Customer behavior and enterprise strategy in a multi-agent economic model

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Abstract. In this paper we describe how the customer's varying demands affect the enterprise volume and assortment of production. The model includes the following agent classes: customer, bank, labor market, state, enterprise, market, university, and mass media. The model allows us to evaluate the relation between the efficiency of enterprises' investment strategies and customer's prosperity and unemployment level. The possibility of obtaining a new specialty by a fired agent is considered in the paper as well.

Keywords: *Multiagent systems, virtual economics, employment/ unemployment, investment strategy, reeducation, indices' dynamics.*

1 Introduction

The problems of multi-agent modeling in economics attract more and more scientists' attention, since the pioneer article by Pr. Leigh Tesfatsion [1]. Multi-agent simulation for food market is considered in the manuscript [2]. The related topics on negotiations are discussed in the article [3]. In this paper we are particularly interested in enterprise simulation and consumer behavior issues partly covered in the articles [4-5].

While the ACE [1] was the first model to introduce such processes of enterprise activity as selling some of its capacity if the production is lossmaking, our model covered the enterprise operation in the context of employees' continuous education (the introduction of the agent class University into the model) and the influence of Mass Media on the customers' demand and decisions what to buy.

The goal of this paper is to make the process of an enterprise's adaptation to the changing demand in the model of economics clear and to show how these changes reflect on the customers' occupational level.

