate and adjust their arrangements in response to changing fiscal conditions and evolving market requirements.

We conducted another experiment in which a country was cut off from the global markets at tick 1000 (it can no longer import and export). This setup aims to observe the impact of abruptly removing one participant from international trade midway through the simulation. Figure29 displays the relevant outcomes.

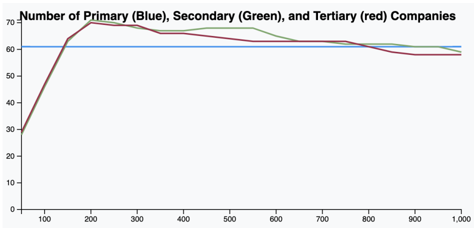

Figure 21: Total number of companies per sector (Before)

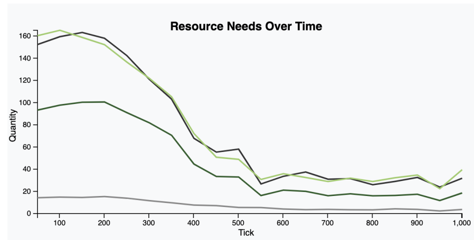

Figure 22: Needs per resource (Before)

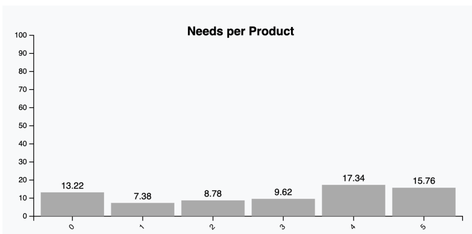

Figure 23: Percentage of needs per product (Before)

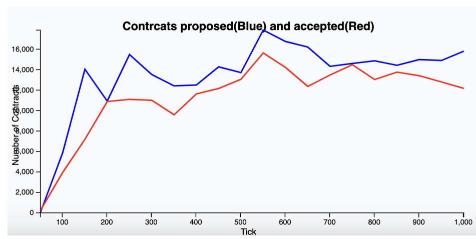

Figure 24: Evolution of proposed vs. accepted contracts (Before)

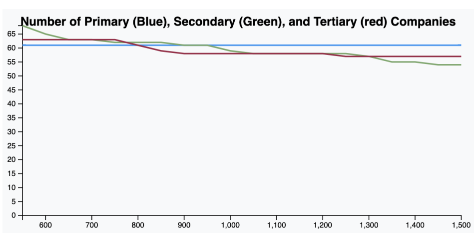

Figure 25: Total number of companies per sector (After)

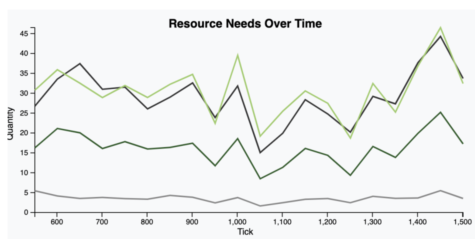

Figure 26: Needs per resource (After)

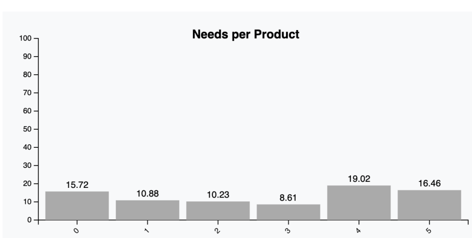

Figure 27: Percentage of needs per product (After)

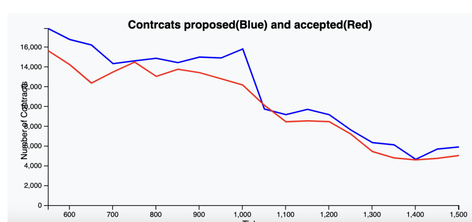

Figure 28: Evolution of proposed vs. accepted contracts (After)

Figure 29: Results for the market disconnection experiment, where a country is cut off at tick 1254 under auto tax policy. The first four plots correspond to the scenario before disconnection, while the last four correspond to the scenario after disconnection.

