A study on virtual market model for e-Marketplace server
Toshiya Kaihara*

Abstract

Internet procurement is now in progress and is regarded as an information infrastructure for global business. As the number and diversity of EC (electronic commerce) participants grows at the agile environment, the complexity of purchasing from a vast and dynamic array of goods and services needs to be hidden from the end user. Putting the complexity into the EC system instead means providing flexible auction server for enabling commerce within different business units. Market mechanism could solve the product distribution problem in the auction server by allocating the scheduled resources according to market prices. In this paper, we propose an e-Marketplace server for B2B EC with multi-agent paradigm, named market-oriented programming, that mediates amongst unspecified various companies in the trade, and demonstrate the applicability of the economic analysis to this framework. The proposed server facilitates a sophisticated e-Marketplace, which conducts a Pareto optimal solution for all the participating business units, in the coming agile era.

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1. Introduction

Internet procurement is now in progress and is regarded as an information infrastructure for global business management in virtual enterprise (VE) environment [1–3]. As the number and diversity of electronic commerce (EC) participants grows under the agile conditions in VE, the complexity of purchasing from a vast and dynamic array of goods and services needs to be hidden from the end user. Putting the complexity into the EC system instead means providing a flexible auction server for enabling commerce within different business units. Market mechanism could solve the product distribution problem in the auction server by allocating the scheduled resources according to market prices.

Solving product distribution problem in the e-Marketplace for B2B EC presents particular challenges attributable to the distributed nature of the computation. Each business unit in EC represents independent entities with conflicting and competing product requirements and may possess localised information relevant to their interests. To recognise this independence, we treat the business units as agents, ascribing each of them to autonomy to decide how to deploy resources under their control in service of their interests.

Assuming that a product distribution problem in
e-Marketplace transactions must be decentralised, markets can provide several advantages as follows:

(i) Markets are naturally distributed and agents make their own decisions about how to bid based on the prices and their own utilities of the goods.
(ii) Communication is limited to the exchange of bids and process between agents and the market mechanism.

In market-oriented programming we take the metaphor of an economy computing a multi agent behaviour literally, and directly implement the distributed computation as a market price system. In this paper, we propose an auction server for the e-Marketplace with the market-oriented programming that mediates amongst unspecified various companies in the trade, and demonstrate the applicability of the economic analysis to this framework. The proposed server facilitates a sophisticated e-Marketplace, which conducts a Pareto optimal solution for all the participating business units, in the coming agile age.

2. Virtual market

2.1. Basic concept

Agent activities in terms of products required and supplied are defined so as to reduce an agent’s decision problem to evaluate the tradeoffs of acquiring different products in market-oriented programming. These tradeoffs are represented in terms of market prices, which define common scale of value across the various products [4,5].

In this paper the framework of general equilibrium theory [6], which is proposed in microeconomics research field, has been adopted. In economics, the concept of a set of interrelated goods in balance is called general equilibrium. The general equilibrium theory guarantees a Pareto optimal solution at competitive equilibrium in perfect competitive market. The connection between computation and general equilibrium is not all foreign to economists, who often appeal to the metaphor of market systems computing the activities of the agents involved.

Some apply the concept more directly, employing computable general-equilibrium models to analyse the effects of policy options on a given economic system [7]. Since EC constructs a virtual market in cyber space, market-oriented programming is obviously well-structured for EC economic model.

2.2. Market-oriented programming

In market-oriented programming we take the metaphor of an economy computing a multi agent behaviour literally, and directly implement the distributed computation as a market price system [8,9]. Suppose \( P_t(s) \) is the price of product \( s \) in time \( t \), \( f_{ms} \) is the supply function in supply agent \( m \) for product \( s \) in time \( t \), and \( g_{ns} \) is the demand function in demand agent \( n \) for product \( s \) in time \( t \), shown in Fig. 1. The algorithm of the proposed market-oriented programming for EC is shown as follows:

**Step 1.** A supply agent \( m \) sends bids to the market to indicate its willingness to sell the product \( s \) according to its current price \( P_t(s) \) in time \( t \). The supply agent willingness is defined as a supply function in the bid message. The agent can send bids to the market within the limits of its current inventory level.