2 Model Architecture

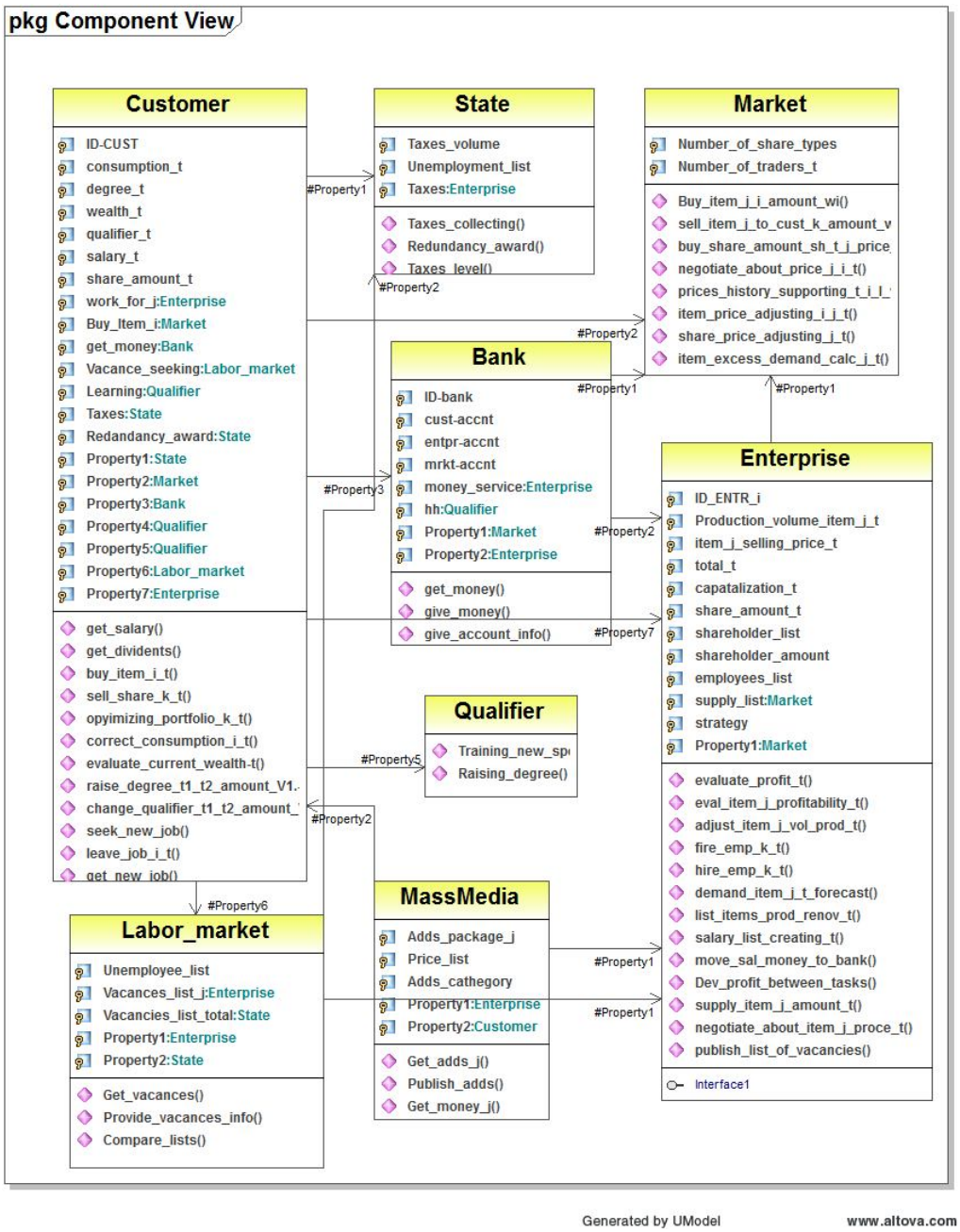

Fig. 1. Classes diagram

The key issues in designing adequate and effective model of economics are to understand and analyze the following interrelated phenomena:

- effect of demand on production level;
- possibility of increasing the volume of output depending on profit distribution strategy;
- dependence of model's macroeconomic indices on tax level and the enterprise investment strategy;
  - impact of the state's tax policy on macroeconomic indices;
  - dependence of the amount of working population on the enterprise's investment strategy, tax level and university fee.

While doing this research the authors considered changing composite demand of the economic agents to be the main driving force for economic development. We also believe that economic efficiency is mainly determined by the correspondence of actual output to the modifying consumer needs and demand.

Classes diagram of the model actors is presented in the figure 1:

- ENTERPRISE acts as a seller on the market, a client of the bank, a taxes provider and an employer.
- MARKET organizes goods exchange among enterprises and customers, matches the aggregate demand and aggregate supply and forms an equilibrium price on the base of bargaining;
- STATE collects taxes from the enterprises and pays redundancy relieves;
- BANK (FIRST_NAT_BANK) organizes money transactions among agents;
- LABOR_MARKET lists vacancies that enterprises possess and send messages about them to the job seekers;
- QUALIFIER is an educational institution that performs an employee's training and requalification for a definite fee;
- MASS MEDIA receives orders from the enterprises for an advertising campaign, then selects a random sample of customers with aim to increase the value of the subjective utility function of the advertised product.

3 Customer Behaviour

Customer h, h = 1,2, … H may be described by initial capital C_h and consuming profile F_{hi}. Customer may be also described by qualification and degree. Qualification Li is defined by kind of production he involved in. Assume that there are three levels of degree: degree1, degree2, degree3. Consuming profile has the next restrictions: consumed product cost must be less or equal than

$k_1 * B_h$, where B_h – income which includes salary, dividends and profits from stock market operations or redundancy relieves (for those who are unemployed).

Consumed products volume combination shouldn't be less than subsistence minimum level. Customer adjusts consuming level according to his profits. Different products/consuming level is defined by functions such as sine wave (seasonal fluctuation), large period sine wave (age fluctuation), almost constant function, exponential decreasing function, exponential increasing (popular) function, logical function.

Total consuming level of product i by all consumers during period T is:

$$Q_i = \sum_{t=1}^{T} \sum_{h=1}^{H} F_{hit} \le V_i \tag{1}$$

F_{hit} may be presented as a function or in a table view. Customer h consuming level is bounded by condition of his survival that can be defined as follows:

$$E_h = \sum_{t=1}^{T} \sum_{i=1}^{N} F_{hit} \cdot C_i \ge E^0 \tag{2}$$

where C_i – share of product i which is necessary for h customer survival.

