Reconstruction of an Agent-Based Simulation Model about Labor Market Policies

Master Thesis

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Abstract

In this master thesis an agent-based macroeconomic model used for economic policy experiments featuring a distinct geographical dimension and heterogeneous workers with respect to skill types is to be introduced and reconstructed with the help of the AOR simulation technology that was developed by the Chair of Internet Technology.

Zusammenfassung

In dieser Masterarbeit wird ein agenten-basiertes makroökonomisches Modell für die wirtschaftspolitischen Experimente mit einem eigenen geographischen Dimension und heterogenen Arbeitnehmern in Bezug auf Skill-Typen vorgestellt und mit Hilfe der am Lehrstuhl Internet-Technologie entwickelten AOR-Simulationstechnologie rekonstruiert.

Table of Contents

Introduction 1
The economic model 2
    Background to the model 2
    General description 2
    Analysis of the model 3
Reconstruction of the model in AOR Simulator 11
    AOR Simulations Framework 11
    Scenario model 11
Simulation results 17
Conclusion 18

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Introduction

So far agent-based modeling (ABM) is a powerful simulation modeling technique that has been extensively developed and well used in a lot of areas, because it can provide many effective methods to facilitate the research into the complex problems of different scientific fields. The model which will be in this paper described aims to use ABM to explore the fields of economics to analyse the effects of different spatial concentrations of economic policy measures depend on spatial frictions in the labor market. The purpose of this paper is to remodel it as a multi-agent based simulation using the Agent-Object-Relationship (AOR) simulation technology that was developed by Prof. Dr. Gerd Wagner and other team members at the Brandenburg University of Technology.

The paper is organized as follows. In Section 2 the economic model will be introduced. Section 3 describes the principles of AOR modeling and simulation in which the model will be implemented. Section 4 provides some simulation results, and Section 5 concludes.

The economic model

The model was developed by Herbert Dawid, Simon Gemkow, Philipp Harting and Michael Neugart and has been implemented in the Flexible Large-Scale Agent Modeling Environment (FLAME) developed by Simon Coakley, Mike Holcombe and others at the University of Sheffield (see http://www.flame.ac.uk for more information and references). It is an agent-based macroeconomic model. Its main purpose is to investigate how the spatial skill distribution in the absence of policy intervention influences the speed of technological change, the flow of labor force and the growth of wage level.

Background to the model

The model was developed as part of a larger simulation platform for European policymaking known as EURACE. EURACE is a major project aiming at creating a complete agent-based model of the European economy for evaluating European economic policies. The EURACE model has a distinct spatial structure simulating the regional statistical units used by Eurostat. It contains various (typically, regional) artificial markets for real commodities (that is, consumption goods, investment goods and labor) and markets for financial assets (such as loans, bonds and stocks). For a general overview of the EURACE model, see http://www.eurace.org.

General description

The model is a simplified version based on EURACE's labor market module. It describes an economy that contains three markets namely an investment (or capital) goods, a consumption goods and a labor market in a regional context. The main components of the model are agents, which are the main body of these markets. In this model there are two types of active agents and two types of passive agents in the sense that active agents can take decisions, whereas passive ones can not. Each type of agent has one or several `roles' corresponding to its activities in the markets. The following summarizes these roles.

Active Agents:

- Households
  - Comsumption Goods Market: Role of Buyer
  - Labor Market: Role of Worker
- Consumption Goods Producer (henceforth called CGP)
  - Investment Goods Market: Role of Buyer
  - Consumption Goods Market: Role of Seller
  - Labor Market: Role of Employer

Passive Agents:

- Malls
  - Consumption Goods Market: Information Transfer between Consumption Goods Producers and Households
- Capital Goods Producer (henceforth called IGP)
  - Investment Goods Market: Role of Seller

Agents are distributed over $R = 2$ regions where the consumption goods market is local, the other two markets are global. The minimal time unit in the model is a day, but some actions occur on weekly or monthly basis.