Before the cut-off at tick 1000, the market reached a largely stable state: resource needs had fallen and remained nearly constant, product demands were met, and contract proposals and acceptances both stayed high with no indications of slowing down. After the cut-off, resource needs shifted into an upward trajectory, needs per product slightly increased, and both proposed and accepted contracts declined relative to their prior levels. Nevertheless, neither the primary nor the tertiary sector exhibited significant changes in the total number of companies, while secondary firms continued to display moderate variability. This outcome implies that disconnecting one participant from global trade can destabilize resource availability and diminish contract activity, but does not necessarily provoke large-scale corporate failures or an overall market collapse.

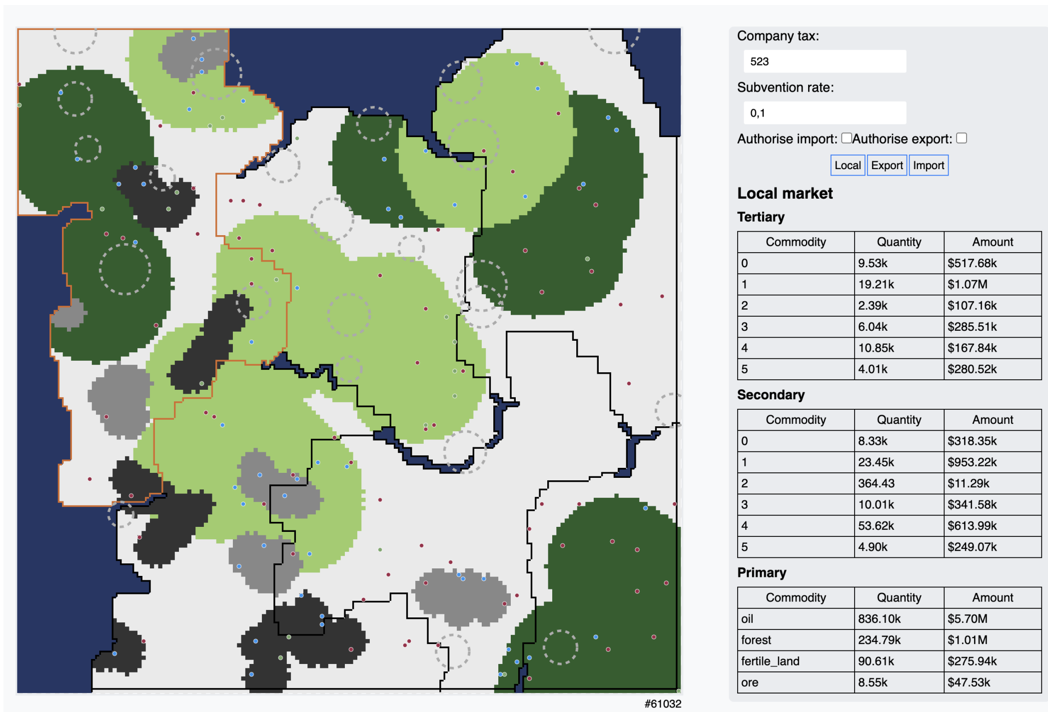

Figure 30: First part, locking a country for 1780 ticks

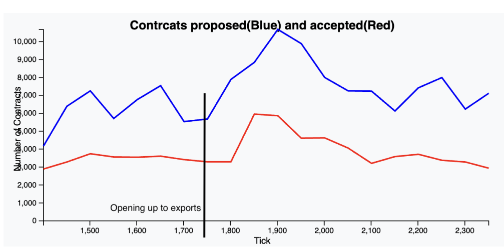

Figure 31: Evolution of proposed vs. accepted contracts after opening up to export (black line)

