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Information Value and Interregional Input-Output Structure

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Abstract: This paper establishes an economic theory of information value and volume that differs from Shannon's mathematical theory of communication (Shannon, 1948). The economics of information should be recognized as an important frontier field of economics to explore the 4th industrial revolution including Internet of the things (IoT) and artificial intelligence (AI). However, we need to construct an fundamental way to analyse information flow and stock. Because of this, the value of information goods as a non-market or market good is measured as agents' willingness to pay (WTP) for travel and telecommunication from the overall viewpoint of transportation and telecommunication economics. And we construct an economic model for analysing the information flow between head and branch offices. This firms' total profit is maximised by optimally imputing the amount of time which employees devote to collecting and processing internal and external information. Here, factors of production are internal and external information flows and stock information. Finally we propose information input-output table explaining inter-regional information flow of the sample economic model.

JEL: D210, J290, L630 L960, R15, R41

Keywords: value of information; information flow; willingness to pay; value of time;
face-to-face communication; telecommunication
information input-output table; head office; branch offices
Firm behaviour; Spatial economic model

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1. Introduction

This paper constructs an economic theory of information value and volume that considers information input–output structures between business regions from the overall viewpoint of transportation and telecommunication economics. We examine an economic model of head and branch offices to determine the amount of time allocated to processing and communicating internal and external information depending on the value of information and stock.

The economics of information should be recognized as an important frontier field of economics. It is important for economists to explore information revolution including Internet of the Things (IoT) and artificial intelligence (AI). The new economic theory of information and these analytical frameworks is applied to our future advanced information society. This study's contributions are as follows. First, it proposes an economic measure of the value of information that differs from Shannon's mathematical theory of communication (Shannon, 1948). Second, it defines the value of general information—a non-market good—as agents' willingness to pay (WTP) for travel and telecommunication to acquire such information. Third, the firm's desire to maximise profits enables us to examine how time is allocated to meet the demand for internal and external information. Fourth, it describes the production function as a function of information communication and processing. Finally, after solving issues related to the demand for information, an information input–output table can be obtained.

Sociologist Daniel Bell (1973) famously coined the term 'post-industrial society' and emphasised the role of scientific and technical knowledge in information-based economies. Machlup (1962) and Porat (1977), pioneers in economic information analysis, classified information industries and other industries and studied how these industries contribute to the gross domestic product (GDP) using input–output analysis. Other research followed these pioneers, including OECD (1980), Jonscher (1983) and Ohira and Hiromatsu (1990). Studies in economic geography since the 1960s have principally examined firms in London (United Kingdom) and in Stockholm (Sweden) and discussed various problems including traffic congestion, air pollution and housing. Economic geographers have explored the role of information in urban economies. Wood (1969) recognised the importance of information linkages between firms and commodity linkages. Törnqvist (1970) empirically explained face-to-face and less direct forms of communication between head and branch offices and between offices and production facilities. Goddard (1973) measured information flow between firms in London's central business district (CBD) by dividing its centre into 500-metre grids. Pye (1977) studied office location cost, including telecommunication and transportation costs. Takita and Suda (1992) and Takita (1994, 1996) modelled information flows of face-to-face communication and telecommunication. In 1993, the Clinton Administration presented the Information Superhighway Project, and the Internet became acknowledged as a major conduit of information worldwide. Mun (1993) presented an urban business office location model that considered communication activities. Ota and Fujita (1993) and Sasaki (1993) analysed the effects of information technology on urban spatial structure. Takita (1997, 1999) proposed a new system for information flow analysis that integrates transportation and telecommunication as a comprehensive approach to information flow. Kobayashi and Fukuyama (1998) analysed human contacts in a knowledge society. Many

countries accelerated construction of an advanced information society. Overall, information is currently recognised as a significant managerial resource alongside people, goods and money. Myao and Ukhaneva (2017) extends the focus of traditional demand studies to incorporate both mobile and VoIP calling. Pantea (2017) analyses that ICT is displacing workers of seven European countries in the short run.

2. Definition and Production of Information

We define the volume and value of information as a function of the preferences of the business agents who request the information. Shannon's mathematical theory of communication (Shannon, 1948) proposes information entropy as a measure of uncertainty in a message. This paper posits a new concept of measuring information as a way to evaluate an organisational communication network and an information economy.

Baker (1965) and DeSerpa (1971) study the economic theory of time, and DeSerpa (1973) examined the value of travel time. Many transportation researchers measure the value of travel time in the contexts of business, sight-seeing, leisure and recreation (for examples, Gonzales (1997) and Jara-Diaz (2007)). Generally, their studies employ willingness to pay (WTP) to save travel time as their measure of the value of investment in transportation. This study measures the value of information according to agents' WTP for travel and communication to obtain information. Though personal information is a non-market good, it often has high value. We create an analytical method for constructing economic models of information.

2.1 Volume of Information

Volume of information is defined as a function of face-to-face communication time (F) and telecommunication time (T). For near future, the 4th and 5th information revolutions including Internet of the Things (IoT) and artificial intelligence (AI) and additional information technologies are related to information productivity of telecommunication a_T compared to that of physical communication or face-to-face communication a_F .

$$I^f = I^f(F, T) = ((a_F F)^\rho + (a_T T)^\rho)^{\frac{1}{\rho}}. \quad (1)$$

where a_F and a_T ¹ denote the impact of face-to-face communication and telecommunication on volume of information. From information function (1), information volume is measured by face-to-face communication time ($I = a_F F$) when telecommunication can be neglected ($a_T(t) = 0$ for $t = 0$). Parameter ρ is the value of

¹Parameter $a_T = a_T(t)$ ($0 \leq a_T(t) \leq a_F$) gradually increases from $a_T = 0$ to $a_T = a_F$. The value of $a_T(t)$ describes the degree of technological progress of telecommunication at present time t . Parameter a_F does not change over time. However, AI chess players win real professional player.

the constant elasticity of substitution (CES). The elasticity of substitution $[\sigma = \frac{\rho}{\rho-1} (1 > \rho \neq 0)]$ between face-to-face communication $F (> 0)$ and telecommunication $T (> 0)$ is the factor ratio F/T corresponding to a 1% change in the marginal rate of substitution. We assume that the function of information flow is homogeneous of degree one.