**Step 2.** A demand agent \( n \) sends bids to markets to indicate its willingness to buy the product \( s \) according to its current price \( P_t(s) \) in time \( t \). The demand agent willingness is defined as a demand function in the bid message. The agent can send bids to the

![Fig. 1. Market-oriented programming.](image-url)
market within the limits of its domestic budget. Each product has its own market, and they construct a competitive market mechanism as a whole.

**Step 3.** The market in product \( s \) sums up demand functions \((\sum f_{mis})\) and supply functions \((\sum g_{mis})\), then revises balanced price \( Pt'(s) \) of product \( s \) in time \( t \). All the market must revise their balanced price via the same process.

**Step 4.** Check the balanced prices of all the products and if all the prices are converged, the acquired set of the prices is regarded as equilibrium price, then go to Step 5. If not, go to Step 1.

**Step 5.** If dealing time is up, then stop. And if not, \( t = t + 1 \) and go to Step 1.

There exist the following subjects to build up an appropriate Marketplace model with the market-oriented programming concept:

(i) Definitions of supply and demand functions in the agents.

(ii) Budget constraint in the agents.

We try to clarify these subjects in the next section.

### 3. Agent definitions

#### 3.1. Supply agent

Suppose supply agent \( i \) has production function \( H_i \), which defines manufacturing efficiency from input resources \( X_i \) to products \( Y_i \):

\[
Y_i = H_i(X_i)
\]

where

\[
X_i = \{x_{i1}, x_{i2}, x_{is}\}
\]

\[
Y_i = \{y_{i1}, y_{i2}, y_{is}\}
\]

In this paper we adopt a basic Cobb–Douglas function as the production function described in the following equation:

\[
y = ax^b \quad \text{(where } 0 < a, 0 < b < 1) \]

It is well known that Cobb–Douglas function handles economical scale in market by index constant \( b \), and in case of \( 0 < b < 1 \) the production function is defined as a convex function, in other words, a diminishing returns function. In case production function is defined as convex type, market prices are established at a predictable level in the general equilibrium theory.

Finally production function \( h_{is} \) of agent \( i \) for product \( s \) is given by:

\[
y_{is} = h_{is}(x_{is}) = a_{is}x_{is}^b \]

Suppose the single unit cost of \( x_{is} \) is \( p_{0is} \) and the single unit sale of \( y_{is} \) is \( p_{is} \), then the profits \( E_{is} \) of agent \( i \) for product \( s \) is defined as Eq. (6):

\[
E_{is} = p_{is}y_{is} - p_{0is}x_{is} = p_{is}y_{is} - p_{0is}(y_{is}/a_{is})^{1/b_{is}} \quad (6)
\]

Supply agent utility in the dealing is motivated to earn maximum profit and supply function is conducted from iso-profit curve with maximum return. Finally supply function \( f_{is} \) with maximum profit is given as follows:

\[
\max E_{is} = \frac{\partial E_{is}}{\partial y_{is}}
\]

\[
= p_{is} - (p_{0is}/b_{is})(y_{is}/a_{is})^{(1-b_{is})/b_{is}} = 0 \quad (7)
\]

then \( y_{is} = f_{is}(p_{is}) = a_{is}(b_{is}p_{is}/p_{0is})^{b_{is}/(1-b_{is})} \) where \( 0 < a_{is}, 0 < b_{is} < 1 \)

#### 3.2. Demand agent

Suppose demand agent \( i \) has demand function \( G_i \), which defines its demanding amounts \( Z_i \) of the target products, then we have:

\[
Z_i = G_i(P_i)
\]

where:

\[
P_i = \{p_{i1}, p_{i2}, p_{is}\} \quad (9)
\]

\[
Z_i = \{z_{i1}, z_{i2}, z_{is}\} \quad (10)
\]

