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THE EFFECTS OF THE TRANSPORTATION COSTS IN R&D TECHNOLOGY SECTOR ON THE ENDOGENOUS GRWOTH

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The paper centers on investigating theoretically how the transportation costs of R&D technology, none of the transportation costs in final goods and intermediate inputs, affect the long-run endogenous economic growth. The basic ideas adopted in this paper are different from well-known models in the sense that the prices of R&D technology are influenced by the transportation cost in R&D technology sector and the accumulated profit of the intermediate inputs over time is equal to the price of R&D technology, and thus the transportation costs indirectly influence the endogenous growth. That is, the larger are only the transportation costs of R&D technology, the higher is the price of R&D technology and the slower is endogenous economic growth.

Keywords: Transportation Costs, R&D Technology, Endogenous Growth
JEL classification: D42, D50, L12, O12, O31

1. INTRODUCTION

Transportation is essential to economic activities. It is because people trade materials, labor, or ideas, and firms trade technology, expertise, intermediate inputs, or administrative functions with each others. All these transactions require communications and also require transportation of goods or people. The economies with efficient communication systems and low transportation costs may increase the extent to which transactions are easily linked, and thus the economy may take advantage of more efficient transportation and thus enjoy higher economic growth.

In this regard, this paper raises questions that what kind of transportation costs among final goods, intermediate input, or R&D technology affect the engine of growth and how transportation costs offset the engine of economic growth. To solve the

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questions, this paper will describe a well-known general equilibrium model with a monopolistic competition market in order to examine the offset of the engine of growth by transportation costs. Throughout this paper, we will focus on how the transportation costs of final goods, intermediate inputs, or R&D technology may cause the profits of the intermediate inputs and thus affect the endogenous growth of the world economy.

The literature on endogenous growth can be categorized depending on what is the engine of the growth. Vernon (1966) and Young (1991) investigated that the knowledge production function alone determines endogenous growth in the R&D industry and thus predetermines growth performances. Romer (1990) introduced imperfect competition in the intermediate input market, which allows intermediate producers to be compensated with monopoly rents for a successful innovation. Goo and Park (2007) theoretically described that the final goods production function plays an important role in determining the degree of monopoly power in intermediate input market and thus long run endogenous growth of an economy. In a word, many papers since Romer (1990) have tended to suppose that monopoly rent and the expansion of the variety of intermediate inputs generated by technological progress are necessary for the endogenous growth, however, they may ignore the fact that transportation costs, especially the transportation costs of R&D technology, affect the endogenous growth. Even though many researchers visit endogenous growth related to transportation costs, there exist few studies that link transportation costs to final goods, intermediate inputs, and R&D technology with the endogenous economic growth.

Recently, Yamamoto (2003) showed the relationship between the transportation costs of the intermediate inputs and economic growth by stating that when the transportation costs of materials such as the intermediate inputs were too high, the economy achieved no growth in international trade model. However, different profits in intermediate input market may be affected by the transportation costs of R&D technology such as expertise of human technology in the sense that the transportation costs of R&D technology may cause the different monopoly power in intermediate-input markets, which in turn changes the profits of intermediate input producers, and thus induces differently their investments in new technology. A key feature of this paper, therefore, is its introduction of the effects of transportation costs in different sectors on the economic endogenous growth. In other words, the movement of the R&D technology involves transportation costs, which will generate different the monopoly power and thus ex-ante profits in the intermediate input markets.

This paper will show how the transportation costs in the R&D technology sector play an important role in determining the degree of monopoly power and thus long-run economic growth and welfare. The basic approach adopted in this paper differs from Martin and Ottaviano (1999) and Yamamoto (2003) in the sense that they consider whether trade can happen or not depends on the size of transportation costs in the regional trade model. However, this paper assumes that all goods are tradable in the world economy and considers that the technology of final goods, intermediate inputs, and R&D technology may provide different incentive to make investments in new technology because the transportation costs of each sector offset the perceived profit opportunities differently from the previous models. This model, therefore, focuses on the effects of the transportation costs of various sectors on the economic growth. It is worth while considering the introduction of transportation costs affecting the degree of monopoly power. The paper establishes that the transportation costs of R&D technology sector can have a detrimental effect on the degree of monopoly power and thus endogenous growth.

