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Estimating innovation input–output matrix and innovation linkages in the East Asian region and the USA

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Abstract

This paper develops a multi-sector innovation model and derives a theoretical and empirical framework for an innovation version of the input–output matrix. Using industry-level total factor productivity data, we estimate innovation input–output matrices and examine the properties of innovation linkages for two areas: the East Asian region and the integrated region of East Asia and the USA. Our empirical examination favors unbalanced as opposed to balanced growth and identifies core and bottleneck sectors that are the targets of the unbalanced growth strategy. In particular, we found that sectors with high innovation backward and forward linkages are likely to become bottlenecks.

Keywords: Innovation input–output matrix, Innovation linkages, Innovation forward linkages, Innovation backward linkages, Unbalanced growth

JEL Classification: O33, R15

1 Background

There is growing recognition of the critical importance of innovation policy for advanced countries to recover from economic downturn and thrive in a highly competitive global economy. Such policy is also important for developing countries to promote and sustain economic growth. While growing interest in innovation policies has recently emerged, little attention has been paid to complementarity among heterogeneous technologies.[1] According to Rosenberg (1982), the complementarity constitutes a major characteristic of technological change. This implies that sufficient attention should be paid to the inter-sectoral spillover effects of innovation in implementing innovation policies.

Indeed, according to Hirschman (1958), the lack of inter-dependence and linkage among various industries is a typical characteristic of underdeveloped economies. Economic development and growth inevitably accompany the evolution of intensified inter-sectoral relations. Because technological change plays a critical role in this process, as

[1] For example, according to the OECD innovation strategy (OECD 2010), the following five priorities for government action promote innovation: (1) empowering people to innovate; (2) unleashing innovation in firms; (3) creating and applying knowledge; (4) applying innovation to address global and social challenges; and (5) improving the governance and measurement of policies for innovation. Although they definitely constitute crucial policy guidelines for innovation, complementarity among technologies has not been taken into account in the form of explicit policy implications.

suggested by the endogenous growth literature (see, for example, Grossman and Helpman 1991; Aghion and Howitt 1998); a sector's technological inter-dependence must be properly understood to implement development and growth policies that promote innovation.

While several studies measure inter-sectoral spillover effects in a few specific industries (see, for example, Bernstein and Nadiri 1988; Jaffe 1989; Jaffe et al. 1993), there is little empirical research that comprehensively evaluates inter-sectoral (technological) spillover effects within a country or region. Coe and Helpman (1995) and Badinger and Egger (2008) estimated international research and development (R&D) spillovers in a sample of countries associated with the Organization for Economic Co-operation and Development (OECD),[2] but their R&D spillover measures were aggregated into a few variables so that more specific inter-sectoral spillover effects were not revealed.

Dietzenbacher (2000) conducted one of the few empirical studies that analyzes technological spillover effects by disentangling them into product and process innovations under an input–output framework.[3] However, the model assumes a standard Leontief economy, and the paper evaluates the overall spillover effects of each sector.[4] This approach means that the spillover effects between two sectors could not be recovered.[5] Similarly, while both Bos et al. (2014) and Wolff and Nadiri (1993) share a similar research interest with that of the present paper, their empirical analyses were more concerned with overall spillover effects and made no attempt to reveal *inter-sectoral* spillover effects in innovation.

The purpose of this paper is first to provide the micro-foundation for a new empirical framework that evaluates the properties of innovation linkages among manufacturing sectors under a multi-sector general equilibrium framework. "Innovation linkages" refer to the effect of sector-specific innovations on productivity growth within an economy or region. For example, an increase in productivity in the ith sector affects productivity growth in other sectors, which in turn exerts some influence on the original sector. These mutual inter-dependences are termed "innovation linkages" in this paper.

Although we could start our empirical evaluation from the innovation version of the input–output matrix (innovation input–output matrix, hereafter) without specifying the underlying theoretical model, this would conceal its implicit assumptions. Therefore, to lay down the micro-foundation of the matrix, we first develop the general equilibrium model behind the matrix. After deriving this matrix, we estimate innovation linkages in East Asian countries and draw implications for growth strategies in the East Asian region and in the USA. In particular, we are interested in measuring innovation backward and forward linkages.

[2] International R&D spillover effects were measured in these studies by regressing foreign R&D capital on domestic TFP.

[3] Process innovation is defined in this study as "more output can be produced with the same amounts of the different inputs, affecting the coefficients column-wise. This implies a shift of the production function and the isoquant." Produce innovation means that "in each of the n production processes, the same amount of output can be obtained with a smaller amount of this product as an input." See Dietzenbacher (2000, p. 28).

[4] Dietzenbacher (2000) evaluated spillover effect of innovation as "the percentage of the total output change that occurs in sectors i other than the innovated sector k." See Dietzenbacher (2000, p. 32).

[5] For example, suppose the effect of innovation in the ith sector on innovation in the jth sector is denoted by γ_{ij}, which is referred to as inter-sectoral spillover effect of the ith sector on the jth sector. The overall spillover effect is measured by $\sum_j \gamma_{ij}$. Then, we cannot recover each inter-sectoral spillover effect γ_{ij} ($j = 1, \ldots, n$) from the aggregate value of $\sum_j \gamma_{ij}$.