The main actors in the investment goods market are IGP and CGPs. The investment goods market is global meaning that CGPs in both regions buy investment goods from the unique IGP. Investment goods are offered with infinite supply at an exogenously given price and there exists only one type of investment goods. The quality and price of supplied investment goods increase randomly over time.

CGPs, Households and Malls take part in the consumption goods market. Consumption goods are sold at malls. Malls are seen as the non-profit local market platforms. On the consumption goods market CGPs act globally in the sense that all CGPs store and offer their products at every regional mall, but households act locally because every household comes to the mall in his region to buy goods at posted prices.

CGPs and Households play in the labor market. The CGP needs more laborers in order to expand its production scale. For this reason, it offers job vacancies based on the planned output. The household who is job seeker looks for a suitable position based on the corresponding salaries of these vacancies. Thus, a search-and-matching process is used to represent the interaction between CGPs and Households in this market. Specifically, the labor market is global with spatial frictions determined by commuting costs that arise if job seekers accept jobs outside their own region.

Analysis of the model

This section focuses on the analysis of the model. In general, there are three ingredients in this model: market, agent and activity. Markets do not act, because they have no intentions and cannot perform actions. However, they can provide some contexts for agents to act in. Agents always act within markets. They take some activities with different roles. Therefore, the analysis is concentrated on agents, which are involved in different markets and characterized by different actions.

Households

The model consists of a large number of households, who are simultaneously taking the roles of buyers and workers. Households receive their income and determine how much to spend and how much to save. In general, the household makes some decisions with the related roles affecting the markets as follows.

1. Allocate budget on consumption and saving
2. Choice of consumption goods
3. Search for a job
4. Acquire specific skills

Allocate budget on consumption and saving

The household acting as the role of buyer (or consumer) sets once a month the consumption budget which is spent on the consumption goods market and consequently determines the remaining part which is saved.

Table 1. The savings decision

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
personal consumption budget	B^{cons}	consumptionBudget	The consumer decides about the budget that he will spend for consumption	
the available liquidity	Liq^{Avail}	cashOnHand	The cash on hand that contains current income (i.e. labor income and dividends distributed by	

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
			capital and consumption goods producers) and assets carried over from the previous period	
mean income	Inc^{Mean}	meanIncome	The mean individual (labor) income of a consumer over the last periods	
the percentage of mean income	Φ	phi	$\Phi \leq 1$ is the percentage of the mean income such that the consumer spends all cash on hand below that level	*0.9*
marginal saving propensity	κ	savingPropensity	$0 < \kappa < 1$ is the saving propensity	*0.1*

Algorithm: There exists a critical value $\Phi * Inc^{Mean}$ of cash on hand to determine how much cash on hand will be spent for consumption in this month. When the available liquidity Liq^{Avail} is below this critical value the whole cash on hand will be spent. Thus, the consumption budget $B^{cons} = Liq^{Avail}$. In the opposite case the consumer will save a part of his cash on hand, so he sets his consumption budget according to the following consumption rule

$$B^{cons} = Liq^{Avail} - k * \left(Liq^{Avail} - \Phi * Inc^{Mean}\right) \quad (1)$$

Choice of consumption goods

The consumer purchases consumption goods according to his consumption budget. He splits the consumption budget into four equal shares, each of which is used for shopping per week. After determining the weekly budget, each consumer visits once a week to the mall in his region to buy goods. When visiting the mall he collects information about prices and quantities of different goods and then purchases goods according to his preference and available stocks of goods at posted prices. The model includes neither any kind of horizontal product differentiation, nor any kind of quality differentiation. Therefore, choice probabilities depend solely on prices.

Consumers make their purchasing decisions based on the prices of different goods using a stochastic rule as described in a standard logit model. In the marketing literature it is standard to describe individual consumption decisions. This model represents the stochastic influence of factors not explicitly modeled on consumption decisions, see [Guadagni and Little 1983].