The mechanism to affect the endogenous growth is as follows. The price of the R&D technology is the sum of the expected future profits of production of an intermediate input discounted by market interest rates. The prices of R&D technology are directly influenced by the transportation cost of the R&D technology. That is, the transportation costs of the R&D technology also indirectly affect the sum of the expected future profits of an intermediate input and thus influence the endogenous growth indirectly.

The paper is organized as follows. In section 2, we explain the basic model. Final goods production function is the product differentiation form by following the CES function. In the R&D technology, we assume that any new inventor can access the existing stocks of ideas accumulated over time up to a given moment of time. There are the transportation costs of final goods, intermediate goods, and R&D technology sectors, which may influence the degree of monopoly power. In section 3, we derive economic growth. We will investigate of which sector the transportation costs may offset the monopoly power and thus change the long-run endogenous growth of the world economy. In section 4, we discuss a comparison between previous papers and this paper and the contribution of the paper. Section 5 reports concluding remarks.

2. A THEORETICAL MODEL

The model is basically similar to Romer (1990), Grossman and Helpman (1995), and Goo and Park (2007). The economic environment consists of consumable final goods, a continuum of intermediate inputs, and a set of R&D technology. The production technology of final goods exhibits imperfect substitution among intermediate inputs, thereby generating product differentiation for each intermediate input producer through its degree of substitutability. Each intermediate input producer is differentiated in the sense that it alone can access its own blueprint. A new intermediate input producer emerges when a potential entrant expects positive ex ante profits from producing a new intermediate input by applying a newly developed blueprint from the R&D industry. The R&D firm employs both labor and a set of historically accumulated R&D stocks to invent a new idea. Moreover, transportation costs exist in the final goods, intermediate input, and R&D technology sectors. Following the spirit of Dixit and Stiglitz (1977), we assume that both the final goods market and the R&D market are perfectly competitive, while the intermediate input market is monopolistically competitive.

According to Romer (1990) and Goo and Park (2007), the economic profits anticipated by intermediate producers are the main factors that determine whether the economy continues to grow. We wish to examine carefully how the transportation costs in R&D technology sector offset the engines of growth. This paper assumes that the movement of goods among the three sectors incurs transportation costs and thus the price of goods demanded is higher than the price of goods produced due to transportation costs.

The present paper uses a broad concept of the transportation costs in the R&D technology sector, including the movement of human technology, ideas, and expertise related to movement of R&D technology, which arise because transactions involving R&D technology require communication between experts under efficient administrative functions or movement of ideas under strengthened security systems. In Rauch (1996) and Davis (1998), the transportation costs of idea-intensive goods (insurance and freight as percentage of customs value) are different from those of homogeneous goods and near-homogeneous goods. According to Keller and Yeaple's (2008) analysis using firm-level data, physical shipping costs and technology transfer costs increase the firms, marginal costs and also costly technology transfer gives rise to increasing marginal costs and complex technologies are relatively costly to transfer. Thus, this paper assumes that the transportation costs in the R&D technology sector raise marginal costs.

2.1. Demand Function

A standard representative consumer's problem is used. There is an immortal representative consumer who tries to maximize her lifetime utility,

$$U^E = \int_0^\infty e^{-\rho t} u(C_t)dt ,$$

where $u(C_t)$ is the sum of the utility discounted at the rate $\rho \geq 0$, by allocating her income into either consumption C_t or investment a_t. To ensure a balanced consumption path, the utility function is further specified as

$$u(C_t) = \frac{[C_t]^{1-\sigma}}{1-\sigma}, \sigma > 0 .$$

Clearly, the utility function increases monotonically and is concave, thereby satisfying the Inada conditions. The representative consumer's income consists of wage income w_t and the returns from her asset, a_t, on which she receives the market rate of return r_t. For simplicity, we assume that she is endowed with a fixed amount of labor in each moment of time t, for example 1 unit of labor, that she cannot accumulate human capital, and that time is continuous.