The concepts of backward and forward linkages were originally proposed by Hirschman (1958). Backward linkages refer to the stimuli going to sectors that supply the inputs required by a particular activity, whereas forward linkages are the inducements to set up new activities that utilize the output of the proposed activity. If these linkage effects are sufficiently strong, underdeveloped countries are more likely to recover from poverty. A number of empirical studies have been conducted to measure the linkage effects based on input–output matrices and to identify key sectors (Chenery and Watanabe 1958; Rasmussen 1956; Schultz 1977; Dietzenbacher and van der Linden 1997; Miller and Lahr 2001). However, these inter-sectoral linkages are concerned with commodity transactions, which differ from innovation linkages.

This paper defines "innovation backward linkages" of the *i*th sector as the increase in productivity growth in this sector that results from productivity growth in other sectors. "Innovation forward linkages" refer to the effect of productivity growth in this sector on productivity growth in other sectors.[6] In other words, the former regards the sector as a user of innovation and measures the magnitude of benefits received from inter-sectoral spillover effects. The latter regards the sector as a supplier of innovation and measures its contribution to productivity growth in other sectors. These linkage effects can be evaluated using an innovation input–output matrix in which inter-sectoral spillover effects in innovation are described.[7]

The contribution of this paper is twofold. First, we provide a theoretical and empirical framework for deriving and constructing the *innovation* input–output matrix, which must be differentiated from the *technology* and *commodity* input–output matrices. Second, based on the former matrix, we conduct an empirical analysis of innovation backward and forward linkages and test policy effectiveness in our data. This paper distinguishes itself from the existing literature in this field by proposing a new innovation input–output matrix.

In the empirical section of this paper, the properties of innovation linkages are examined from the following two perspectives. First, we test whether a (regional) balanced growth policy is more conducive to the promotion of innovation than a (regional) unbalanced one. Note that the balanced growth policy tries to promote innovation in all sectors equally, while the unbalanced policy primarily supports innovation in selected sectors (Rosenstein-Rodan 1943; Hirschman 1958; Streeten 1959; Murphy et al. 1989). If the balanced growth policy is innovation promoting, then a uniform, balanced growth policy should be implemented. Otherwise, a sector-specific, unbalanced growth policy should be pursued. The indicator used for this test is the difference in innovation forward linkages across sectors. The outcome of our empirical examination indicates that policy should favor unbalanced growth over a balanced growth.

Second, after the unbalanced growth strategy is selected, the specific targets of the growth strategy should be identified. We identify targets in terms of "core" and "bottleneck" sectors. Core sectors refer to high-growth sectors that have high innovation

[6] For example, suppose an improvement in dynamic random access memory (DRAM) increases the productivity of personal computer (PC) and videogame sectors that use DRAM. Innovation backward linkages of the PC (videogame) sector measure its productivity gain as a result of DRAM improvement. Innovation forward linkages correspond to the sum of productivity gains in PC and videogame sectors.

[7] In what follows, we simply use the term "inter-sectoral spillover effects" instead of "inter-sectoral spillover effects in innovation." These spillover effects measure how innovation in one sector affects innovation in other sectors and vice versa. See also footnote 4.

forward linkages, while bottleneck sectors are low-growth sectors that have high innovation backward linkages. The unbalanced growth strategy should promote innovation in core and bottleneck sectors, and these sectors can be identified only through measuring innovation linkages.

We constructed the innovation input–output matrix using industry-level TFP data for Japan, Korea, China, and the USA and examined the properties of the innovation linkages in these countries. Japan, Korea, and China are included as they represent East Asian countries that have experienced high economic growth and development in the past. Moreover, the three economies have close ties, with official negotiations on a trilateral free trade pact having recently been attempted. Indeed, it is predicted that Japan, Korea, and China will soon form an integral economic region (see, for example, Wong 2006). In addition, these countries have established strong economic relations with the USA beyond their regional boundaries. It is therefore critical to examine the underlying innovation relations not only in the East Asian region, but also in the integrated region of East Asia and the USA and to ascertain the difference between the two.

Innovation promoting multi-regional growth strategies can be derived from the estimates of an innovation input–output matrix in a target region. If the target differs, the corresponding innovation input–output matrix and innovation linkages also differ, leading to different growth strategies. Hence, it should be noted that the empirical analysis in this paper is conducted using the pooled samples of the two regions selected for the study.

The remainder of the paper is organized as follows: Section 2 develops a basic theoretical model that provides a framework for the following empirical studies. Section 3 empirically estimates innovation input–output matrices and innovation linkages and derives policy implications. Finally, Sect. 4 presents conclusions.

2 The model

In this section, we develop an innovation input–output model. Consider a discrete-time closed economy (region) with n commodities and n technology components, the latter being produced by intermediate (technology component) sectors.[8] Thus, two stages of production prevail in this economy. In the first stage, technology components are produced by intermediate sectors through inter-sectoral technology transactions. In the second stage, commodity sectors purchase technology components and produce outputs. The production structure of the model is illustrated in Fig. 1.

2.1 Commodity production

The jth commodity is produced using capital, labor, and the jth technology component as inputs. Its production function is given by

$$y_{j,t} = q_{j,t} K_{j,t-1}^{\beta} L_{j,t-1}^{\alpha}, \tag{1}$$

where the subscripts j and t refer to the jth sector and time, and K_j and L_j denote the amounts of capital and labor used in this sector, respectively. It is assumed that the

[8] The intermediate sectors in this model do not produce intermediate goods. Instead, they produce technology components that are transformed to production technologies of commodity sectors.