The CES function (1) of information flow includes three cases:

Leontief function: $\lim_{\rho \rightarrow -\infty} I^f = \lim_{\rho \rightarrow -\infty} ((a_F F)^\rho + (a_T T)^\rho)^{1/\rho} = \min_{F,T} [F/a_F, T/a_T].$

Cobb–Douglas function: $\lim_{\rho \rightarrow 0} I^f = \lim_{\rho \rightarrow 0} ((a_F F)^\rho + (a_T T)^\rho)^{1/\rho} = F^{a_F} T^{a_T}.$

Linear function: $\lim_{\rho \rightarrow -1} I^f = \lim_{\rho \rightarrow -1} ((a_F F)^\rho + (a_T T)^\rho)^{1/\rho} = a_F F + a_T T.$

2.2 Optimal Combination of Face-to-face and Telecommunication

In the cases of accessing an informational source via face-to-face and telecommunication, we consider the minimisation of the total cost of both mediums.

$$\min C_I^f = \omega_F F + \omega_T T \quad (2)$$

$$\text{s. t. } ((a_F F)^\rho + (a_T T)^\rho)^{1/\rho} = I^f, \quad (3)$$

where I^f denotes volume of information and ω_F and ω_T are the individual generalised costs of face-to-face communication and telecommunication, respectively, considering the financial costs of travel, telecommunication and time.

From Equations (2) and (3), the Lagrange function Ψ is expressed as

$$\text{Minimise } \Psi = \omega_F F + \omega_T T + \lambda (I^f - ((a_F F)^\rho + (a_T T)^\rho)^{1/\rho}),$$

where λ is a Lagrange multiplier.

First-order conditions for this total cost minimisation problem are as follows:

$$\frac{\partial \Psi}{\partial F} = \omega_F - \lambda \left(\rho a_F^\rho F^{\rho-1} \left(\frac{1}{\rho} \right) ((a_F F)^\rho + (a_T T)^\rho)^{\frac{1}{\rho}-1} \right) = 0. \quad (4)$$

$$\frac{\partial \Psi}{\partial T} = \omega_T - \lambda \left(\rho a_T^\rho T^{\rho-1} \left(\frac{1}{\rho} \right) ((a_F F)^\rho + (a_T T)^\rho)^{\frac{1}{\rho}-1} \right) = 0. \quad (5)$$

$$\frac{\partial \Psi}{\partial \lambda} = I^f - ((a_F F)^\rho + (a_T T)^\rho)^{\frac{1}{\rho}} = 0. \quad (6)$$

From a system of nonlinear simultaneous Equations (4)–(6), we obtain Equations (7) and (8).

$$\lambda = \frac{\omega_F}{a_F^\rho F^{\rho-1} ((a_F F)^\rho + (a_T T)^\rho)^{\frac{1}{\rho}-1}} = \frac{\omega_T}{a_T^\rho T^{\rho-1} ((a_F F)^\rho + (a_T T)^\rho)^{\frac{1}{\rho}-1}}. \quad (7)$$

$$I^f - ((a_F F)^\rho + (a_T T)^\rho)^{\frac{1}{\rho}} = 0. \quad (8)$$

2.3 Conditional Demand Functions of Face-to-face Communication and Telecommunication

Solving (7) and (8), the conditional demand functions of face-to-face communication and telecommunication are presented as

$$F^*(\omega_F, \omega_T; I^f) = \frac{\omega_F^{\sigma-1}}{a_F^\sigma} \left(\left(\frac{\omega_F}{a_F} \right)^\sigma + \left(\frac{\omega_T}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I^f. \quad (9)$$

$$T^*(\omega_F, \omega_T; I^f) = \frac{\omega_T^{\sigma-1}}{a_T^\sigma} \left(\left(\frac{\omega_F}{a_F} \right)^\sigma + \left(\frac{\omega_T}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I^f. \quad (10)$$

The ratio of telecommunication to face-to-face communication T^*/F^* changes depending on the two ratios of cost and technological progress $\left(\frac{\omega_T}{\omega_F} \right)^{\sigma-1} / \left(\frac{a_T}{a_F} \right)^\sigma$.

The Lagrange multiplier, or shadow price of information, is

$$\begin{aligned} \lambda(\omega_F, \omega_T) &= \frac{\omega_F}{a_F^\rho \left(\frac{\omega_F^{\frac{\rho}{\rho-1}}}{a_F^{\frac{\rho}{\rho-1}}} \left(\left(\frac{\omega_F}{a_F} \right)^\sigma + \left(\frac{\omega_T}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} (I^f) \right)^{\rho-1} ((I^f)^\rho)^{\frac{1}{\rho}-1}} \\ &= \frac{1}{\left(\frac{a_F^\rho}{\omega_F} \right) \left(\frac{\omega_F^{\rho-(\rho-1)/(\rho-1)}}{a_F^{\rho/\rho-1}} \right)^{\rho-1} \left(\left(\frac{\omega_F}{a_F} \right)^\sigma + \left(\frac{\omega_T}{a_T} \right)^\sigma \right)^{-\frac{\rho-1}{\rho}}} = \left(\left(\frac{\omega_F}{a_F} \right)^\sigma + \left(\frac{\omega_T}{a_T} \right)^\sigma \right)^{\frac{1}{\sigma}}. \end{aligned}$$

2.4 Value of Information

We define the value of general information, which is not distributed as a market good, as agents' WTP for accessing information face-to-face and via telecommunication. From Equations (9) and (10), the value function of information is expressed as

$$V_I^f = \omega_F F^* + \omega_T T^* = v_F^f(\omega_F, \omega_T) I^f + v_T^f(\omega_F, \omega_T) I^f = v_I^f(\omega_F, \omega_T) I^f. \quad (11)$$

Unit values of face-to-face communication and telecommunication are defined as two types of marginal willingness to pay (MWTP) for each: $v_F^f(\omega_F, \omega_T) \equiv \frac{\omega_F^\sigma}{a_F^\sigma} \left(\left(\frac{\omega_F}{a_F} \right)^\sigma + \left(\frac{\omega_T}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}}$ and $v_T^f(\omega_F, \omega_T) \equiv \frac{\omega_T^\sigma}{a_T^\sigma} \left(\left(\frac{\omega_F}{a_F} \right)^\sigma + \left(\frac{\omega_T}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}}$. The unit value of information $v_I^f(\omega_F, \omega_T) \equiv \left(\left(\frac{\omega_F}{a_F} \right)^\sigma + \left(\frac{\omega_T}{a_T} \right)^\sigma \right)^{\frac{1}{\sigma}}$ can be interpreted as agents' MWTP for communicated information.