Table 2. Selection of consumption goods

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the selection probability	*Prob*	selectionProbability	The consumer decides which consumption good to buy on the basis of the selection probability of every consumption good sampled by him	
available stocks of goods	G_{week}	availableProducts	The consumption good whose quantity is positive at the attended mall will be sampled in week (of period)	
the price of the consumption good	p_i	productSalesPrice	The price of the consumption good i	

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the value of the consumption good	$v(p_i)$	consumptionValue	A function whose parameter is p_i determines the subjective value of the consumption good i for consumer	$-ln(p_i)$
the intensity of choice by consumer	λ^{cons}	intensityOfProductChoice	The intensity of choice by consumer	*8.5*

Algorithm: The decision of a consumer which consumption good to buy is random, where purchasing probabilities are based on the values he attaches to the different choices he is aware of. The consumer selects one consumption good $i \in G_{week}$, where the selection probability reads

$$Prob = \frac{Exp\left[\lambda^{cons} * v\left(p_i\right)\right]}{\sum_{i \in G_{week}} Exp\left[\lambda^{cons} * v\left(p_i\right)\right]} \tag{2}$$

Once the consumer has selected a consumption good he tries to spend the whole weekly budget for that consumption good if the stock at the mall is sufficiently large. In case the consumer cannot spend all his budget on the consumption good selected first, he has a single opportunity to select another good. If the budget is then not completely spent, the remaining amount is rolled over to the following week.

Search for a job

On the labor market households who are job seekers search for jobs (there are the unemployed plus a certain fraction of on-the-job searchers). They see posted vacancies and apply to the ones if the wage offers exceed the current reservation wage of the job seeker. After applying they receive zero, one or more job offers and rank these offers with respect to the wage offer. In case the offered position is outside the home region of the job seeker, commuting costs are subtracted from the offered wage. If two or more wage offers are equal then these are ordered randomly. Job seekers accept at most one job with the highest offered wage and update their reservation wage which is the new wage. If job seekers are still unemployed they decrease their reservation wage.

Acquire specific skills

The household is characterized by a general skill level and specific skills. His general skill level is determined by outside factors like government and economic policy. The specific skills of workers are acquired on the job.

Table 3. Specific skills (of workers) decision

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the average quality of the capital stock	A_i	averageQualityOfCapitalStock	The average quality of the investment goods employed by CGP i	
general skill level	b^{gen}	generalSkillLevel	Every worker has a level of general skills $b^{gen} \in \{1, \ldots, b^{gen}_{\max}\}$	*[1…5]*
specific skill level	b_t	specificSkillLevel	Every worker has a level of specific skills in period t	
increasing in the general skill level of the worker	$\chi(b^{gen})$	chi	A function whose parameter is b^{gen} governs the speed of specific skill improvement	

Algorithm: While being employed each worker adjusts his specific skills to the average quality of the capital stock of his employer. The adjustment speed $\chi(b^{gen})$ depends positively on the general skill level of the worker.

$$b_{t+1} = b_t + \chi\left(b^{gen}\right) * \left(A_i - b_t\right) \tag{3}$$

where the formula of the function $\chi(b^{gen})$ is

$$\chi\left(b^{gen}\right) = 1 - 0.5^{1/\left(20+0.25*\left(b^{gen}-1\right)*\left(4-20\right)\right)} \tag{4}$$

Brief interpretation: There are 5 general skill groups 1 to 5, where 1 is the lowest skill group and 5 is the group with the highest skills. A worker from skill group 1 needs 20 months to close half of the gap between his specific skills and the technology of his employer, where a worker of skill group 5 needs only one fifth of that time, namely 4 months. Therefore, the higher the general skill level of a worker, the faster he acquires the specific skills associated with a given job.