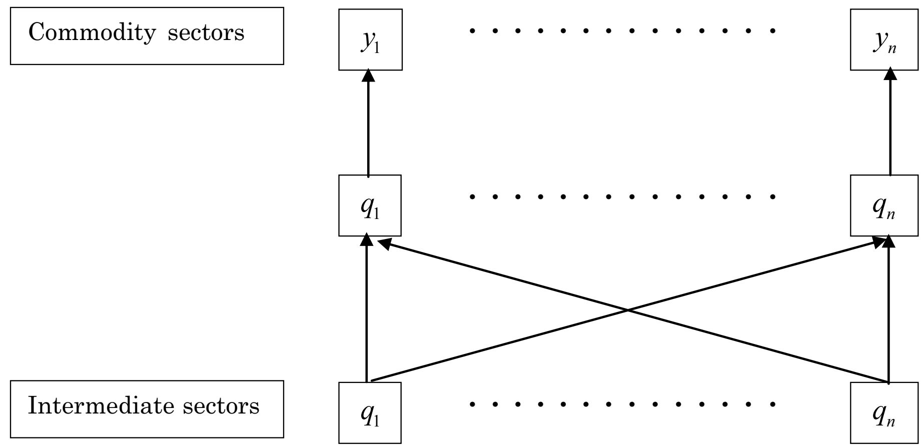

Fig. 1 Production structure

production of a given commodity takes one period to complete, so that the subscripts on the RHS variables are $t-1$, instead of t. As capital accumulation is not our primary concern, no capital depreciation is assumed to simplify the model. As we will see, constant returns to scale prevail in this production function with respect to K_j, L_j, and q_{ij}.

q_j corresponds to the productivity level of production technology in a standard production function, but this production technology must be procured at each period by purchasing one unit of technology from the jth intermediate supplier. In contrast, a standard production function assumes that production technology is available without costs, once a production function is given.

Thus, while the standard input–output model is primarily concerned with commodity production and its transaction flow, the model in this paper departs from the latter in that the production of production technology is taken into account. That is, the production technology in each commodity sector must be produced at each time by the corresponding intermediate supplier that purchases relevant technology components from other intermediate suppliers. This assumption reflects the fact that manufacturing plants must continuously procure engineering services and technical support from internal engineering departments or external contractors for their operation. This can be understood as the purchasing of relevant technology components from intermediate sectors.

Although we conceptually distinguish between intermediate and commodity sectors, it is possible that a commodity producer owns the corresponding intermediate sector as well. That is, production technology could be internally produced by a commodity producer itself, rather than being purchased from an intermediate supplier. Indeed, because no relation-specific investment is assumed in this model and constant returns to scale prevail in both intermediate and commodity sectors, as we will see, the ownership structure does not matter. Thus, we suppose that each commodity producer and intermediate supplier behaves independently, while solving the equilibrium as if the commodity producer owns the corresponding intermediate sector.

2.2 Production of production technology

The intermediate sector supplies one unit of technology component to its own and other intermediate sectors, in addition to the corresponding commodity producer. That is, each technology component is produced using technology components of its own and other sectors as inputs.[9] Because this model is directly concerned with the production of production technology, a change in the quality level of the technology component is referred to as "technological change" or "innovation." This change is caused by technology shocks in each intermediate sector. Although endogenous innovation can be easily incorporated into the model (see Harada 2014, for this application), we maintain the assumption of exogenous technology shocks in this paper because our empirical study does not require the explicit endogeneity of innovation.

We assume that technology components are produced according to an o-ring-type production function. Kremer (1993) proposes an o-ring production function that incorporates the fact that mistakes in any series of tasks can dramatically reduce the product's value. In his model, production consists of many tasks, all of which must be successfully completed for the product to have full value. It is assumed that highly skilled workers cannot substitute for low-skilled workers. Skill refers to the probability that a worker will complete a task successfully.

Harada (2014) extended the o-ring production function to the model of production technology and its endogenous innovation. This paper follows the basic model of Harada (2014) and assumes that the production function of production technology represents a technological system.[10] This consists of a series of interrelated technology components. High-quality technology components cannot be substituted for low-quality ones. Thus, in our model, the series of tasks are regarded as a series of technology components, which are provided by their own sector as well as other intermediate sectors in an economy.

Production technology that is utilized in the *j*th commodity sector is produced in the *j*th intermediate supplier according to[11]

$$q_{j,t} = A_j \prod_{i=1}^{n} q_{ij,t-1}, \tag{2}$$

where $q_{ij,t-1}$ is the quality level of the technology component i at time $t-1$ that is used in the production of the *j*th technology component at time t, and A_j denotes the intrinsic productivity level whose growth rate is assumed to be constant. Because it seems more reasonable to assume that the current technology is produced using the previous technology components rather than contemporaneous ones, once again, a one period lag is imposed in (2).

[9] Thus, each intermediate supplier can be upstream because it supplies its technology components to other intermediate suppliers. It can also be downstream because it purchases technology components from other suppliers.