The consumer's problem is summarized as follows. Given her initial stock of assets at time 0, a_0, and her intertemporal budget constraints

$$P_{C_t} C_t + \dot{a}_t \le w_t + r_t a_t \quad \text{for} \quad \forall t \in [0, \infty),$$

where P_{C_t} is the price of the consumption good at time t, she chooses C_t to maximize her lifetime utility, that is

$$U = \int_0^\infty e^{-\rho t} \frac{[C_t]^{1-\sigma}}{1-\sigma} dt .$$

The maximizing function C_t is continuously twice differentiable and is chosen from the set of such functions defined on $[0,\infty)$. Therefore, the set of necessary conditions for the consumer's problem becomes

$$\frac{\dot{C}_t}{C_t} = \frac{1}{\sigma}\left[r_t - \rho - \frac{\dot{p}_{C_t}}{P_{C_t}} \right] \quad \text{for} \quad t \in [0, \infty),$$

given the initial condition a_0. The transversality condition is that the present value of her asset should approach zero as time approaches infinity, that is, $\lim e^{-\rho t} U(C_t) a_t = 0$ as $t \to \infty$, where $U(C_t)$ is the marginal utility of consumption.

2.2. The Production Technology of Final Goods Sector[1]

This section briefly describes the production function for final goods. Formally, the final goods are produced by the set of intermediate inputs X_i, $i \in [0, A]$ where A denotes the level of R&D stocks. For convenience, labor is not used as an input for final goods production. Suppose Y represents final goods

$$Y = \left[\int_0^A [X_i]^\mu di \right]^{\frac{1}{\mu}},$$

where for the production function $\mu \in (0,1)$, there are external effects from employing a variety of inputs, and A represents the total number of intermediate inputs. For example, suppose the prices of all inputs are the same. Then the quantity of each input

[1] For convenience, the notation of time, *t*, is not used from here.

employed in production will be the same and thus

$$Y = [A]^{\frac{1}{\mu}} X_i \ .$$

Therefore, the external effect on the productivity of final goods production is $[A]^{\frac{1}{\mu}}$.

Assuming that the final goods market is perfectly competitive, the firm will maximize its profit given the price of the final goods P_Y and the prices of intermediate inputs P_{X_i}, as follows:

$$\max g_Y P_Y \left[\int_0^A [X_i]^{\mu} di\right]^{\frac{1}{\mu}} - \int_0^A P_{X_i} X_i \, di \quad \text{for} \quad \forall i \in [0, A] \, .$$

As mentioned above, the movement of final goods, intermediate inputs, and R&D technology incurs transportation costs. We assume that the price of final goods demanded is higher than the price of final goods produced due to transportation costs. If a unit of final goods is moved, the price P_Y of final goods consumed increases with transportation costs because of $0 < g_Y < 1$.[2] Likewise, if a unit of intermediate input (or R&D technology) is moved, the new prices of intermediate input (or R&D technology) demanded is also higher than the price of intermediate input (or R&D technology) produced due to transportation costs.

Now, by a first-order condition with respect to X_i, we can derive the demand for the differentiated *i-th* intermediate input as

$$g_Y P_Y \left[\int_0^A [X_i]^{\mu} di\right]^{\frac{1-\mu}{\mu}} [X_i]^{-[1-\mu]} = P_{X_i} \ .$$

This demand equation implies that the relationship between the *i-th* and the *j-th* inputs is

[2] For analytical convenience, transportation costs of the iceberg type could be assumed to be proportional to the quantity of goods shipped to another place and the key assumption in this regard is the separability between the demands for the goods. However, there is no geographical distance between producers and consumers in the world economy so that this paper does not need to introduce the iceberg type costs. But the notion of transportation costs used in this paper is analogous to iceberg type costs except that a fraction of the goods melts away before they reach their destination in iceberg type costs.

$$\frac{[X_i^E]^{-[1-\mu]}}{P_{X_i}^E} = \frac{[X_j^E]^{-[1-\mu]}}{P_{X_j}^E} .$$

This equation combined with the final good production function yields the demand for X_i as

$$X_i = [P_{X_i}]^{-\frac{1}{1-\mu}} \left[\int_0^A [P_{X_i}]^{-\frac{\mu}{1-\mu}} di \right]^{-\frac{1}{\mu}} Y \quad \text{for all} \quad i \in [0, A] .$$