If the customer is unemployed his profit during period t is defined by his state aid

$$B_{\text{hu}} = \sum_{t=1}^{T} B_{\text{hut}} \cdot \tag{3}$$

Current wealth is distributed the following way:

- Taxes make up γB_h, where γ - taxes rate, $0 \le \gamma \le 1$;
- Current expenses βBh , where β - $0 \le \beta \le 1$;
- Savings, aimed for requalification or education. Amount, remaining after taxes paying $(1-\gamma)B_h$. For current expenses $\beta(1-\gamma)B_h$. $C_{edu}=1-\beta(1-\gamma)B_h$ remains for education. Market basket cost of the customer h for period T is

$$\sigma_{\text{h}} = \sum_{t=1}^{T} \sum_{i=1}^{N} \varphi_{it} F_{hit} , \tag{4}$$

and shouldn't surpass βB_h, i.e. $\sigma_h \le \beta B_h$. If this condition is not satisfied the customer adjust his consumption the following way:

$$F_{hit+1} = F_{hit} + \alpha (\sigma_h - \beta B_h) , \tag{5}$$

and checking survival condition

$$E_h = \sum_{t=1}^{T} \sum_{i=1}^{N} F_{hit} \cdot C_i \ge E^0 . \tag{6}$$

If this condition is not satisfied during period T_{max} the customer leaves the model. In case when the customer is unemployed he can browse the vacancies list on the labor market. If he finds a vacancy of the enterprise j corresponding to his qualification in the list, he can conclude a contract with this enterprise,

and after that he will be included into the salary list. If he buys enterprise's shares he will also be included into the list of dividends obtaining. To improve his level of earning he may increase his degree (if it is not maximum) using qualifier's service and paying the necessary sum S_{edu} under condition that $C_{edu} \geq S_{edu}$. At the result his degree and his earning u_{hjt} will increase after some period of. If there is no qualification for him in the vacancies list he can get new qualification using qualifier's services under condition that $C_{edu} \geq S_{edu2}$, where S_{edu2} - services cost on degree increasing and getting new qualification.

The aim of each customer is to increase its quality of life. The quality of life in the model consists of wealth and value of utility function connected with a customer's individual consumption profile. To increase his quality of life a customer uses his believes. According to them he can improve his quality of life by the following actions:

- constant job seeking according to a customer's qualification and degree (including requalification);
- buying/selling shares on the stock market and getting the dividends;
- saving money on a bank account;
- becoming an enterprise owner by buying its controlling interest

So as there are only five kinds of products in the model the customer profile consists of relative consuming rate for each kind of product (figure 2).