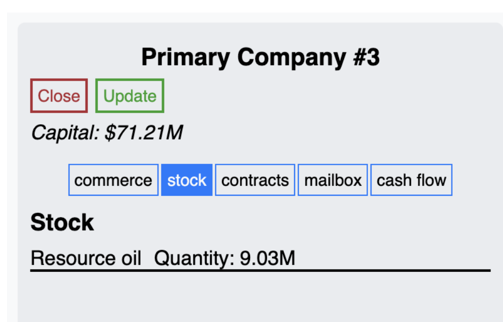

Figure 32: Main oil company

Figure 33: Results for Experiment 6: lock country

In experiment 6, we wanted to see how countries cut off from the rest of the world (no imports or exports) behave. To enable the country cut off from the rest of the world to function as well as possible, we lowered taxes to around $500 per 50 ticks. At the start of the simulation, the blocked country found it harder to stabilise, with businesses falling rapidly due to a poor supply chain. The only companies that managed to stay in place were the primary companies (they were much less affected by fluctuations due to bankruptcies and competition on the tertiary market). Subsequently, the country's economic market began to stabilise thanks to the primary companies, which were well established and responded very quickly to demand. After 1780 ticks, the global market has relatively stabilised, but we can see that end-customer demand for products is still a little high. Indeed, by blocking imports and exports from the largest country (with the most resources), the global market has been weakened. At the end of this first part of the simulation, the blocked country has one of the best economies 30. It should be noted, however, that the country itself is poor (very few state funds). In fact, the other countries have made millions of dollars in profits thanks to import and export taxes. More precisely, after 1780 ticks, the country is stuck with a $400k money fund, while one of its neighbours has more than $130M. Now, we will try to reinsert the country in the global markert by allowing only exports, with an export taxe of 10% (huge).

After the opening up of the country to exportation, we can observe than a large number of new contracts 31 were signed: more than 10,000 requests for contracts, of which 6,000 were accepted (beware, some contracts can be quickly revoked afterwards if renegotiated). This information shows that even if the export price is high, the market needs the country's blocked resources. To go into more detail, we can mention one of the country's biggest oil extraction companies, which has just opened up to exports. This company was quick to negotiate prices a little below its usual rate with companies outside the country, winning a large number of contracts, which even after taxes are still more attractive. This aggressive entry into the market completely caught the other pre-oil extraction companies off guard. 600 ticks later, this company has $70M in capital and is charging prices equivalent to those of its competitors, despite the export tax. In fact, the company's aggressive entry into the market undermined its competitors, which had a direct impact on their ability to produce (less money to extract). As a result, this company rose to the top of the market thanks to its ability to produce the large quantities demanded by the market. This example is significant given that few countries have access to oil, in fact, countries with oil reserves continue to favour their (smaller) local extraction companies in order to avoid all import-export taxes. This observation also applies to less scarce resources, although the lack of abundance of oil makes this case more significant. Finally, in 600 ticks, the country that was initially blocked generated more than $40M in revenue from taxes, compared with less than $10M for neighbouring countries. We can compare this example with China. After the Second World War, the country remained closed in on itself. In 1978, China opened up to the world market by devaluing its currency in order to be competitive on the export market but (conversely) not at all on the import market. The behaviour of the simulated country and that of China are very similar. The simulated country, thanks to a very aggressive entry by betting on quantity in the public market, is ahead of all the others.