2.3. The Production Technology of Intermediate Input Sector

Given the demand for intermediate inputs derived above, each firm in the monopolistically competitive input market seeks a maximum profit as $\Pi_{X_i} = g_X P_{X_i} X_i - wL_{X_i}$, where g_X is the transportation costs of the intermediate inputs ($0 < g_X < 1$). For simplicity, we assume constant returns to scale and productive technology to ensure perpetual positive growth of the economy. Suppose that each firm in the market transforms $\frac{1}{\beta}$ units of labor $(\beta \geq 1)$ into 1 unit of output. Then the necessary condition for profit-maximizing, X_i , becomes

$$P_{X_i} = \frac{w}{g_X \mu\beta} .$$

Note that the intermediate input price captures nothing but the typical equilibrium condition for a monopolistically competitive firm. This simple form of equation is based on the hypothesis that each individual firm is so small that a change in its output will not affect the total quantity of final goods produced. Suppose that each firm in the intermediate input sector has the same production technology; then the equilibrium quantities of all differentiated intermediate inputs are the same and are given by the final goods' production function,

$$X_i = [A]^{-\frac{1}{\mu}} Y . \tag{1}$$

The price of final goods is a geometric average of each differentiated intermediate input price as

$$P_Y = \frac{1}{g_Y}\left[\int_0^A [P_{X_i}]^{-\frac{\mu}{1-\mu}} di\right]^{-\frac{1-\mu}{\mu}}.$$

Finally, we derive the following from this price relationship, the prices of intermediate inputs, and the zero-profit condition in the final goods markets:

$$P_Y = [A]^{-\frac{1-\mu}{\mu}} \frac{w}{g_Y \mu\beta}. \quad (2)$$

The price of good Y reflects only the wage rate, the number of intermediate inputs required in its production, and the transportation costs of the final good. The price of final good *Y* increases with transportation costs because of $0 < g_Y < 1$.

We can now explicitly compute the profit of each firm in the market for intermediate inputs. Because a firm's profit in this market is defined by $\Pi_{X_i} = g_X P_{X_i} X_i - wL_{X_i}$, it can be expressed as

$$\Pi_{X_i} = \frac{1-\mu}{\mu\beta}[A]^{-\frac{1}{\mu}} wY.$$

Therefore, each intermediate input producer's profit is positive when its price and the wage rate are positive. Given a positive level of initial technology, the Inada conditions of the utility function ensure positive final goods production. These positive profits provide market incentive for new inventions.

2.4. The Production Technology of R&D Sector

We assume that a new blueprint is developed by labor and historically accumulated R&D stock. In addition, we assume that any new inventor can access the existing stock of ideas, which have accumulated over time. Formally, the R&D technology is $\dot{A} = \varphi AL_A$, where φ is an output coefficient of labor, A is the current stock of ideas, and L_A is the amount of labor devoted to the R&D sector. Hence, an R&D firm maximizes its profit $\Pi_A = g_A P_A \varphi AL_A - wL_A$ at the price of a new blueprint P_A where g_A is the transportation cost of the R&D technology ($0 < g_A < 1$). The firm's first-order condition is $g_A P_A \varphi A = w$. Because we consider the R&D industry perfectly competitive, Π_A is zero at the optimum. Finally, we recognize that the price of a blueprint is the expected future profits discounted at the market interest rate $P_A = \int_t^{\infty} e^{-R_s} \Pi_{X_i}(s) ds$, where $R_s = \int_t^s r_h \, dh$. Moreover, the non-arbitrage condition for R&D investment at equilibrium can be derived by differentiating the above equation with respect to time to get $\Pi_{X_i} + \dot{P}_A = rP_A$.

3. LONG-RUN BALANCED GROWTH EQUILIBRIUM

We can complete the model by stating all of the market clearing conditions. First, because all final goods are consumed, the final goods market clearing condition implies that $C = Y$, and $P_C = P_Y$ for all time. Here, we normalize the price of the consumption and final goods as $P_Y = P_C = 1$. Second, the labor market is cleared if $\overline{L} = \overline{L}_X + \overline{L}_A$ for all time, where the bars above the variables denote aggregated amounts of each variable, $\overline{L}$ is the total labor endowment of the economy, and $\overline{L}_X (= \int_0^A L_{X_i} di)$ is the aggregated labor employed in the intermediate input market. Third, the asset market clearing condition becomes

$$a = P_A A = \frac{w}{g_A \varphi} \quad \text{for all time with} \quad a_0 = P_{A_0} A_0 ,$$

where A_0 is the initial level of technology in the economy.