Fig. 2. Customer's consumption profile

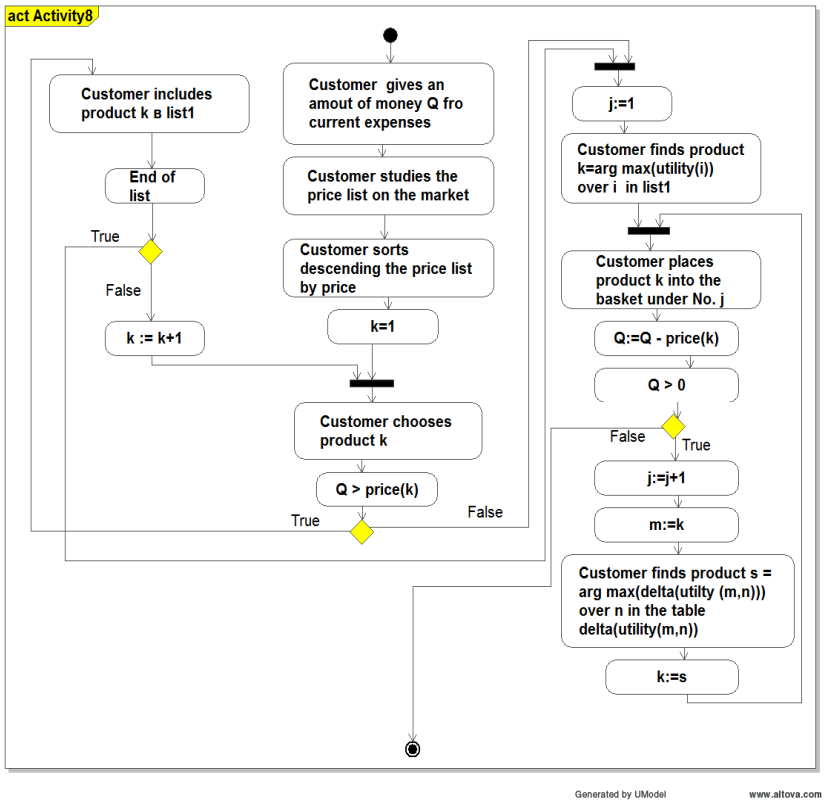

Fig. 3. Customer strategy

When a customer joins the market he uses his limited financial resources and the Douglas-Cobb utility function [7].

The algorithm of customer strategy is shown in the figure 3. First of all the customer makes up a list of products that he can afford to buy at a definite sum not depending whether he/she needs it or no. After that he sorts descending the price list by the value of utility function. The first product he buys is the one that is the most useful and then uses the matrix that shows the increment of utility function for each pair of sequentially bought products. Using this matrix the customer gets a product that gives the maximum increment of utility function at each time step and acts like that until he depletes the available financial resources.

According to Jonathan Silver [6] let us introduce a time dependant utility function. When a customer joins the market he uses his limited financial resources and the following utility function:

$$U_h(x_0, x_1, \ldots, x_n, t) = \prod_{i=0}^{n} x_i^{\alpha_{ih}(t)}(t) \tag{7}$$

where x_0 – amount of wealth possessed by a customer;

x_I – quantity of product i (in monetary terms);
t – time;
$\alpha_i > 0$, $\Sigma\, \alpha_i < 1$.

The time dependant character of the utility function shows, on the hand, that utility of a product bought on the previous time step drops dramatically for a customer. On the other hand, as the product is being worn out his utility rises. Utility of products produced by different enterprises also differs.

The algorithm of customer strategy is shown in the figure 3. First of all the customer makes up a list of products that he can afford to buy at a definite sum not depending whether he/she needs it or not. After that he sorts the price list in descending order by the value of utility function. The first product he buys is the one that is the most useful and then uses the matrix that shows the increment of utility function for each pair of sequentially bought products. Using this matrix the customer gets a product that gives the maximum increment of utility function at each time step and acts like that until he depletes the available financial resources.

4 Enterprise Investment Strategy

It is considered that the agent ENTERPRISE acts in perfect competition.

All the enterprises in the model produce the same types of goods. Some of them belong to the group of basic consumer goods (food, clothes), others are articles of secondary necessity (mobile phones) and others are luxury goods (automobiles, cottages) at each time horizon. In the model we use the Cobb-Douglas production function. The profit maximization problem is stated as follows:

$$V_{ijt}(z_1(t), z_2(t)) = p_0(t) z_1^{\beta} z_2^{1-\beta}, \tag{8}$$

where p_0 – price of produced goods;
p_i – price of resource i;
z_1 – labor force spent to produce a unit of output;
z_2 – capital spent to produce a unit of output, given that

$$p_1(t) \cdot z_1(t) + p_2(t) \cdot z_2(t) = M(t). \tag{9}$$

An enterprise is trying to find an optimal volume of output taking into account the balance between total income and total costs and to minimize the difference between the level of output and demand.