2.5 Value Ratio of Face-to-face Communication and Telecommunication to Information

The equation $v_F^f(\omega_F, \omega_T) + v_T^f(\omega_F, \omega_T) = v_I^f(\omega_F, \omega_T)$ is derived from Equation (11). The value ratio of face-to-face communication and telecommunication to information $\tau_F(\omega_F, \omega_T)$ and $\tau_T(\omega_F, \omega_T)$ is explained as

$$\tau_F(\omega_F, \omega_T) \equiv \frac{v_F^f(\omega_F, \omega_T)}{v_I^f(\omega_F, \omega_T)} = \frac{\left(\frac{\omega_F}{a_F} \right)^\sigma}{\left(\frac{\omega_F}{a_F} \right)^\sigma + \left(\frac{\omega_T}{a_T} \right)^\sigma} = \frac{1}{1 + \left(\frac{\omega_T/a_T}{\omega_F/a_F} \right)^\sigma}.$$

$$\tau_T(\omega_F, \omega_T) \equiv \frac{v_T^f(\omega_F, \omega_T)}{v_I^f(\omega_F, \omega_T)} = \frac{v_T^f}{v_I^f} = \frac{\left(\frac{\omega_T}{a_T}\right)^\sigma}{\left(\frac{\omega_F}{a_F}\right)^\sigma + \left(\frac{\omega_T}{a_T}\right)^\sigma} = \frac{\left(\frac{\omega_T/\omega_F}{a_T/a_F}\right)^\sigma}{1 + \left(\frac{\omega_T/\omega_F}{a_T/a_F}\right)^\sigma}.$$

3. Model

The economic model presented in Section 3 addresses the firm's allocation of working time to internal and external informational activities. A framework is proposed for discussing the value and volume of information as a non-market good.

3.1 Assumptions

This section presents the behavioural assumptions governing this model.

- (1) The enterprise has one head office and several branches. The head office is senior in the hierarchy, and the branches are subordinate. All branches are equally efficient.
- (2) The head office and some branch offices occupy two-dimensional space.
- (3) Office activities comprise the routine processing of stock information and the internal and external dissemination of information. These three informational activities determine the volume of sales products.
- (4) The head office and all branch offices produce the same product and sell it at the same price.
- (5) Internal informational transfers occur between the head and branch offices but not between branches. Individual offices pay for travel, telecommunication and labour. They consider labour cost when providing information to other offices.
- (6) External communication by the head office includes high-level contracts with top executives and other firms. External communication by branch offices includes business contracts with regional firms or consumers. Individual branches bear the costs of travel, telecommunication and labour.
- (7) Information is collected face-to-face and via telecommunication.
- (8) The enterprise maximises the total profits of its head office and branches.

3.2 Information Structure of A Single Head Office and Branch Offices

This section examines the two-tiered communication between a head office and branch offices. Figure 1 illustrates the informational activities of both.

(1) Head Office

The head office collects *internal information* regarding sales, markets and management from branch offices and *external information* about national projects and sales from the central government and head offices of other enterprises. Head offices of major Japanese enterprises are generally concentrated in the central Tokyo Metropolitan Area, known as Marunouchi. Economies of urban agglomeration arise from face-to-face communication in central business districts (CBDs). Advanced information

communication technology has multiplied the variety of information communicated externally via the Internet. External communication includes business-to-business and business-to-consumer formats. Information is communicated in two ways: *face-to-face* and *via telecommunication*. Further, the head office performs *routine tasks* in each office such as processing stock information for business planning and market analysis. Computers and software aid in processing information and communicating internally and externally via the Internet.

(2) Branch Office

Through face-to-face communication and via telecommunication, each branch office collects internal information regarding previous products, market strategies and business management from the head office and external information concerning public projects, sales of rival companies, trade from other enterprises and local government. Processing information for marketing strategies and business planning is a routine task for branch