Here we consider a stationary economy in the long run, in which labor allocations among the sectors remain constant and state variables change at constant rates over time. Recall that $g_A P_A \varphi A = w$. Hence, on the stationary equilibrium path, the rate of growth of A, that is

$$\gamma_A \equiv \frac{\dot{A}}{A} ,$$

is the same as the rate of change in the wage rate

$$\gamma_W \equiv \frac{\dot{w}}{w} .$$

We use γ to denote growth rate, with its subscript indicating the corresponding variable. We can then derive the relationship between the equilibrium quantity of an input and the rate of interest:

$$X_i = \frac{1}{g_A}\frac{\mu}{1-\mu}\frac{\beta}{\varphi}\frac{r}{A}. \tag{3}$$

Hence, $\gamma_X = \gamma_r - \gamma_A$ holds. Obviously, from the asset market clearing condition, $a = P_A A$ for all t, the asset levels change at the same rate as the wage rate $\gamma_a = \gamma_w$, because

$$a = AP_A = \frac{w}{g_A \varphi} \quad ,$$

at the stationary optimum. In addition, by combining the labor market clearing condition, the symmetric property of labor employment, and the intermediate input production functions, i.e.,

$$\overline{L}_X = A\frac{X}{\beta},$$

we obtain $\gamma_A = -\gamma_X$. Combining these growth relationships, $\gamma_X = \gamma_r - \gamma_A$ and $\gamma_A = -\gamma_X$, we establish that $\gamma_r = 0$ on a stationary equilibrium path. In addition, combining Equation (3) with the labor market clearing condition implies that

$$\gamma_A = \varphi\overline{L} - \frac{1}{g_A}\frac{\mu}{1-\mu} r . \tag{4}$$

Once we know that the interest rate is constant on the stationary equilibrium path, we can derive more relationships among the growth rates of state variables. More specifically, by combining Equation (4) with the production function for Y and Equation (1), we obtain

$$Y = \frac{1}{g_A}\frac{\mu}{1-\mu}\frac{\beta}{\varphi} r[A]^{\frac{1-\mu}{\mu}} .$$

It follows that along the equilibrium path,

$$\gamma_Y = \gamma_r + \frac{1-\mu}{\mu}\gamma_A .$$

Therefore, because $\gamma_r = 0$, and $\gamma_A = \gamma_w$, we can derive relationships such as

$$\gamma_Y = \frac{1-\mu}{\mu}\gamma_A .$$

Thus, the balanced growth rates between final goods and technology differ by a factor of $\frac{1-\mu}{\mu}$.

Finally, to complete the set of properties for the balanced growth path, first, we find the stationary interest rate:

$$r = \frac{g_A\sigma}{g_A+\sigma}\frac{1-\mu}{\mu}\left[\varphi\overline{L} + \frac{\mu}{1-\mu}\frac{\rho}{\sigma}\right]. \tag{5}$$

From Equations (4) and (5), we get

$$\gamma_A = \frac{g_A}{g_A+\sigma}[\varphi\overline{L} - \frac{1}{g_A}\frac{\mu\rho}{1-\mu}],$$

$$\gamma_Y = \gamma_C = \frac{g_A}{g_A+\sigma}\frac{1-\mu}{\mu}\left[\varphi\overline{L} - \frac{1}{g_A}\frac{\rho\mu}{1-\mu}\right].$$

Then, the balanced stocks of blueprints evolve as

$$A_t = A_0 \exp\left[\frac{g_A}{g_A+\sigma}\left[\varphi\overline{L} - \frac{1}{g_A}\frac{\mu\rho}{1-\mu}\right]\right]t .$$

Hence, the economy experiences positive persistent growth in R&D whenever

$$\varphi\overline{L} > \frac{1}{g_A}\frac{\mu\rho}{1-\mu} .$$

The transversality condition for the perpetually growing economy is

$$\frac{1-\mu}{\mu}g_A\varphi\overline{L} > \rho > \frac{g_A}{g_A+1}\frac{1-\mu}{\mu}(1-\sigma)\varphi\overline{L} .$$

Here, we can find the relationship between the growth rate of consumption and that of R&D, both of which are determined by the same parameter values: the intertemporal rate of substitution σ; the total labor endowment $\overline{L}$; the rate of time preference ρ;

the R&D production coefficient φ; the rate of input substitution μ and the transportation costs of R&D technology g_A.