Consumption goods producer (CGP)

The CGP plays the role of buyer, seller and employer and makes a large number of decisions to influence the markets. Overall, it operates the sequence of events in the following way:

1. Product stock (optimal inventory) decision
2. Production inputs (labor and capital) decision
3. Investment (in investment goods) decision
4. Employment (hiring and firing) decision
5. Production (quantity) decision
6. Pricing decision (which price to set)
7. Dividend payment decision

Product stock (optimal inventory) decision

The CGP keeps a stock of its products at every regional mall. It decides once a month whether the inventories at different malls need to be refilled in order to try to avoid the shortage of supplied goods and maximize the expected profit. To that end the CGP checks the current stock level reported by each mall it serves and determines an optimal stock level for each mall using a standard managerial method, which is based on a solution to the ""

Table 4. Quantity choice

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the optimal stock level	Y	optimalStockLevel	The CGP replenishes its stock at each mall in every period up to a given optimal stock level	
the price of the consumption good	p_i	productSalesPrice	The price of the consumption good i	
the unit cost of production	c_{t-1}	unitCostOfProduction	The unit cost of production in period t - 1 (the previous period)	

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
holding cost	C^{inv}	holdingCost	Holding cost per unit remaining at the mall for one period	*0.1*
monthly discount factor	ρ	rho	The discount rate which takes into account the time value of money	*0.95*
the current stock level	*SL*	currentStockLevel	The level of the stock which is checked at each mall	
the desired replenishment quantity	D_r	replenishmentQuantity	The desired replenishment quantity at the mall in region r	
the sum of the orders	D^{plan}	sumOfOrders	The sum of the planned delivery volumes for the malls	
the planned output	Q^{plan}	plannedOutput	The planned output that is used for the determination of the input factor needs	
a linear combination	ξ	xi	For combining the planned current demand with weight xi and the historic demand with weight (1 - xi)	*0.5*

The CGP applies an optimal inventory policy to determine whether and how much to replenish inventory. The optimal inventory policy is the following:

- If the current stock level is greater than or equal to the optimal stock level $SL \geq Y$, the CGP does not need to replenish inventory D_r=0.
- If the current stock level is less than the optimal stock level $SL < Y$, the CGP needs to replenish inventory $D_r = Y - SL$.

Production inputs (labor and capital) decision

In this model for producing the homogenous consumption good two input factors are used, i.e. labor and capital. Based on the planned output the corresponding demand for capital and labor are determined.

Table 5. Factor demand

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the planned output	Q^{plan}	plannedOutput	The planned output that is used for the determination of the input factor needs	
labor intensity of production	α	alpha	0 < α, β and α + β = 1 α and β are the output elasticities of labor and capital	*0.662*
capital intensity of production	β	beta		*0.338*
the average quality of the capital stock	A_i	averageQualityOfCapitalStock	The average quality of the investment goods employed by CGP i	

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the average level of specific skills of employees	B	averageSpecificSkillLevel	The average level of specific skills of employees	
labor input	L^{plan}	plannedLaborInput	The planned labor force is directly related to the planned production quantity	
capital input	K^{plan}	grossInvestment	The planned capital stock is directly related to the planned production quantity	
the price of the investment good	p^{inv}	investmentSalesPrice	The price of the investment good	
The average wage of employees	w^e	laborPrice	The average wage of employees	

Algorithm: Two cases have to be considered for the factor demand determination:

Investment (in investment goods) decision

The existing capital stock of the CGP depreciates over time. Once there is a positive demand for investment goods, the CGP purchases the needed amount from the IGP thereby upgrading its capital stock.

Table 6. Investment demand

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the gross investment	K_t	grossInvestment	The stock of machines etc. needed for production	
the new investment	I	newInvestment	The CGP needs more investments in order to expand its production scale	
the depreciation rate of capital	δ	delta	The depreciation rate of capital	*0.01*

Algorithm: The capital stock of the CGP is updated as old capital is replaced by new investments.

$$K_{t+1} = (1-\delta) * K_t + I \tag{5}$$

Employment (hiring and firing) decision

After determining the required labor force during the calculation of planned production inputs, the CGP compares it to the existing labor force, and then decides to post vacancies or to dismiss workers depending on the difference between the required labor force and the existing labor force. In case a CGP has to downsize the labor force, it fires workers with the lowest general skill levels until the needed number of workers is reached.