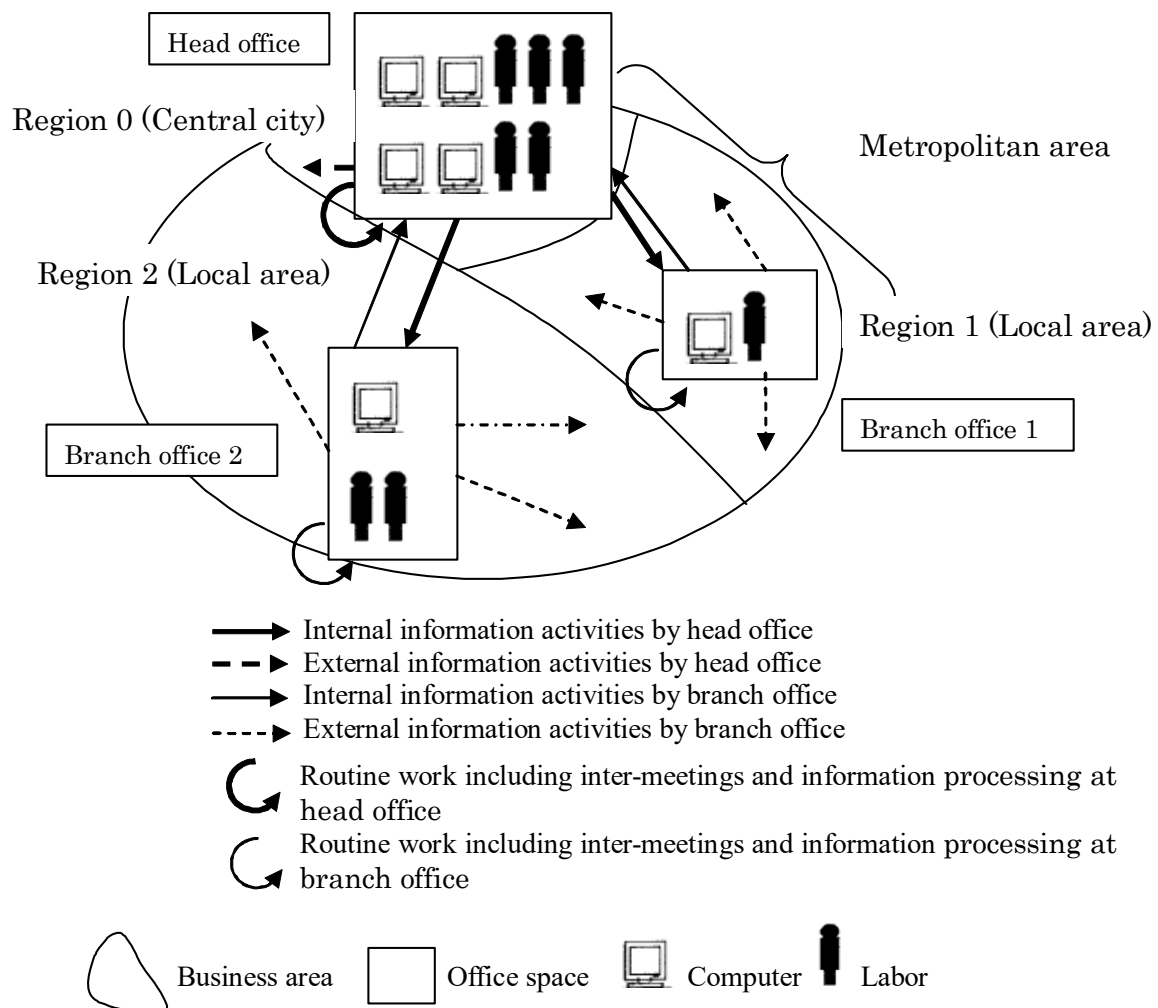


Figure 1: Information Structure of Headquarters and Branch Offices between Regions

Note: Face-to-face communication and telecommunication are used in information activities

office employees. Branch office computers assist these routine information processing operations by sending or receiving messages and files via E-mail. If consumers send personal and contract information through the WWW site, business offices use computers to confirm their orders. Thus, telecommunication partially substitutes for travel and face-to-face communication.

3.3 Information as Factors of Production

From the information structure of head and branch offices between regions (Figure 1), information matrices indicate stock information processing inside offices and internal and external information flow between head and branch offices. In this model, information is a valuable factor of production, albeit a non-market good.

(1) Internal information

(a) Information stock

Internal information stock matrix $\mathbf{I}_{Internal}^s = \left(\begin{array}{c|ccc} I_0^s & 0 & \cdots & 0 \\ \hline 0 & I_1^s & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & I_J^s \end{array} \right)$ within the head office and

J branch offices express how routine tasks for accessing stock information (I_j^s) include information processing and inter-meetings at the head or branch offices in region j .

(b) Information flow

Internal information is disseminated to head office 0 ($I_{10}^f, \dots, I_{J0}^f$) from branches in regions J ($1, \dots, J$) via face-to-face communication (F_{10}, \dots, F_{J0}) and telecommunication (T_{10}, \dots, T_{J0}). Another internal information is disseminated to branch office j ($I_{01}^f, \dots, I_{0J}^f$) from face-to-face communication at the head office in region 0 (F_{01}, \dots, F_{0J}) and via telecommunication (T_{01}, \dots, T_{0J}).

The internal information flow matrix between the head office and J branch offices

$\mathbf{I}_{Internal}^f = \left(\begin{array}{c|ccc} 0 & I_{01}^f & \cdots & I_{0J}^f \\ \hline I_{10}^f & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ I_{J0}^f & 0 & \cdots & 0 \end{array} \right)$ is decided by face-to-face communication and

telecommunication $\mathbf{F}_{Internal} = \left(\begin{array}{c|ccc} 0 & F_{01} & \cdots & F_{0J} \\ \hline F_{10} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ F_{J0} & 0 & \cdots & 0 \end{array} \right)$ and $\mathbf{T}_{Internal} = \left(\begin{array}{c|ccc} 0 & T_{01} & \cdots & T_{0J} \\ \hline T_{10} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ T_{J0} & 0 & \cdots & 0 \end{array} \right)$.

Here, $I_{ij}^f = I^f(F_{ij}, T_{ij})$ is satisfied.

(2) External information

External information (I_{jj}^f) is disseminated from market area j via face-to-face communication (F_{jj}) and telecommunication (T_{jj}).

The external information flow matrix $\mathbf{I}_{External}^f = \begin{pmatrix} I_{00}^f & 0 & \cdots & 0 \\ 0 & I_{11}^f & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & I_{JJ}^f \end{pmatrix}$ from the head

office 0 and branch offices 1 to J is calculated by face-to-face communication

$\mathbf{F}_{External} = \begin{pmatrix} F_{00} & 0 & \cdots & 0 \\ 0 & F_{11} & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & F_{JJ} \end{pmatrix}$ and telecommunication $\mathbf{T}_{External} = \begin{pmatrix} T_{00} & 0 & \cdots & 0 \\ 0 & T_{11} & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & T_{JJ} \end{pmatrix}$.

Here, $I_{ij}^f = I^f(F_{ij}, T_{ij})$ is satisfied.

3.4 Profit maximisation

This enterprise comprises one head office and multiple branches. They process stock information and access internal and external information to produce goods and services. Information is an important factor of production related to labour; other factors, such as capital, remain fixed in the short run. This economic model is based on the expression of informational volume and value in Section 2. The value of each piece of information depends on economic agents' MWTP to access and process it. Various types of information, $(I_0^s, I_{00}^f, I_{10}^f, \dots, I_{j0}^f, \dots, I_{j0}^f$ and $I_j^s, I_{jj}^f, I_{0j}^f)$, are non-market goods and important factors of production.

Total profit (π) of the head office and J branch offices is maximised in an open economy wherein labourers can move between regions. And the firm can input or process optimal internal and external information. Here it considers the value and volume of information as a non-market good. π_j denotes the profit of head office $j = 0$ or branch office $j = 1, \dots, J$.

$$\text{Max}_{I_0^s, I_{00}^f, I_{10}^f, \dots, I_{j0}^f, \dots, I_{j0}^f, I_j^s, I_{jj}^f, I_{0j}^f} \pi = \pi_0(I_0^s, I_{00}^f, I_{10}^f, \dots, I_{j0}^f, \dots, I_{j0}^f) + \sum_{j=1}^J \pi_j(I_j^s, I_{jj}^f, I_{0j}^f). \quad (11)$$

(1) Profit of Head Office

Here, stock information available from head office 0 (I_0^s) exists at head office 0 . Internal information is sent to head office 0 (I_{j0}^f) from branches $j = 1, \dots, j, \dots, J$. External information received by head office 0 (I_{00}^f) flows from the head offices of other firms in region 0 .