[10] This specification departs from the standard specification under the input–output analysis such as dynamic TFP model in Kuroda and Nomura (2004). However, we employ the o-ring function in this paper for the following reasons. First, the o-ring function allows characterization of the equilibrium structure of the technology system consisting of many technology components, whose innovation could also be endogenously determined. Second, this production function gives rise to closed-form solutions. Third, it provides the underlying economic structure behind the innovation matrix, rather than implicitly assuming some TFP spillovers.

[11] The technology component q is treated as if it is an intermediate good in this model.

In this specification, one unit of each technology component is produced by its own and other technology components. The jth technology component produced in this production function is, in turn, supplied to its own and other technology components, in addition to the jth commodity producer. In the following equations, time subscripts are omitted to simplify the notation.

The risk neutral commodity producer maximizes

$$\max_{L,K,q} P_{j,t} A_j \prod_{i=1}^{n} q_{ij,t-1} K_{j,t-1}^{\beta} L_{j,t-1}^{\alpha} - \sum_i p\left(q_{ij,t-1}\right) - r_{t-1} K_{j,t-1} - w_{t-1} L_{j,t-1},$$

where $P_{j,t}$ denotes the price of the jth commodity, $p(q_{ij,t-1})$ is the factor price of the ith technology component,[12] and $r_{t\text{-}1}$ and $w_{t\text{-}1}$ refer to the rental and wage rates, respectively. The first-order conditions are:

$$L_{j,t-1} = \left(\alpha A_j P_{j,t} w_{t-1}^{-1} \prod_{i=1}^{n} q_{ij,t-1} K_{j,t-1}^{\beta}\right)^{\frac{1}{1-\alpha}},$$

$$K_{j,t-1} = \left(\beta A_j P_{j,t} r_{t-1}^{-1} \prod_{i=1}^{n} q_{ij,t-1} L_{j,t-1}^{\alpha}\right)^{\frac{1}{1-\beta}},$$

$$P_{j,t} A_j K_{j,t-1}^{\beta} L_{j,t-1}^{\alpha} \prod_{i \neq h}^{n} q_{ij,t-1} = p'\left(q_{hj,t-1}\right).$$

Further solving these equations for $\prod_{i=1}^{n} q_{ij,t-1}$ yields

$$L_{j,t-1} = \left(\beta r_{t-1}^{-1}\right)^{\frac{\beta}{1-\alpha-\beta}} \left(\alpha w_{t-1}^{-1}\right)^{\frac{1-\beta}{1-\alpha-\beta}} \left(A_j P_{j,t} \prod_{i=1}^{n} q_{ij,t-1}\right)^{\frac{1}{1-\alpha-\beta}},$$

$$K_{j,t-1} = \left(\beta r_{t-1}^{-1}\right)^{\frac{1-\alpha}{1-\alpha-\beta}} \left(\alpha w_{t-1}^{-1}\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(A_j P_{j,t} \prod_{i=1}^{n} q_{ij,t-1}\right)^{\frac{1}{1-\alpha-\beta}},$$

$$p'\left(q_{hj,t-1}\right) = \left(\alpha w_{t-1}^{-1}\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\beta r_{t-1}^{-1}\right)^{\frac{\beta}{1-\alpha-\beta}} \left(A_j P_{j,t} \prod_{i \neq h} q_{ij,t-1}\right)^{\frac{1}{1-\alpha-\beta}} q_{hj,t-1}^{\frac{1}{1-\alpha-\beta}-1}. \qquad (3)$$

Labor and capital market clearing conditions are

$$\sum_j L_{j,t-1} = \bar{L}, \quad \sum_j K_{j,t-1} = \bar{K}, \qquad (4)$$

where $\bar{L}$ and $\bar{K}$ denote the total amounts of labor and capital, respectively. r and w are determined to satisfy these conditions in equilibrium.

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[12] According to Fig. 1, the jth technology component is supplied to the ith intermediate supplier who in turn supplies the production technology to the ith commodity sector. However, as described above, because of constant returns, it makes no difference to assume that the ith commodity producer behaves as if it directly purchases the jth technology component.

2.3 Factor price of the technology component

Intermediate suppliers provide the technology component in elastically to each intermediate supplier. Suppose that the quality levels are represented by a quality ladder (see, for example, Aghion and Howitt 1992)

$$q_{ij,t-1} = e^{\mu_{ij,t-1}}, \tag{5}$$

where $\mu_{ij,t-1}$ takes positive values representing the current quality level.

Substituting (5) into (3) gives[13]

$$p'\left(q_{hj,t-1}\right) = \left(\alpha w_{t-1}^{-1}\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\beta r_{t-1}^{-1}\right)^{\frac{\beta}{1-\alpha-\beta}} q_{hj,t-1}^{\frac{\sum_{i\neq h}\mu_{ij,t-1}}{(1-\alpha-\beta)\mu_{hj,t-1}}-1} P_{j,t}^{\frac{1}{1-\alpha-\beta}}.$$

Integrating this yields the factor price schedule of technology component h as

$$\begin{aligned} p\left(q_{hj,t-1}\right) &= (1-\alpha-\beta)\theta_{hj,t-1}E_{j,t}, \\ \theta_{hj,t-1} &= \frac{\mu_{hj,t-1}}{\sum_{i=1}^{n}\mu_{ij,t-1}}, \end{aligned} \tag{6}$$

where $E_{j,t} \equiv P_{j,t}y_{j,t}$ is the output value of the jth commodity, and $\sum_h \theta_{hj,t-1} = 1$.[14] Thus, the commodity producer earns zero profits, as $\alpha P_{j,t}$ and $\beta P_{j,t}$ are paid to labor and capital, respectively. The jth intermediate sector receives $\sum_h p(q_{hj,t-1})$ from the jth commodity producer and $\sum_{\ell\neq j} p(q_{j\ell,t-1})$ from other intermediate sectors, which in turn are allocated to each intermediate sector supplying to the jth technology component.