In another case, if a CGP has a positive demand for labor, vacancies are posted together with a wage offer. The incoming applications are ranked with respect to the general skill level. More specifically, applicants with higher general skill levels are ranked higher. If there exist two or more applicants who have the same general skill level, they are ranked by chance. The CGP sends as many job offers as it has vacancies to the highest ranked applicants. If the CGP then receives job acceptances from the applicants, it updates the number of employees and the number of vacancies. Otherwise there are still some vacancies and the CGP increases the offered wage.

On the whole, together with the job search activities of Households (see section 2.3.1.3),

a search-and-matching process is used to represent the interaction between CGPs and Households in this market.

Production (quantity) decision

The production technology is represented by a Cobb-Douglas type production function. In economics, the Cobb-Douglas functional form of production functions is widely used to represent the relationship of an output to inputs. In this model for producing the homogenous consumption good two input factors are used, i.e. labor and capital.

Table 7. Factor demand

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the quantity of production	Q	producedQuantity	The quantity of production	
labor intensity of production	α	alpha	0 < α, β and α + β = 1 α and β are the output elasticities of labor and capital	*0.662*
capital intensity of production	β	beta		*0.338*
the average quality of the capital stock	A_i	averageQualityOfCapitalStock	The average quality of the investment goods employed by CGP i	
the average level of specific skills of employees	B	averageSpecificSkillLevel	The average level of specific skills of employees	
labor input	L	plannedLaborInput	The planned labor force is directly related to the planned production quantity	
capital input	K	grossInvestment	The planned capital stock is directly related to the planned production quantity	

Algorithm: The production quantity of a CGP is given by

$$Q = \min[B, A_i] * L^{\alpha} * K^{\beta} \quad (6)$$

where,

$\min[B, A_i]$: Complementarity between B and A_i.

Pricing decision (which price to set)

The price of the consumption good produced by the CGP changes with the unit cost in production.

Table 8. Pricing

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the price of the consumption good	p_i	productSalesPrice	The price of the consumption good i	

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
Mark-up factor	μ	markUpFactor	The difference between the cost of a product and its sales price	*0.2*
the unit cost of production	c_{t-1}	unitCostOfProduction	The unit cost of production in period t - 1 (the previous period)	

Algorithm: The CGP sets the price of its product according to the standard rule

$$p_i = (1+\mu) * c_{t-1} \tag{7}$$

Dividend payment decision

At the end of every month CGPs have to check whether they are in a profitable position that households can receive dividends from them. The CGP pays dividends depending on its monthly realized profit and current balance of saving account according to a simple dividend policy.

Table 9. Dividend payment decision

Variable/ Parameter	Symbol	Name (in the sim model)	Description	Value
the sales revenue	Rev_t	productSalesRevenue	The sales revenue in period t	
cost of production	C	costOfProduction	The production cost	
the monthly realized profit	Pro	monthlyRealizedProfit	The monthly realized profit is the difference between the sales revenue and the production cost	Rev_t-C
the current balance of saving account	Acc	currentBalanceOfSavingAccount	The current balance of saving account	
the dividends	Div	dividends	The CGP pays dividends to all households	
a fixed proportion	div	div	The CGP pays a fixed proportion $div \in [0,1]$ of its profit as dividends to all households	*0.9*

Algorithm: If the monthly realized profit of a CGP is not positive, the CGP pays no dividends and the losses are entered on the current balance of saving account. In case of positive profit, the CGP pays dividends based on a simple dividend policy that defines three kinds of dividend rates depending on the current balance of saving account. The rule states

1. If the balance is negative $Acc < 0$ and the debt is on a scale above the last monthly revenue $|Acc| > Rev_{t-1}$, the CGP pays no dividends $Div = 0$.

2. If the balance is positive $Acc > 0$ and savings are above the monthly revenue $Acc > Rev_t$, the CGP disburses all profits as dividends $Div = Pro$.