$$\pi_0 = PQ_0(I_0^s, I_{00}^f, I_{10}^f, \dots, I_{j0}^f, \dots, I_{j0}^f) - v_0^s I_0^s - \left(v_{I_{00}^f} I_{00}^f + \sum_{j=1}^J c_{I_{j0}^f}^f I_{j0}^f \right) - \sum_{j=1}^J c_{0j}^f I_{0j}^f.$$

(12)

Sales products of head office 0 $[Q_0(I_0^s, I_{00}^f, I_{10}^f, \dots, I_{j0}^f, \dots, I_{j0}^f)]$ depend on informational activities at head office $(I_0^s, I_{00}^f, I_{10}^f, \dots, I_{j0}^f, \dots, I_{j0}^f)$. P denotes the sales price of market goods.

$$Q_0((I_0^s, I_{00}^f, I_{10}^f, \dots, I_{j0}^f, \dots, I_{j0}^f)) = (I_0^s)^{\beta_0} (I_{00}^f)^{\gamma_{00}} \prod_{j=1}^J (I_{j0}^f)^{\gamma_{0j}} \quad (13)$$

$\mu_0 \equiv \beta_0 + \gamma_{00} + \sum \gamma_{0j} < 1$ and $\mu_j \equiv \beta_j - \gamma_{jj} - \gamma_{0j} < 1$ are satisfied.

(2) Profit of Branch Offices

Stock information available from branch office j (I_j^s) exists at branch office $j = 1, \dots, j, \dots, J$. Branch office j obtains internal information (I_{0j}^f) from the head office in region 0. Branch office j collects external information (I_{jj}^f) from other firms and customers in region $j = 1, \dots, j, \dots, J$.

$$\pi_j = PQ_j(I_j^s, I_{jj}^f, I_{0j}^f) - v_j^s I_j^s - (v_{jj}^f I_{jj}^f + c_{I_{0j}^f}^f I_{0j}^f) - c_{I_{j0}^f}^f I_{j0}^f. \quad (14)$$

The sales product of branch office j $[Q_j(I_j^s, I_{jj}^f, I_{0j}^f)]$ depends on informational activities $(I_j^s, I_{jj}^f, I_{0j}^f)$ at branch office $j = 1, \dots, j, \dots, J$.

$$Q_j(I_j^s, I_{jj}^f, I_{0j}^f) = (I_j^s)^{\beta_j} (I_{jj}^f)^{\gamma_{jj}} (I_{0j}^f)^{\gamma_{0j}}. \quad (15)$$

$\mu_j \equiv \beta_j - \gamma_{jj} - \gamma_{0j} < 1$ are satisfied.

The value of information depends on economic agents' MWTP to access and process the information as discussed in Section 2. First, labour cost $j = 1, \dots, j, \dots, J$ v_j^s to the head office or branch office covers inter-meeting and information processing. Second, individual offices consider only the general cost of external communication, including travel, telecommunication and labour. They do not usually pay labour costs of other firms and customers. The value of external information to the head and any branch office ($v_{I_{jj}^f}^f$) is measured as their MWTP to collect it from other firms and customers in region $i = 0, \dots, i, \dots, J$. The value of internal information to the head and any branch office ($v_{I_{ij}^f}^f$) is their MWTP to access and process it from office j to office i .

The firm's total value of internal information disseminated from head or branch office j to branch or head office i ($v_{I_{ij}^f}^f I_{ij}^f$) can be measured by the informational costs of office j —the initiator of the request for information ($c_{I_{ij}^f}^f I_{ij}^f$)—and office i as its supplier ($c_{I_{ij}^f}^i I_{ij}^f$).² In the case of internal information disseminated between the head

² The value that the initiator places on information flow from region i to region j is expressed as a function of face-to-face communication (F_{ij}) and telecommunication (T_{ij}) and as a function of the following integrated information (T_{ij}).

and branch offices, the initiator of the information request pays for travel, telecommunication and labour. The supplier of the information pays only labour costs.

$c_{I_{ij}}^{f^j} + c_{I_{ij}}^{f^i} = v_{I_{ij}}^f$ is satisfied for $(i, j) = (0, 1), \dots, (0, j), \dots, (0, J) \text{ or } (1, 0), \dots, (j, 0), \dots, (J, 0)$.

3.5 First-order conditions

Total profit π of this enterprise is maximised. From Equations (11)–(15), first-order conditions are shown as follows:

1) Head office

$$\frac{\partial \pi}{\partial I_0^s} = \frac{\partial \pi_0}{\partial I_0^s} = P \frac{\partial Q_0}{\partial I_0^s} - v_{I_0}^s = 0. \quad (16)$$

$$\frac{\partial \pi}{\partial I_{00}^f} = \frac{\partial \pi_0}{\partial I_{00}^f} = P \frac{\partial Q_0}{\partial I_{00}^f} - v_{I_{00}}^f = 0. \quad (17)$$

$$\frac{\partial \pi}{\partial I_{j0}^f} = \frac{\partial \pi_0}{\partial I_{j0}^f} + \frac{\partial \pi_j}{\partial I_{j0}^f} = \left(P \frac{\partial Q_0}{\partial I_{j0}^f} - c_{I_{j0}}^{f^0} \right) - c_{j0}^{f^j} = P \frac{\partial Q_0}{\partial I_{j0}^f} - v_{I_{j0}}^f = 0 \text{ for } j = 1, \dots, j, \dots, J. \quad (18)$$

2) Branch office

$$\frac{\partial \pi}{\partial I_j^s} = \frac{\partial \pi_j}{\partial I_j^s} = P \frac{\partial Q_j}{\partial I_j^s} - v_{I_j}^s = 0. \quad (19)$$

$$\frac{\partial \pi}{\partial I_{jj}^f} = \frac{\partial \pi_j}{\partial I_{jj}^f} = P \frac{\partial Q_j}{\partial I_{jj}^f} - v_{I_{jj}}^f = 0. \quad (20)$$

$$\frac{\partial \pi}{\partial I_{0j}^f} = \frac{\partial \pi_j}{\partial I_{0j}^f} + \frac{\partial \pi_0}{\partial I_{0j}^f} = \left(P \frac{\partial Q_j}{\partial I_{0j}^f} - c_{I_{0j}}^{f^j} \right) - c_{I_{0j}}^{f^0} = P \frac{\partial Q_j}{\partial I_{0j}^f} - v_{I_{0j}}^f = 0 \text{ for } j = 1, \dots, j, \dots, J, \quad (21)$$

where $c_{I_{j0}}^{f^0} + c_{I_{j0}}^{f^j} = v_{I_{j0}}^f$ and $c_{I_{0j}}^{f^j} + c_{I_{0j}}^{f^0} = v_{I_{0j}}^f$ are satisfied for $j = 1, \dots, j, \dots, J$.