$$\left(V_{ijt}(z_1, z_2) - Q_i(t)\right)^2 = \varepsilon^2(z_1, z_2) \to \min \tag{10}$$

Task solution for finding the minimum with given limits on labor force and capital may be found using Lagrange function:

$$L(z_1, z_2) = (\varepsilon^2(z_1, z_2) - \lambda(M(t) - p_1(t) \cdot z_1(t) - p_2(t) \cdot z_2(t))) \tag{11}$$

$$\frac{\partial L}{\partial z_1} = 0;$$

$$\frac{\partial L}{\partial z_2} = 0;$$

$$\frac{\partial L}{\partial \lambda} = 0.$$

According to the expressions above an enterprise accomplishes its investment strategies in an effort to remove the mismatch between demand and supply on the market using some extra heuristics (figure 4). In the figure curves of changing demand and supply are shown.

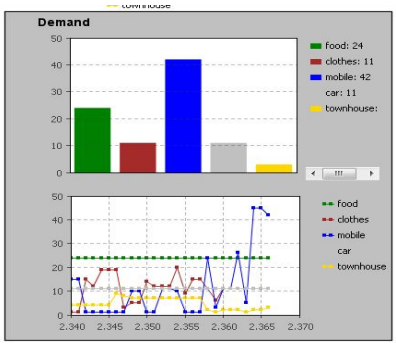

Fig. 4. Demand, supply and prices on the market

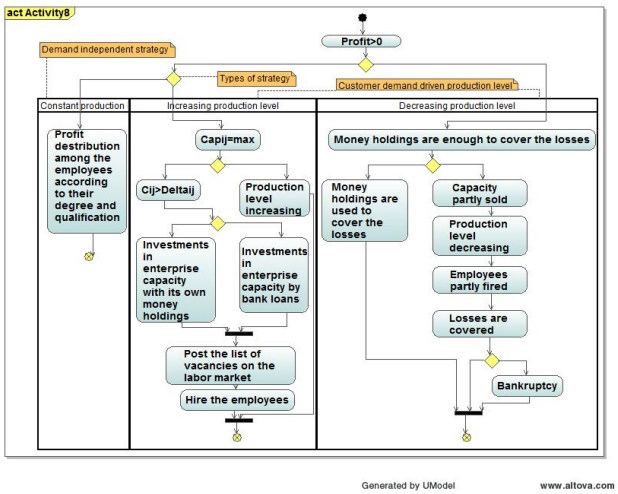

Fig. 5. Enterprise investment strategies

Enterprise investment strategy is presented in the figure 5 as an Altova UModel activity diagram. The customer driven enterprise strategy in the model is realized as follows. Three activity partitions display three types of enterprise strategies. The first one corresponds to the case when all profit obtained by an enterprise is divided among the employees according to their qualification and degree. The second one shows the case when an enterprise gets a positive profit and uses it to increase the production level according to the customers' demand. The third one describes the situation when an enterprise has a negative profit and it covers its losses by partly selling its capacity. If nevertheless the losses are not covered and the enterprise's capital becomes negative the enterprise is declared bankrupt and leaves the model.

5 Results

The model is implemented and simulated within the AnyLogic environment (http://www.xjtek.com/). The number of the model participants as well as enterprises is set before the model start up and may be modified in progress. The initial enterprise capacity is preset in a random way and its output depends on demand later on as described above. It is calculated according to the production strategy of an enterprise and the demand for each product which is defined by incoming consumer requests for a particular product that are registered by an enterprise and put in a line on a FIFO discipline. The initial enterprises' capital is distributed in a random manner according to Pareto distribution and the initial consumer's wealth is set according to random uniform distribution.

As stated above, a customer profile consists of the relative rate of consumption for each kind of products presented in the model (food, clothes, mobile phone, car, townhouse, and savings). A customer may be in one of four possible states: employed, unemployed, student, dead.

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