The net gains are

$$\theta_{jj,t-1}\left(\sum_h p\left(q_{hj,t-1}\right) + \sum_{\ell\neq j} p\left(q_{j\ell,t-1}\right)\right) = p\left(q_{jj,t-1}\right) + \theta_{jj,t-1}\sum_{\ell\neq j} p\left(q_{j\ell,t-1}\right).$$

The LHS represents the revenues of the jth sector, and the RHS refers to the sum of the payments made to that sector. These two accounts should be equal. If production of the jth technology component does not require its own technology component, the net gains are zero.

2.4 Household

The representative household maximizes its utility function

$$u_t = \sum_{j=1}^{n} \ln y_{j,t}, \tag{7}$$

subject to

$$E_t = \sum_{j=1}^{n} P_{j,t}y_{j,t} = w_{t-1}\bar{L} + r_{t-1}\bar{K}. \tag{8}$$

[13] Note that e disappears in the following equation because it is represented in terms of $q_{hj,t-1}$.

[14] This integration is made to derive the solution that satisfies (3) and zero profits. The imposition of this integration condition is not implied by the model. Rather, this corresponds to the "guess" method of deriving value function in dynamic programming. It is easy to check that the solution satisfies both. p is strictly convex with respect to the q that ensures an optimum exists.

As w_{t-1} and r_{t-1} are determined in (4), the amount of expenditure is also determined in this equation. Assuming $E_t = 1$, we can specify the demand for each commodity as

$$y_{j,t} = \frac{1}{nP_{j,t}}. \tag{9}$$

This implies that $E_{j,t} \equiv P_{j,t}y_{j,t} = 1/n$. Then, we can determine all factor prices in (6). The remaining unknown variables are r_{t-1}, w_{t-1}, and P_j. However, we have already derived two market clearing conditions in (4) and n equations in (9). Because $y_{j,t}$ in (9) can be represented as

$$y_{j,t} = \left(\alpha w_{t-1}^{-1}\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\beta r_{t-1}^{-1}\right)^{\frac{\beta}{1-\alpha-\beta}} \left(\prod_{i=1}^{n} q_{ij,t-1}\right)^{\frac{1}{1-\alpha-\beta}} P_{j,t}^{\frac{\alpha+\beta}{1-\alpha-\beta}}, \tag{10}$$

we have $n + 2$ unknown variables and equations. This completes the model.

2.5 Allocation of the technology component

Now, let us derive the innovation input–output matrix from this theoretical model. In this model, each technology component is assumed to be supplied by independent suppliers. However, because each technology component exists in a non-physical form similar to blueprints, it is assumed that its output is duplicated without additional costs. Hence, the allocation of a technology component across sectors does not require the equality of supply and demand. Instead, we assume that it is allocated to each sector as

$$\mu_{ij,t-1} = \vartheta_{ij}\mu_{i,t-1}, \tag{11}$$

where $\vartheta_{ij} \geq 0$ is the degree of technology transfer from the ith technology component to the jth intermediate sector, and μ_i measures the total quality level of the ith component. The magnitude of ϑ_{ij} is determined based on technological inter-dependence between the two components and the absorptive capacity of the jth sector. Because duplication costs are zero, we do not require $\sum_j \vartheta_{ij} = 1$. Note that ϑ_{ij} should be positive, because the firm does not purchase the ith technology component if $\vartheta_{ij} < 0$. The matrix of ϑ_{ij} can be referred to as the *technology* input–output matrix.

2.6 Innovation input–output matrix

From (5) and (11), the productivity growth can be derived as

$$\hat{q}_{ij,t-1} = \gamma_{ij}\hat{q}_{i,t-1}, \tag{12}$$

where ^ denotes the growth rate (e.g., $\hat{q} \equiv \dot{q}/q$, $\dot{q} \equiv \partial q/\partial t$), and γ_{ij} measures the effects of innovation in the ith sector on that of the jth sector. If $\gamma > 0$, innovation is complementary to current productivity growth; however, if $\gamma < 0$, innovation is substitutable and has a negative effect on current productivity growth. Finally, $\gamma = 0$ implies that there is no innovation effect.

If innovation in the ith sector is neutral in the sense that ϑ_{ij} remains intact, we should have $\hat{q}_{ij} = \vartheta_{ij}\hat{q}_i$ from (5) and (11). In this case, $\gamma_{ij} = \vartheta_{ij}$ holds. However, innovation often changes the complementary relations between two technologies. Therefore, some innovation in the ith sector might have a substitution effect on innovation in the jth sector.

For example, the introduction of a fully automated manufacturing plant improves productivity, but it may impede process innovation, because skilled workers and foremen, who are responsible for improvement in cost and quality, would be replaced by high-tech equipment. In this case, we should have $\vartheta_{ij} \geq 0 > \gamma_{ij}$.