Substituting production functions (13) and (15) into equations (16)–(21), we derive

1) Head office

$$\beta_0 P (I_0^s)^{\beta_0-1} (I_{00}^f)^{\gamma_{00}} \prod_{j=1}^J (I_{j0}^f)^{\gamma_{0j}} - v_{I_0}^s = 0. \quad (22)$$

$$\gamma_{00} P (I_0^s)^{\beta_0} (I_{00}^f)^{\gamma_{00}-1} \prod_{j=1}^J (I_{j0}^f)^{\gamma_{0j}} - v_{I_{00}}^f = 0. \quad (23)$$

$$\gamma_{j0} P (I_0^s)^{\beta_0} (I_{00}^f)^{\gamma_{00}} (I_{j0}^f)^{\gamma_{j0}-1} \dots (I_{j0}^f)^{\gamma_{j0-1}} \dots (I_{j0}^f)^{\gamma_{j0}} - v_{I_{j0}}^f = 0 \text{ for } j = 1, \dots, j, \dots, J. \quad (24)$$

2) Branch office

$$\begin{aligned} V_{ij} &= \omega_{F_{ij}} F_{ij} + \omega_{T_{ij}} T_{ij} = (\omega_{F_{ij}}^j + \omega_{F_{ij}}^i) F_{ij} + (\omega_{T_{ij}}^j + \omega_{T_{ij}}^i) T_{ij} \\ &= (\omega_{F_{ij}}^j F_{ij} + \omega_{T_{ij}}^j T_{ij}) + (\omega_{F_{ij}}^i F_{ij} + \omega_{T_{ij}}^i T_{ij}) \\ &= (\omega_{F_{ij}}^j v_{F_{ij}}^f I_{ij}^f + \omega_{T_{ij}}^j v_{T_{ij}}^f I_{ij}^f) + (\omega_{F_{ij}}^i v_{F_{ij}}^f I_{ij}^f + \omega_{T_{ij}}^i v_{T_{ij}}^f I_{ij}^f) \\ &= (\omega_{F_{ij}}^j v_{F_{ij}}^f + \omega_{T_{ij}}^j v_{T_{ij}}^f) I_{ij}^f + (\omega_{F_{ij}}^i v_{F_{ij}}^f + \omega_{T_{ij}}^i v_{T_{ij}}^f) I_{ij}^f = c_{I_{ij}}^{f^j} I_{ij}^f + c_{I_{ij}}^{f^i} I_{ij}^f \\ &= v_{I_{ij}}^f I_{ij}^f \end{aligned}$$

$$\beta_j P(I_j^S)^{\beta_j-1} (I_{jj}^f)^{\gamma_{jj}} (I_{0j}^f)^{\gamma_{0j}} - v_{I_j^S} = 0 \text{ for } j = 1, \dots, J. \quad (25)$$

$$\gamma_{jj} P(I_j^S)^{\beta_j} (I_{jj}^f)^{\gamma_{jj}-1} (I_{0j}^f)^{\gamma_{0j}} - v_{I_{jj}^f} = 0 \text{ for } j = 1, \dots, J. \quad (26)$$

$$\gamma_{0j} P(I_j^S)^{\beta_j} (I_{jj}^f)^{\gamma_{jj}} (I_{0j}^f)^{\gamma_{0j}-1} - v_{I_{0j}^f} = 0 \text{ for } j = 1, \dots, J. \quad (27)$$

3.6 Demand function of business information

Solving equations (22)–(27), we determine the demand functions of business information flows and stocks.

1) Demand for information within head office

a) Demand for stock information inside head office 0 is

$$I_0^S = \frac{\beta_0}{v_{I_0^S}} P^{\frac{1}{1-\mu_0}} \left(\frac{\beta_0}{v_{I_0^S}} \right)^{\frac{\beta_0}{1-\mu_0}} \left(\frac{\gamma_{00}}{v_{I_{00}^f}} \right)^{\frac{\gamma_{00}}{1-\mu_0}} \prod_{j=1}^J \left(\frac{\gamma_{j0}}{v_{I_{j0}^f}} \right)^{\frac{\gamma_{j0}}{1-\mu_0}}.$$

b) Demand for external information by head office 0 from business area $j = 1, \dots, J$ is

$$I_{00}^f = \frac{\gamma_{00}}{v_{I_{00}^f}} P^{\frac{1}{1-\mu_0}} \left(\frac{\beta_0}{v_{I_0^S}} \right)^{\frac{\beta_0}{1-\mu_0}} \left(\frac{\gamma_{00}}{v_{I_{00}^f}} \right)^{\frac{\gamma_{00}}{1-\mu_0}} \prod_{j=1}^J \left(\frac{\gamma_{j0}}{v_{I_{j0}^f}} \right)^{\frac{\gamma_{j0}}{1-\mu_0}}.$$

c) Demand for internal information by head office 0 from branch office $j = 1, \dots, J$ is

$$I_{j0}^f = \frac{\gamma_{j0}}{v_{I_{j0}^f}} P^{\frac{1}{1-\mu_j}} \left(\frac{\beta_j}{v_{I_0^S}} \right)^{\frac{\beta_j}{1-\mu_j}} \left(\frac{\gamma_{00}}{v_{I_{00}^f}} \right)^{\frac{\gamma_{00}}{1-\mu_j}} \prod_{j=1}^J \left(\frac{\gamma_{j0}}{v_{I_{j0}^f}} \right)^{\frac{\gamma_{j0}}{1-\mu_0}},$$

where $\mu_0 \equiv \beta_0 + \gamma_{00} + \sum \gamma_{0j} < 1$ is satisfied for branch office $j = 1, \dots, J$. $v_{I_{j0}^f} = \left(\left(\frac{\omega_{Fj0}}{a_F} \right)^\sigma + \left(\frac{\omega_{Tj0}}{a_T} \right)^\sigma \right)^{\frac{1}{\sigma}}$ is calculated for the head or branch office $j = 0, \dots, J$.