3. In the remaining case, if the balance is between these critical levels of the above two cases, the CGP pays out a fixed proportion of profits as dividends $Div = div * Pro$.

Malls

Mall is modeled as a passive agent in this model, so it cannot take decisions. This agent performs the selling role of CGP in the region. It keeps and receives consumption goods produced by CGPs, then sells them and collects every product sales revenue that is reported back to the corresponding CGP.

Capital Goods Producer (IGP)

In this model, the IGP is unique and acts globally. It only has one role and plays the role of seller on the investment goods market. It supplies investment goods infinitely to all CGPs. The investment good as a kind of productive factor of CGP has two properties, i.e. quality and price, which are increased by simple rules.

- The quality and price of the investment good increase over time due to technological change. The price varies with the quality.
- Every month the quality is increased by 5% with probability 10% where with probability 90% there is no change of quality.

Finally, in order to close the model, the monthly revenue of the IGP is uniformly distributed to all households.

Reconstruction of the model in AOR Simulator

This section deals with the

AOR Simulations Framework

In this chapter, the concepts of AOR modeling and modeling methodologies will be introduced.

An agent-based approach for the conceptual modeling of organizational information systems, called Agent-object-Relationship (AOR).

A description language for agent-based simulations,

Scenario model

This part describes

Statistics

Some valuable data for analysis and research are extracted from the variables of the model. Simulation statistics are generated while the simulation is running and appear on the panel in AOR Simulator.

- **outputLowSkillRegion** type: Float

  description: Counts the total outputs in the low skill region.

- **outputHighSkillRegion** type: Float

  description: Counts the total outputs in the high skill region.

DataTypes

Because not all the attributes can be declared with the standard data types, the AOR framework allows defining the custom (that is, nonstandard) data type.

ComplexDataType

This tag is used to define the new complex data type. It can have attributes. These complex data types can be used in the same way as the standard data types.

- **ProductInStock:** Represents a product, which is offered by a CGP and stored at malls. It has some attributes as follows.
  - **firmId** type: Integer

    description: Holds the "identity" of the CGP agent, which provides the product.
  - **price** type: Float

    description: Holds the price of the product.
  - **quantity** type: Float

    description: Holds the amount of the product, which is sold at malls.
- **ProductListItem:** Represents a product, which can be sampled by consumers. The attributes can be summarized as follows.
  - **firmId** type: Integer

    description: Holds the "identity" of the CGP agent, which provides the product.
  - **consumptionValue** type: Float

    description: Holds the value of the product depending on the price of the product.
  - **selectionProbability** type: Float

    description: The consumer decides which product to buy with the selection probability that depends solely on the price.
- **ProductDemandRecord:** Represents the market demand of a product in a period. The attributes are given below.
  - **mallId** type: Integer

    description: Holds the "identity" of the mall agent.
  - **demand** type: Float

    description: Holds the sales volume of the product.
  - **maximumDemand** type: Float

    description: Holds the maximum volume of sales in all periods.
  - **optimalStockLevel** type: Float

    description: Holds an optimum order point for each mall.
- **InventoryPosition:** Represents the desired replenishment quantity for a mall. The attributes are as follows.
  - **mallId** type: Integer

    description: Holds the "identity" of the mall agent.
  - **quantity** type: Float

description: Holds the desired replenishment quantity of the product for the mall.

- **adjustmentFactor** type: Float

  description: Holds the ration for each mall.

- **WorkerInFirm:** Represents a household, who is employed. It has some attributes as follows.
  - **householdId** type: Integer

    description: Holds the "identity" of the household agent.

  - **wage** type: Float

    description: Holds the wage of the worker.

  - **generalSkillLevel** type: Integer

    description: Holds the general skill level of the worker.

  - **specificSkillLevel** type: Float

    description: Holds the specific skill level of the worker.

- **JobApplicationRecord:** Represents a job applicant, who needs to find a suitable position. The attributes can be summarized as follows.
  - **householdId** type: Integer

    description: Holds the "identity" of the household agent.