Note that both ϑ_{ij} and γ_{ij} refer to the technological impacts of the *i*th sector on the *j*th sector. However, ϑ_{ij} represents the effect of the *productivity level* of the *i*th sector on that of the *j*th sector. In other words, ϑ_{ij} refers to the productivity spillover effect. However, γ_{ij} measures the impact of *productivity change* (i.e., innovation) of the *i*th sector on that of the *j*th sector. This represents the innovation spillover effect. Thus, the difference between ϑ_{ij} and γ_{ij} is accounted for by whether the spillover effects imply productivity relations or innovation relations. The matrix of γ_{ij} can be referred to as the *innovation* input–output matrix.

From (2) and (12), this matrix can be represented as

$$\hat{q}_{j,t} = \hat{A}_{j,t} + \sum_i \gamma_{ij}\hat{q}_{i,t-1}.$$

Thus, we obtain

$$\begin{bmatrix} \hat{q}_{1,t} \\ \vdots \\ \hat{q}_{n,t} \end{bmatrix} = \begin{bmatrix} \hat{A}_{1,t} \\ \vdots \\ \hat{A}_{n,t} \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \cdots & \gamma_{1n} \\ \vdots & \ddots & \vdots \\ \gamma_{n1} & \cdots & \gamma_{nn} \end{bmatrix}' \begin{bmatrix} \hat{q}_{1,t-1} \\ \vdots \\ \hat{q}_{n,t-1} \end{bmatrix}.$$

In matrix notation, this is rewritten as

$$\hat{Q}_t = a_t + \Gamma'\hat{Q}_{t-1}. \tag{13}$$

Γ' corresponds to an innovation input–output matrix. This matrix indicates how productivity growth in each sector is related to the others. In particular, we are interested in the backward and forward linkages of this innovation input–output matrix. Let us refer to them as innovation backward and forward linkages to differentiate them from corresponding linkages derived from a (commodity) input–output matrix. The innovation backward and forward linkages are, respectively, calculated as

$$\mathrm{Ib}_j = \sum_{i=1}^{n} \gamma_{ij},$$

$$\mathrm{If}_j = \sum_{i=1}^{n} \gamma_{ji}.$$

The former measures the direct increase in productivity growth in the *j*th technology component when all technology components increase their productivity level. As is clear from (13), a sector with high innovation backward linkages tends to enjoy higher productivity growth when all sectors experience productivity growth.

Conversely, the innovation forward linkage measures the effect of the productivity growth in the *j*th technology component on all sectors. In other words, the innovation forward linkage indicates the benefits provided by the *j*th technology component to all sectors. By definition, a sector with high innovation forward linkages does not necessarily enjoy higher productivity growth, although this sector contributes to productivity growth in other sectors.

2.7 Balanced versus unbalanced growth

The innovation forward linkage represents a marginal effect on economic growth. If the innovation forward linkages are the same across sectors, there is no reason to select a specific sector as a target of growth policy. Instead, it would be desirable to increase productivity in all sectors in a balanced manner without generating inequality. However, if the innovation linkages are different, it would be more innovation promoting to focus on the sector with the maximum innovation forward linkages and provide subsidies.

The idea that a significant advance in a few sectors is more successful than small advances in many sectors simultaneously is suggested by proponents of "unbalanced growth" (Hirschman 1958; Streeten 1959), as opposed to "balanced growth" (Rosenstein-Rodan 1943; Murphy et al. 1989). According to Streeten (1959), the conditions favoring unbalanced growth include the following: (1) indivisibilities are important, (2) expansion costs are important, (3) higher incomes are created than would be by balanced growth, and (4) incentives to invent and to apply inventions are strengthened. If these conditions are satisfied, then the choice of investment priorities would be a stimulus for growth. That is, the growth policy should focus on the sectors that generate the strongest stimuli for growth. In this model, (3) and (4) can be evaluated by innovation forward linkages.

Suppose that, currently, no innovation takes place in all sectors, and each sector generates innovation $\hat{q} = 1$ by the fixed amount of R&D investment, ϕ. To make subsequent analysis as simple as possible, assume that $\hat{q} = k$ is achieved by the R&D investment of $k\phi$. That is, the innovation production function is linearly dependent on R&D investment. Assume that the social planner has a budget of $n\phi$. Under a balanced growth policy, the social planner subsidizes all sectors equally, so that each sector receives ϕ and its growth rate is $\hat{q} = 1$. In contrast, under an unbalanced growth policy, the social planner selects m sectors ($m < n$), whose innovation forward linkages are higher than other sectors, and subsidizes these. Hence, each selected sector receives $n/m\phi$ and achieves $\hat{q} = n/m$.