External information from head office 0 is disseminated to business area $j = 1, \dots, J$ face-to-face and via telecommunication: $F_{00} = \frac{\omega_{F00}^{\sigma-1}}{a_{F00}^\sigma} \left(\left(\frac{\omega_{F00}}{a_F} \right)^\sigma + \left(\frac{\omega_{T00}}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I_{00}^f$ and $T_{00} = \frac{\omega_{T00}^{\sigma-1}}{a_{T00}^\sigma} \left(\left(\frac{\omega_{F00}}{a_F} \right)^\sigma + \left(\frac{\omega_{T00}}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I_{00}^f$.

Internal information from head office 0 is disseminated to branch office $j = 1, \dots, J$ face-to-face and via telecommunication, $F_{j0} = \frac{\omega_{Fj0}^{\sigma-1}}{a_{Fj0}^\sigma} \left(\left(\frac{\omega_{Fj0}}{a_F} \right)^\sigma + \left(\frac{\omega_{Tj0}}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I_{j0}^f$ and

$$T_{j0} = \frac{\omega_{Tj0}^{\sigma-1}}{a_{Tj0}^\sigma} \left(\left(\frac{\omega_{Fj0}}{a_F} \right)^\sigma + \left(\frac{\omega_{Tj0}}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I_{j0}^f.$$

2) Demand for information within a branch office

a) Demand for stock information within branch office j is

$$I_j^s = \frac{\beta_j}{v_{I_j^s}} P^{\frac{1}{1-\mu_j}} \left(\frac{\beta_j}{v_{I_j^s}} \right)^{\frac{\beta_j}{1-\mu_j}} \left(\frac{\gamma_{jj}}{v_{I_{jj}^f}} \right)^{\frac{\gamma_{jj}}{1-\mu_j}} \left(\frac{\gamma_{0j}}{v_{I_{0j}^f}} \right)^{\frac{\gamma_{0j}}{1-\mu_j}} \quad \text{for } j = 0, \dots, J.$$

b) Demand for external information from branch office j by business area j is

$$I_{jj}^f = \frac{\gamma_{jj}}{v_{I_{jj}^f}} P^{\frac{1}{1-\mu_j}} \left(\frac{\beta_j}{v_{I_j^s}} \right)^{\frac{\beta_j}{1-\mu_j}} \left(\frac{\gamma_{jj}}{v_{I_{jj}^f}} \right)^{\frac{\gamma_{jj}}{1-\mu_j}} \left(\frac{\gamma_{0j}}{v_{I_{0j}^f}} \right)^{\frac{\gamma_{0j}}{1-\mu_j}} \quad \text{for } j = 0, \dots, J.$$

c) Demand for external information from branch office by head office 0 is

$$I_{0j}^f = \frac{\gamma_{0j}}{v_{I_{0j}^f}} P^{\frac{1}{1-\mu_j}} \left(\frac{\beta_j}{v_{I_j^s}} \right)^{\frac{\beta_j}{1-\mu_j}} \left(\frac{\gamma_{jj}}{v_{I_{jj}^f}} \right)^{\frac{\gamma_{jj}}{1-\mu_j}} \left(\frac{\gamma_{0j}}{v_{I_{0j}^f}} \right)^{\frac{\gamma_{0j}}{1-\mu_j}},$$

where and $\mu_j \equiv \beta_j - \gamma_{jj} - \gamma_{0j} < 1$ and $v_{I_{ij}^f} = \left(\left(\frac{\omega_{F_{ij}}}{a_F} \right)^\sigma + \left(\frac{\omega_{T_{ij}}}{a_T} \right)^\sigma \right)^{\frac{1}{\sigma}}$ are satisfied.

Information is disseminated face-to-face and via telecommunication, $F_{jj} =$

$$\frac{\omega_{F_{jj}}^{\sigma-1}}{a_{F_{jj}}^\sigma} \left(\left(\frac{\omega_{F_{jj}}}{a_F} \right)^\sigma + \left(\frac{\omega_{T_{jj}}}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I_{jj}^f \quad \text{and} \quad T_{jj} = \frac{\omega_{T_{jj}}^{\sigma-1}}{a_{T_{jj}}^\sigma} \left(\left(\frac{\omega_{F_{0j}}}{a_F} \right)^\sigma + \left(\frac{\omega_{T_{0j}}}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I_{jj}^f.$$

Information is disseminated face-to-face and via telecommunication, $F_{0j} =$

$$\frac{\omega_{F_{0j}}^{\sigma-1}}{a_{F_{0j}}^\sigma} \left(\left(\frac{\omega_{F_{0j}}}{a_F} \right)^\sigma + \left(\frac{\omega_{T_{0j}}}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I_{0j}^f \quad \text{and} \quad T_{0j} = \frac{\omega_{T_{0j}}^{\sigma-1}}{a_{T_{0j}}^\sigma} \left(\left(\frac{\omega_{F_{0j}}}{a_F} \right)^\sigma + \left(\frac{\omega_{T_{0j}}}{a_T} \right)^\sigma \right)^{-\frac{1}{\rho}} I_{0j}^f.$$

3.7 Intra-regional Information Input–Output Table (Time-Based)

The aim of this section is to complete an intra-regional information input–output table that displays the information flow to maximise the firm's profit. This firm has a single head office in the metropolitan area and branch offices in two market areas: the metropolitan and another market area.

We observe the information flows between the single head office and selected branches. All endogenous variables are expressed as categories of labour, such as stock information processing and internal and external communication. The direction of each arrow in Figure 1 signifies that head or branch officers contact other officers within the firm or meet customers from the business area to communicate information, including sales activities. And these are shown as variables inside the dark thickened frame of Table 1.