In this paper we adopt a power function as the demand function described in the following equation:
Because index constraint $d_i$ in demand functions (Eq. (13)) represents price elasticity, which is unique to product $s$ and should be fixed, a coefficient $c_{is}$ is revised by applying the rule given by Eq. (15) in the proposed strategy:

$$g_i(p_{is}^-) = \begin{cases} 
  c_{is}P_{is}^{-d_i} & (B_i \geq \sum_{s=1}^{S} z_{0is}p_{0is}) \\
  c'_{is}P_{is}^{-d_i} & (B_i < \sum_{s=1}^{S} z_{0is}p_{0is}) 
\end{cases}$$  (15)

Utility of agent $i$ for each product is standardised proportionally into the value between 0 to 1 by $z_{0is}p_{0is}/\sum_{s=1}^{S} z_{0is}p_{0is}$, and the budget for product $s$ is defined as $B(z_{0is}p_{0is}/\sum_{s=1}^{S} z_{0is}p_{0is})$ in Eq. (16). Since demand and budget relationship is given by Eq. (16), the newly revised coefficient $c'_{is}$ is finally attained by Eq. (17):

$$B_i \left[ z_{0is}P_{0is}/\sum_{s=1}^{S} z_{0is}p_{0is} \right] = c'_{is}P_{0is}^{-d_i}P_{0is}$$  (16)

$$c'_{is} = B_i \left[ z_{0is}/\left( \sum_{s=1}^{S} z_{0is}p_{0is} \right) \right]^{1/d_i}$$  (17)

4. Market dynamism

4.1. Experimental e-Marketplace model

The experimental e-Marketplace model based on computational market is constructed so as to analyse qualitative characteristics of the proposed approach by simulation. The followings are the default experimental parameters in the basic e-Marketplace model:

Supply and demand agents
Product types 3 (A,B,C)
Interval time of product supply 1 (day)
Lot size of supplied products from supply agents A: 100, B: 100, C: 200
Required product size in demand agents A: 100, B: 150, C: 200
Price elasticity of products 1.0

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3.4. Utility proportional strategy in budget constraint

In market-oriented program each agent is regarded as a price taker. They assume product costs never be affected by their bidding activities during a dealing. Therefore once they detect product prices were altered after their bid, it is necessary for them to modify their bidding functions according to their strategy in order to find a Pareto optimal solution shown in the previous section.

We propose utility proportional strategy in demand agents as the modification mechanism. In utility proportional strategy demand agents are assumed to have rigid intention and hold a fixed proportional utilities about all the demanding products during a dealing time period $t$ under their budget constraint.
Value of constants in production function
- $a = 1, b = 1/2$
- Initial value of constants in demand function
- $c_0 = 1, d = 1$
- The number of simulation trails
- 100

* Followed by uniform distribution in the interval $\pm 20\%$.

Three types of products {A, B, C} are defined. Product A and C symbolise small lot size product and large lot size product, respectively. We assume that the utility of supply agent/the price elasticity of demand agent is equivalent in all the products as a basic study.

4.2. Basic dealing dynamics

Experimental results on the number of demand/supply products at a demand agent are shown in Fig. 2. Small figures indicate the acquired equilibrium price of each product at daily dealing processes in Fig. 2. The daily difference of equilibrium prices, which were acquired as a Pareto optimal solution led by general equilibrium theory, are within 3% and it is obvious that dealing process in computational market is settled under budget-constraint free environment. It has been confirmed that the converged values of trading in each product differ and depend on the supply and demand balance.

4.3. Supply and demand balance

Fig. 3 demonstrates the relationship between supply/demand ratio and equilibrium price in product A. In this figure the horizontal axis is supply/demand ratio, and ratio: 1.0 means the number of supplied products is completely equivalent to the number of demanded ones. The vertical axis represents non-dimensional equilibrium price, which is divided by the price acquired at (supply/demand ratio) = 1.0.

As the supply/demand ratio increases, equilibrium price decreases. They are in negative correlation, and the experimental values agree well with the theoretical trends of general equilibrium in microeconomics. This result indicates the proposed market-oriented approach successfully constructs a perfect
approach agree well with the theoretical trends of general equilibrium in microeconomics.

Our implementation and experiments successfully demonstrated that the proposed market-oriented approach constructs a perfect competitive market in product distribution problem in the e-Marketplace. A Pareto optimal solution, which is endorsed by general equilibrium theory in competitive market, was acquired in product distribution problem by the metaphor of an economy in multi agent society.