From (7), the growth rate in this economy can be measured by $\sum_j \hat{y}_{j,t}$. Substituting (9) into (10) and rearranging yields

$$\hat{y}_{j,t} = -\hat{P}_{j,t} \propto \sum_{i=1}^{n} \hat{q}_{ij,t-1}. \tag{14}$$

From (12), the economic growth rate in the economy is represented by

$$\sum_j \hat{y}_{j,t} \propto \sum_{i=1}^{n} \gamma_{ij}\hat{q}_{i,t-1} = \sum_{i=1}^{n} \hat{q}_{i,t-1} \sum_{j=1}^{n} \gamma_{ij} = \sum_{i=1}^{n} \hat{q}_{i,t-1}\mathrm{If}_i. \tag{15}$$

Obviously, the magnitude of the ith sector's innovation effect is proportional to If_i. Hence, we can derive the following:

Proposition *Both balanced and unbalanced growth policies achieve the same growth rate if and only if* $\mathrm{If}_i = \mathrm{If}_j$ *for all* $i = j$*. Otherwise, an unbalanced growth policy will achieve a higher growth rate.*

Of course, this proposition is derived from the perspective of economic growth alone. The unbalanced growth policy might generate income inequality, and this might induce some welfare loss. This proposition does not take into account these effects on welfare. If $\mathrm{If}_i = \mathrm{If}_j$ holds for all $i = j$, both growth policies would be equally innovation promoting. In this case, however, balanced growth would be more favorable in terms of social welfare as it does not generate inequality.

3 Empirical analysis

Having presented the theoretical background of the model, we are now in a position to conduct an empirical analysis of the proposition of balanced versus unbalanced growth strategies. For this purpose, we need to construct an innovation input–output matrix.

3.1 Data

For the construction of Γ', we extracted the industry-level TFP data from the International Comparison of Productivity among Asian Countries (ICPA) database of the Research Institute of Economy, Trade and Industry (RIETI) in Japan [International Comparison of Productivity among Asian Countries (ICPA) Database (1998–2000)]. This database provides the relevant data on Japan, Korea, Taiwan, China, and the USA. Because TFP data are not available for a few industries in Taiwan, we removed Taiwan from the study and only constructed innovation input–output matrices for Japan, Korea, China, and the USA. The data cover the years 1980–2000 for most countries. We selected 15 sectors consisting of chemicals, petroleum and coal products, leather, stone/clay/glass, primary metal, fabricated metal, machinery, electrical machinery, motor vehicles, transportation equipment and ordnance, instruments, rubber and miscellaneous plastics, miscellaneous manufacturing, transportation, and communication. Most of these sectors belong to manufacturing industries. Other manufacturing sectors in this database include food, textile, apparel, lumber, furniture, paper, and printing. These sectors were deleted from the sample because they generally belong to low-tech fields.

The service sector consists of electric utilities, gas utilities, trade, finance and real estate, other private services, and public services in the dataset. This sector is excluded from the analysis because the classification of the services sector is rather crude compared with those in the manufacturing sector. Therefore, to estimate rigid innovation linkages, the following empirical analysis focuses only on the 15 manufacturing sectors.

When estimating the innovation linkages, we had to consider the magnitude of the technology use in each sector's innovation activity. For example, some sectors do not use machinery technology during innovation activities. In such cases, the spillover effects from that technology component on the sector's innovation should not be expected, at least directly. To control for the magnitude of the technology component use, we use the R&D expenditure ratio on each technology component as the proxy for the magnitude of use of that technology.

Although such data are generally not publicly available, the "Survey of Research and Development" published annually by the Ministry of Internal Affairs and Communications in Japan reports R&D statistics for expenditure across different sectors at the two-digit SIC level (Survey of Research and Development 2002). We use 2002 data to control for the magnitude of the technology component use in each sector, in the evaluation of innovation backward and forward linkages.[15]

Specifically, suppose that the R&D expenditure in the *i*th technology component by the *j*th sector is R_{ji}. Then, the sector's total R&D expenditure—excluding its own sector's technology—amounts to $R_{j-j} = \sum_{i \neq j} R_{ji}$. We exclude R_{jj} in this sum because it is obvious that the sector's technology is fully used for its own innovation. Define the R&D ratio of the *i*th technology component as $\zeta_{ji} \equiv R_{ji}/R_{j-j}$. This measures the magnitude of use of the *i*th technology component in the sector's innovation. Then, the *i*th sector's TFP growth to be used in this sector is $\zeta_{ji}\hat{q}_i$. We use these transformed values as explanatory variables in the following regression analysis.

3.2 Estimating innovation input–output matrices and innovation linkages

Using TFP growth data on 15 sectors in Japan, Korea, and China, we can construct the innovation input–output matrix Γ' by regression analysis that represents inter-sectoral innovation linkages. The regression equation is derived from (13) as

$$\hat{Q}_t = a_t + \Gamma' \hat{Q}_{t-1} + \varepsilon, \tag{16}$$

where ε is the error term. Note that we have 16 unknown parameters to be estimated for each sector including constant terms, while the data cover approximately 20 years for each country. To circumvent the insufficient number of observations, matrix coefficients were estimated using the pooled sample. Because this sample is an unbalanced panel data, we conducted both fixed- and random-effect regressions. In all 15 sectors, the Hausman specification test selected random-effect models. Table 1 reports the results.

Although we do not interpret these estimates in detail because of space limitations, it should be mentioned that no common pattern can be observed across the 15 sectors. For example, while many sectors have several significant estimates, the electrical machinery and communication sectors receive no significant effects from productivity growth in other sectors. In addition, some coefficients are negative and significant, indicating substitutable effects of productivity growth. However, more than a half of significant coefficient estimates are positive.