  - **generalSkillLevel** type: Integer

    description: Holds the general skill level of the applicant.

  - **specificSkillLevel** type: Float

    description: Holds the specific skill level of the applicant.

- **JobOfferRecord:** Represents a job offer, which is sent to qualified applicants. The attributes are given below.
  - **firmId** type: Integer

    description: Holds the "identity" of the CGP agent.

  - **wageOffer** type: Float

    description: The CGP posts vacancies including the wage offer.

  - **netWageOffer** type: Float

    description: The commuting costs are deducted from the wage offer.

EntityTypes

This tag contains messages, events, agents.

MessageType

Messages are used to communicate between the agents. Every message structure is difined seperately. There are ten message types, two of which have no attributes.

- **TellCurrentStockLevel:** Sent by malls to tell the CGP about the current stock level. This message has one attribute including quantity, which holds the amount of the product.
- **TellSalesRevenue:** Sent by malls to tell the CGP about the sales situation. This message has two attributes including revenue which holds the sales revenue, and quantity that holds the sales volume.
- **TellDismissal:** Sent by CGPs. The household checks whether is fired or not. This message has no attributes.
- **TellVacancy:** Sent by households. The CGP receives applications for vacancies. This message has two attributes which hold the general skill level and the specific skill level of the applicant.
- **JobOffer:** Sent by CGPs to qualified applicants. This message has two attributes which store the offered wage and region where the CGP is located.
- **AcceptJob:** Sent by households to accept the positions. This message has three attributes including wage, generalSkillLevel and specificSkillLevel.
- **ResignJob:** Sent by households. Because the household is offered a better job, he resigned his position. This message has no attributes.
- **DeliverProduct:** Sent by CGPs to deliver the ordered products to the mall. This message has one attribute containing quantity, that holds the delivery quantity.
- **TellWage:** Sent by CGPs. Wage is paid to the worker. This message has two attributes which store the wage of the worker and region where the CGP is located.
- **TellSpecificSkillLevel:** Sent by CGPs. The household checks whether his specific skill level needs to be updated or not. This message has one attribute including specificSkillLevel which holds the adjusted specific skill level.

ActionEventType

Action events are used by agents, which want to perform some actions. There are ten action event types, six of which have no attributes.

- **BuyNewInvestment:** If additional investments are needed the CGP performs the action of purchasing new investment goods from the IGP. This event has no attributes.
- **DismissWorker:** If the CGP wants to decrease the incumbent workforce it performs the action of downsizing. This event has no attributes.
- **PostVacancyInformation:** If additional workers are needed the CGP performs the action of posting vacancies. This event has two attributes including firmId which holds the "identity" of the CGP agent, and wageOffer that holds the offered wage for vacancies.
- **InFirstIterationOfferJob:** After ranking the applicants, the CGP performs the action of offering the positions. This event has no attributes.
- **DistributeProduct:** After production, the CGP performs the action of distributing the products. This event has no attributes.
- **PayWage:** When the CGP updates its labor force, it performs the action of paying wages. This event has no attributes.
- **IncreaseSpecificSkillLevel:** The CGP performs the action of adjusting the specific skills of its employees. This event has no attributes.
- **PayEqualShare:** The IGP performs the action of distributing its revenue to all households. This event has one attribute including share, which holds equal shares of the revenue.

- **PayDividend:** The CGP performs the action of paying dividends to all households. This event has one attribute containing dividend, that holds equal shares of the dividends.
- **SetNewPrice:** Once the CGP needs to adjust the price of its product, it performs the action of updating the price. This event has one attribute which records the new price.

ExogenousEventType

In the simulation, each step is seen as a day. A week consists of 6 steps and a month has 24 steps. There are six exogenous events, which affect state variables whose values cannot be changed by actions of agents.