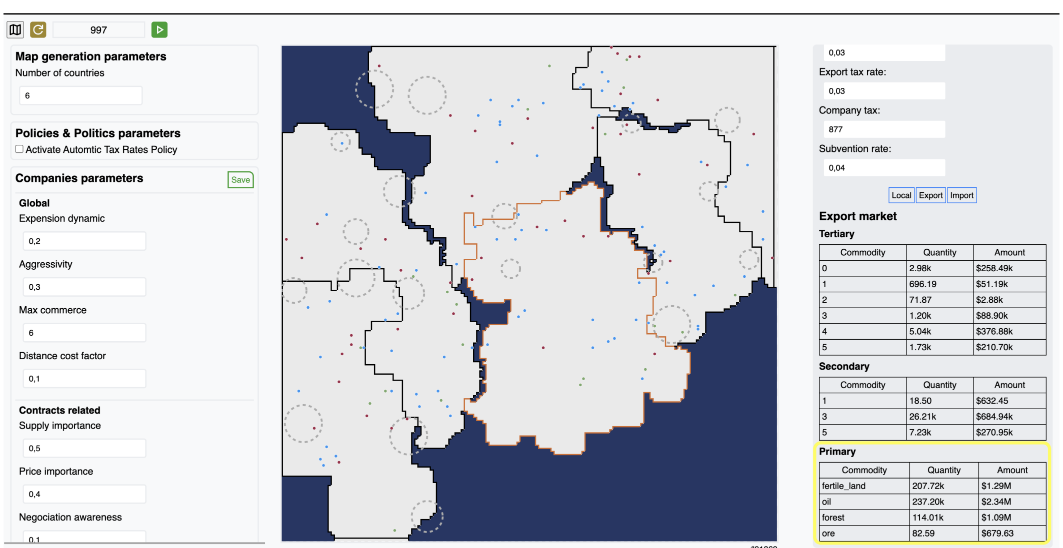

Figure 34: Results for Experiment 7: industrial country

In Figure 34, the country primarily focuses on primary industries and exports a significant volume of raw materials. However, aside from one major secondary enterprise, it lacks a diversified industrial base. Despite this, the country's financial position is strong due to the high production and export of raw resources. Most essential goods are imported, as domestic production and sales predominantly occur abroad before being reintroduced into the local market. The data suggests that the country has successfully developed a robust primary sector but faces challenges in expanding its secondary and tertiary industries due to constraints in available resources, particularly those necessary for industrial development. As a result, its secondary and tertiary businesses have been largely outcompeted by foreign industrial enterprises, leading to their replacement. This pattern of specialization was unexpected, given that most countries have viable opportunities to develop a balanced industrial and service sector.

5 Conclusion

The simulation framework presented in this work successfully demonstrates how firms and markets can adapt to changing tax environments and critical economic events. Despite its inherent complexity, the model captures a range of realistic behaviors, such as firm bankruptcies, sector-specific vulnerabilities, and the emergence of dominant market actors following shifts in trade policies. Notably, a single tick in the simulation can represent several months of real-world activity, enabling the exploration of long-term scenarios—such as the historical evolution of trade policies in a country over multiple decades—in a condensed timeframe.

Moreover, experiments indicate that the model reliably reproduces key macroeconomic patterns, including specialization in resource-rich sectors, dynamic shifts in global supply chains, and the short- or long-term stability of various tax configurations. The realistic negotiation processes between firms, the handling of import and export taxes, and the capacity to simulate disruptive events (e.g., war, trade embargoes) add to the model's fidelity and usefulness for policy exploration.

Nevertheless, several limitations must be acknowledged. First, the computational complexity increases substantially as the number of companies grows and as events (such as contract renegotiations) require processing. This is particularly evident in the heavier computations triggered every 50 ticks, which can cause significant slowdowns. Second, the simplified agent decision rules, while illustrative, may not capture all real-world factors such as changing consumer preferences, labor market dynamics, or regulatory compliance costs beyond taxation. Finally, the granularity of a single tick representing extended real-world timescales means some short-term phenomena—like short-lived speculative bubbles or abrupt policy shifts—cannot be modeled in great detail without further refinement.

Despite these constraints, the model serves as a valuable tool for exploring how economies can evolve under different fiscal regimes and disruptive events. Its capacity to represent realistic behaviors, combined with the ability to run and compare diverse scenarios, makes it a promising basis for future extensions—such as incorporating labor market policies, more nuanced financial instruments, or detailed transport logistics—aimed at deepening our understanding of complex economic systems.

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