It was quite difficult to implement some distribution algorithm into large-scaled complex EC in conventional approach. Our approach is completely distributed and a Pareto optimal solution is attainable only by defining the supply/demand functions into competitive market in product distribution problem each business units, because market mechanism equips dealing protocol by nature. Our approach has been proved to be practical and capable of robustness and reliability coping with the several demands in the e-Marketplace.

4.4. Budget constraint and equilibrium price

The relationship between budget constraint and acquired equilibrium price is shown in Fig. 4. Needless to say, agent strategy under budget constraint is followed by the newly proposed utility proportional strategy, which was described in the previous chapter.

In this figure the horizontal axis represents non-dimensional budget ratio, which is divided by the perfect balanced budget. The vertical axis represents non-dimensional equilibrium price, which is divided by the price acquired at budget ratio $= 1.0$.

They are in positive correlation, and the experimental values agree well with the qualitative trends of general equilibrium theory as well. In general price of goods increases under the condition of plenty of budget in demand agents, because the economy in the competitive market is getting inflated. On the other hand, equilibrium price decreases under deflated economy caused by the shortage of budget in demand agents.

5. Discussion

Several characteristics, which are well-known in economics, of the proposed approach were qualitatively analysed by simulation experiments. Simulation results have proved that all the natures of our approach agree well with the theoretical trends of general equilibrium in microeconomics.

6. e-Marketplace server

6.1. Structure

We developed a prototype e-Marketplace server shown in Fig. 5. The server consists of (i) web server, (ii) relational database, (iii) virtual market model.

![Diagram of e-Marketplace server](Fig. 5. e-Marketplace server.)
Web server: Microsoft Peer Web Server (PWS)
Server side script: Microsoft Active Server Pages (ASP)
Relational database: Microsoft ACCESS 98
Virtual market model: Microsoft Visual C++
ADO: ActiveX Data Object
ODBC: Open Database Connectivity

6.2. Transaction flow

Product suppliers and demanders will access the e-Marketplace server via an Internet Browser. Transaction flow is as follows:

Step 1. All the suppliers and demanders create user accounts and register their personal information on the e-Marketplace server.

Step 2. Suppliers input their products with their preferable price and quantity.

Step 3. Demanders input their preferable price and quantity on the products to buy.

Step 4. Virtual market collects all the bids over a specified interval of time, then clear the market by computing a Pareto optimal solution at the expiration on the bidding interval.

Step 5. All the suppliers and demanders input their final decision on the proposed trade by the virtual market.

Step 6. Final trade is announced to all the participants.

To define supply/demand function shown in Eqs. (7)–(13), only \( a/s \) needs to be acquired, because \( b/s \) is unique to product \( s \) and it is attainable previously by the practical observation. When all the suppliers/buyers input both the amount and the price only for each product they want to sell/buy, then \( a/s \) is automatically calculated by Eqs. (7)–(13), and that means supply/demand function is defined inevitably in the system.

A snap shot of the trading proposal window is shown in Fig. 6, as an example.

We validated the efficiency of the proposed e-Marketplace server with the prototype system. The virtual market implemented in the server successfully produced reasonable clearing on multiple bids with several business units.

7. Conclusions

In this paper, we propose an auction server for the e-Marketplace with the market-oriented programming that mediates amongst unspecified various companies in the trade, and demonstrate the applicability of the economic analysis to this framework.

Simulation results have proved that all the natures of our market-oriented programming based approach perfectly agree with the theoretical trends of general equilibrium in microeconomics. Our approach is completely distributed and a Pareto optimal solution is attainable only by defining the supply/demand functions into each business units, because market mechanism equips dealing protocol by nature. The proposed server facilitates a sophisticated e-Marketplace, which conducts a Pareto optimal solution for all the participating business units, in the coming agile VE era.

There are two obvious extensions. The first is to elaborate the negotiation protocol, possibly by ex-
ploiting several types of elaborated production functions. The second extension is to introduce bounded rationality into the agent. This extension makes the proposed model more practical and flexible in its implementation to a real e-Marketplace system.

References