3.8 OD Table for Business Trip

Table 2 summarises travel from point of origin to destination (OD) for head and branch offices. We next clarify relations between information flows and business trips. We assume the receiver of information visits its sender. Business trips are round trips, and their origin–destination (OD) matrix can be expressed as follows:

Table 1: Intra-Regional Information Input-Output Table (Time-Based Table)

From				To		Metropolitan area				Total output of information		
				Central city		Suburb		Local area				
				Region 0		Region 1		Region 2				
				Headquarters		Branch office		Branch office				
Types of Information				Internal	External	Internal	External	Internal	External	(Unit: hours)		
Metropolitan area	Central	Region 0	Headqu	F	I_0^s	-	F_{01}^f	-	F_{02}^f	-	I_0^s	$F_{01}^f + F_{02}^f$
			arters	T			T_{01}^f		T_{02}^f			$T_{01}^f + T_{02}^f$
		Other firms	F	-	F_{00}^f	-	*2	-	*2		F_{00}^f	
			T		T_{00}^f						T_{00}^f	
	Suburb	Region 1	Branch office	F	F_{10}^f	-	I_1^s	-	*3	-	I_1^s	F_{10}^f
				T	T_{10}^f							T_{10}^f
		Other firms	F	-	*1	-	F_{11}^f	-	*4		F_{11}^f	
			T				T_{11}^f				T_{11}^f	
	Local area	Region 2	Branch office	F	F_{20}^f	-	*3	-	I_2^s	-	I_1^s	F_{20}^f
					T							T_{20}^f
			Other firms	F	-	*1	-	*4	-	F_{22}^f		F_{22}^f
				T						T_{22}^f		T_{22}^f
Demand of labor time *5	Total input of information			I_0^s		I_1^s		I_2^s				
				$F_{10}^f + F_{20}^f + F_{00}^f$		$F_{01}^f + F_{11}^f$		$F_{02}^f + F_{22}^f$				
				$T_{10}^f + T_{20}^f + T_{00}^f$		$T_{01}^f + T_{11}^f$		$T_{02}^f + T_{22}^f$				
	Communication time to give information to the other office			$F_{01}^f + F_{02}^f$		F_{10}^f		F_{20}^f				
				$T_{02}^f + T_{02}^f$		T_{10}^f		T_{20}^f				
	Travel time			$\frac{F_{10}^f t_{10} + F_{20}^f t_{20} + F_{00}^f t_{00}}{M}$		$\frac{F_{01}^f t_{01} + F_{11}^f t_{11}}{M}$		$\frac{F_{02}^f t_{02} + F_{22}^f t_{22}}{M}$				
Supply of labor time *5				L_0^*		L_1^*		L_2^*				

Note: This input-output table does not consider:

- *1. External information flows from visits to branch offices by the headquarters (e.g., headquarters visits to construction sites)
- *2. External information flows from visits to the headquarters by branch offices (e.g., branch office visits to the headquarters to observe suppliers' procedures)
- *3. Internal information flows between branches (e.g., meetings of branch office heads convened by headquarters) This model includes such exchanges as a flow between the headquarters and branches.
- *4. Information and business activities in business areas of other branches
- *5. There are no intra-firm allocations of labor in this open regional economy model.

$$I_0^s + (F_{10}^f + F_{20}^f + F_{00}^f) + (T_{10}^f + T_{20}^f + T_{00}^f) + (F_{01}^f + F_{02}^f) + (T_{02}^f + T_{02}^f) + \frac{F_{10}^f t_{10} + F_{20}^f t_{20} + F_{00}^f t_{00}}{M} \leq L_0^*$$

$$I_1^s + (F_{01}^f + F_{11}^f) + (T_{01}^f + T_{11}^f) + F_{10}^f + T_{10}^f + \frac{F_{01}^f t_{01} + F_{11}^f t_{11}}{M} \leq L_1^*$$

$$I_2^s + (F_{02}^f + F_{22}^f) + (T_{02}^f + T_{22}^f) + F_{20}^f + T_{20}^f + \frac{F_{02}^f t_{02} + F_{22}^f t_{22}}{M} \leq L_2^*$$

where t_{ij} is round-trip travel time between regions i and j.

Table 2: Travel OD Table

	Headquarters (Region 0)	Branch Office 1 (Region 1)	Branch Office 2 (Region 2)	Origin
Headquarters 0 (Region 0)	$\frac{2F_{00}^f}{M}$	$\frac{F_{01}^f + F_{10}^f}{M}$	$\frac{F_{02}^f + F_{20}^f}{M}$	$\frac{2F_{00}^f + F_{01}^f + F_{10}^f + F_{02}^f + F_{20}^f}{M}$
Branch Office 1 (Region 1)	$\frac{F_{10}^f + F_{01}^f}{M}$	$\frac{2F_{11}^f}{M}$	0	$\frac{F_{10}^f + F_{01}^f + 2F_{11}^f}{M}$
Branch Office 2 (Region 2)	$\frac{F_{20}^f + F_{02}^f}{M}$	0	$\frac{2F_{22}^f}{M}$	$\frac{F_{20}^f + F_{02}^f + 2F_{22}^f}{M}$
Destination	$\frac{2F_{00}^f + F_{10}^f + F_{01}^f + F_{20}^f + F_{02}^f}{M}$	$\frac{F_{01}^f + F_{10}^f + 2F_{11}^f}{M}$	$\frac{F_{02}^f + F_{20}^f + 2F_{22}^f}{M}$	$\frac{2(F_{00}^f + F_{10}^f + F_{01}^f + F_{20}^f + F_{02}^f)}{M}$

Note: M is average time of face-to-face communication per business trip.

Trip can be written as

$$\mathbf{Trip} = \left(\begin{array}{c|ccc} \frac{2F_{00}}{M} & \frac{F_{01} + F_{10}}{M} & \dots & \frac{F_{0J} + F_{J0}}{M} \\ \hline \frac{F_{10} + F_{11}}{M} & \frac{2F_{11}}{M} & & 0 \\ \vdots & M & \ddots & \\ \frac{F_{J0} + F_{0J}}{M} & 0 & & \frac{2F_{JJ}}{M} \end{array} \right),$$

where M is the average time spent in face-to-face communication per trip.

4. Conclusion

This paper has proposed an economic theory of information value and volume using an information input–output structure. It also examined an economic model of head and branch offices to determine time imputed to communicate and process internal and external information.

- 1) Our economic approach to measure the value of information differs from Shannon's mathematical theory of communication (Shannon, 1948).
- 2) The value of general information, a non-market good, is termed as willingness to pay (WTP) for travel and telecommunication to acquire it from total viewpoints of transport economics and telecommunication economics.
- 3) The behaviour of an enterprise with two levels of hierarchy—a head office and multiple branch offices—has been modelled. The firm's intent to maximise profits enables us to handle time of information activities related to demand for internal and external information.
- 4) The production function is described as a function of information communication and processing.

- 5) The relation between transportation and communication is demonstrated by the inter-regional information input–output table for head and branch offices and the business trip OD table for head and branch offices.

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