We can infer that as g_A increases (or the transportation costs of R&D technology decrease), the growth rate of R&D increases, because of

$$\frac{d\gamma_A}{dg_A} = \gamma_A \left[\frac{\sigma}{g_A(g_A+\sigma)} + \frac{\left(\frac{1}{g_A^2}\right)\left(\frac{\mu\rho}{1-\mu}\right)}{\varphi\bar{L} - \frac{1}{g_A}\frac{\mu\rho}{1-\mu}} \right] > 0 .$$

The transportation costs of R&D technology offset the monopoly power, thus reducing the incentives for new R&D, and costs of R&D technology are the main factor affecting persistent economic growth, and a low transportation cost of R&D technology is required to achieve a high growth rate.

4. DISCUSSION

In this paper, we constructed a model including the transportation costs of final goods, intermediate inputs, and R&D technology. Abdel-Rahman (1988), Fujita (1988), Rivera-Batiz (1988), and Fujita and Hamaguchi (2001) have argued that when transportation costs are too high, an economy will be caught in a zero-growth trap. Specifically, Yamamoto (2003) argued that if the transportation costs of intermediate inputs are too high, the growth rate will be zero in tradable regional economies. Our results differ mainly in that this paper modeled the impact of the transportation costs in R&D technology sector on persistent endogenous growth in the world economy. We found a detrimental effect of the transportation costs in R&D technology on endogenous growth, i.e., the larger the transportation costs, the lower the R&D productivity and the lower the economic growth. Interestingly, however, growth is not affected by the transportation costs of intermediate inputs or final goods.

The mechanism is as follows. The prices of R&D technology are directly influenced by the transportation cost of the R&D technology. The price of the R&D technology is identical to the sum of the expected future profits from producing an intermediate input discounted by the market interest rate. Therefore, the transportation costs of the R&D technology indirectly affect the sum of the expected future profits of an intermediate input and thus influence endogenous growth indirectly.

We can infer that as g_A increases (the transportation costs of R&D technology decrease), the growth rate of R&D increases, because monopoly rents are an increasing function of g_A. This is because an increase in the transportation costs of R&D technology reduces the incentive to introduce new R&D and thereby leads to slower introduction of new blueprints. Importantly, this paper argues that the growth rates of both the production and consumption of final goods decrease with increasing transportation costs in R&D technology.

5. CONCUDING REMARKS

We followed the model of Goo and Park (2007) to explore the effects of transportation costs on economic growth. The basic ideas adopted in this paper were different from well-known models in the sense that the transportation costs of three sectors are introduced and only the transportation costs of R&D technology affect the degree of monopoly power, and thus the profit in intermediate input sectors and finally influence the endogenous growth. Only the transportation costs in R&D technology affect the degree of monopoly power and thus the profits of intermediate input producers, which induces differently their investments in new technology. A key feature of this paper, therefore, is introduction of the transportation costs in three the sectors on the economic endogenous growth.

We found the negative relations between the transportation costs of R&D technology and the economic growth rate, and no relations between the transportation costs of the other sectors and economic growth. As expected, there was a detrimental effect of transportation costs on growth. However, only the transportation costs of R&D technology affect the growth. The role of the transportation costs in R&D technology is similar to the role of the knowledge spillover or to the degree of accessibility to the existing R&D technology. The increase in the degree of accessibility to the existing knowledge level among R&D developers leads to a rise in endogenous growth rates.

This paper analyzed theoretically the effects of the transportation costs of each sector on the economic growth. Thus to examine the influence of the transportation costs of R&D technology on the endogenous growth is important at this point and finding that only the transportation costs of R&D technology play an important role is also important. Our study was intended to provide a contribution to this end.

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