- **Init:** This event happens at the beginning of the simulation (occurrenceTime="1") and occurs only once.
- **StartOfMonth:** This event simulates at the beginning of every month (occurrenceTime="2") and occurs at every 24 steps during the running of the simulation.
- **AtWeeklyIndividualConsumption:** This event triggers the consumption activities of households (occurrenceTime="3"). It is repeated every 6 steps, namely on a weekly basis.
- **EndFirstIterationLaborSupply:** This event occurs when the first round of hiring activity ends (occurrenceTime="14"). It is repeated every 24 steps, namely on a monthly basis.
- **EndSecondIterationLaborSupply:** This event happens at the end of the second iteration of hiring activity (occurrenceTime="23"). It is also repeated every 24 steps.
- **EndOfMonth:** This event simulates at the end of every month (occurrenceTime="25") and occurs at every 24 steps in the simulation.

AgentType Household Agent

An institutional agent consists of a number of internal agents that perceive events and perform actions on behalf of it, by playing certain roles.

The agents involved in the implementation are listed and specified in the following sections.

Attributes

id is a integer variable which holds the "identity" of the Household agent.

- **region** type: Integer

  description: The region, where the household is located.

- **firm** type: Integer

  description: The CGP, which is the employer of a household.

- **lastFirm** type: Integer

  description: If a household changes his job, the last job is recorded.

- **jobSeeker** type: Boolean

  description: Determines whether a household is job seeker or not.

- **generalSkillLevel** type: Integer
- **specificSkillLevel** type: Float
- **currentWage** type: Float

- **totalIncome** type: Float
- **meanIncome** type: Float
- **currentIncome** type: Float
- **savingAccount** type: Float
- **cashOnHand** type: Float
- **consumptionBudget** type: Float
- **weekConsumptionBudget** type: Float
- **remainingConsumptionBudget** type: Float
- **selectFirstProductId** type: Integer
- **selectSecondProductId** type: Integer
- **spendBudgetForFirstProduct** type: Float
- **spendBudgetForSecondProduct** type: Float
- **purchaseQuantityForFirstProduct** type: Float
- **purchaseQuantityForSecondProduct** type: Float
- **availableProducts** type: ProductListItem
- **jobOffers** type: JobOfferRecord

Functions

ReactionRule

Attributes

a

- **region** type: Integer

  description: The region, where the CGP is located.

- **productSalesPrice** type: Float

  description: The price of the product.

- **productSalesRevenue** type: Float

  description: The monthly realized sales revenue of a CGP.

- **productSalesQuantity**
- **grossInvestment**
- **physicalCapitalStock**
- **newInvestment**

- **totalQualityOfCapitalStock** type: Float

  description: The productivity of capital stock of a CGP.

- **averageQualityOfCapitalStock**
- **producedQuantity** type: Float

  description: The actual output of a CGP.

- **costOfProduction**
- **unitCostOfProduction**
- **monthlyRealizedProfit** type: Float

  description: The monthly realized profit of a CGP.

- **currentBalanceOfSavingAccount**
- **equalDividend**
- **optimalStockLevel**
- **laborSupplyQuantity** type: Integer

  description: The number of vacancies.

- **wageOffer** type: Float

  description: The wage offer of a CGP.

- **lastFourProducedQuantities** type: Float

  description: List of

- **productDemands** type: ProductDemandRecord
- **inventoryPositions** type: InventoryPosition
- **workersInFirm** type: WorkerInFirm
- **dismissalsList** type: WorkerInFirm
- **jobApplications** type: JobApplicationRecord

EnvironmentRules

EnvironmentRule

AtStartOfMonthDetermineEmployedWorkerAsJobSeeker_Rule. Household decides whether to search on the job or not.

Simulation results

In the simulation presented here there are two regions, with 5 firms and 200 households in each region. There are five general skill levels, 1 being the lowest and 5 the highest. The general skill levels are distributed uniformly among workers. The stochastic technology improvement process is defined such that a fully efficient economy would grow at 6% per year on average. The simulation was conducted over 4,000 periods (days), that is roughly 17 years. The values chosen for the parameters are

Conclusion