Besides the statistical significance, not all sectors affect the TFP growth in other sectors because of zero R&D investment. When there is no R&D investment in a particular technology, then we excluded the corresponding TFP growth from the regression analysis. Therefore, the result shows that some sectors do not interact with other sectors in terms of contributing to the latter's innovation. In other words, the result reflects localized interaction across sectors (Horvath 2000).

Note that this estimation assumes the existence of a common innovation input–output matrix across the three countries in the East Asian region, controlling for the influence of country-specific factors. However, as we have mentioned before, each country has

[15] The oldest electrical data are publicly available for 2002; hence, we used this dataset.

Table 1 Innovation input–output matrix (Γ') (excluding the USA)

Variables	Chem.	Petro.	Leather	Clay	P. metal	F. metal	Machine	Electrical
Chemical	0.009 (0.216)	−0.171 (0.133)	1.067 (0.300)	0.726 (0.362)	4.222 (1.935)	2.185 (11.579)	−9.059 (21.257)	1.898 (7.108)
Petroleum	18.055 (8.334)	0.432 (0.135)	−0.508 (1.164)	–	–	−0.250 (0.235)	–	–
Leather	24.978 (10.376)	−12.994 (4.843)	0.225 (0.120)	–	–	–	–	–
Clay glass	−3.116 (1.739)	26.303 (26.536)	−0.600 (2.233)	−0.267 (0.169)	−4.006 (2.623)	−47.194 (63.589)	29.058 (15.170)	0.069 (24.154)
Primary metal	–	–	–	20.926 (14.371)	0.330 (0.153)	1.524 (2.358)	−6.530 (6.652)	33.637 (942)
Fabricated metal	7.192 (11.749)	–	–	2.469 (4.189)	−0.024 (0.811)	0.132 (0.161)	8.073 (6.353)	54.333 (55.605)
Machinery	−1.016 (1.244)	–	2.279 (2.065)	−4.398 (2.177)	−1.261 (0.385)	0.812 (0.744)	0.001 (0.211)	0.957 (2.405)
Electrical machinery	14.029 (43.995)	–	−10.765 (11.523)	−186.645 (227)	8.637 (21.582)	−1.348 (0.762)	1.676 (1.818)	0.056 (0.198)
Motor vehicle	5.572 (3.558)	–	1.264 (0.506)	2.930 (1.051)	3.226 (2.742)	1.418 (1.084)	0.967 (0.839)	0.293 (0.706)
Transportation equipment	–	–	–	−42.926 (51.372)	5.327 (9.362)	153.309 (211)	4.083 (3.305)	59.253 (133)
Instrument	0.537 (0.729)	–	0.251 (1.930)	1.066 (3.979)	302.409 (96.902)	−2.004 (1.775)	−0.499 (0.262)	−2.405 (2.465)
Rubber	−20.284 (7.620)	−3.186 (19.413)	−91.628 (44.036)	3650.780 (10,519)	686.016 (1165)	−21.575 (47.887)	8.522 (20.171)	−0.794 (227)
Misc. manufacturing	0.659 (1.748)	–	−0.519 (1.612)	1.295 (0.839)	9.727 (6.270)	1.004 (0.497)	0.186 (1.088)	54.505 (48.644)
Transportation	–	–	–	−55.674 (57.145)	2.015 (10.425)	−539.495 (241)	−12.498 (3.694)	−173.413 (148)
Communication	8.489 (12.000)		30.121 (13.297)	6.081 (2.099)	−2.250 (11.403)	90.576 (26.440)	5.592 (0.078)	0.140 (0.136)

Variables	Motor	Tran. eq.	Inst.	Rubber	Misc.	Trans.	Comm.
Chemical	115.622 (92.532)	–	–	0.211 (2.199)	19.512 (7.290)	–	1664.010 (1783)
Petroleum	–	–	–	–	–	–	–
Leather	1.387 (3.316)	–	–	–	18.304 (6.370)	–	–
Clay glass	–	–	27.998 (25.270)	–	534.823 (1086)	–	138.125 (327)
Primary metal	−29.039 (16.059)	–	–	–	–	–	−30,813 (36,438)
Fabricated metal	4.100 (8.254)	204.481 (216)	–	49.682 (16.915)	−0.178 (0.475)	308.055 (197)	−455.735 (460)
Machinery	1.252 (0.523)	−0.054 (0.275)	0.637 (0.457)	−41.521 (21.468)	0.458 (0.565)	0.085 (0.248)	4.018 (8.197)
Electrical machinery	−2.247 (14.700)	–	−23.004 (12.822)	224.852 (145)	−0.656 (0.995)	–	0.338 (0.332)
Motor vehicle	0.039 (0.145)	−4.486 (12.202)	3.126 (3.675)	0.858 (0.475)	3.063 (1.248)	5.640 (11.221)	−5.251 (26.525)
Transportation equipment	−0.100 (0.370)	0.269 (0.143)	–	−1.391 (2.345)	2.811 (9.900)	0.507 (1.017)	–
Instrument	−1.799 (11.468)	43.559 (48.389)	−0.238 (0.179)	0.206 (12.569)	−5.016 (6.397)	−11.296 (44.343)	−5.433 (4.708)
Rubber	–	–	–	−0.429 (0.232)	−6.540 (2.348)	–	209.731 (396)
Misc. manufacturing	−2.124 (3.084)	7.452 (18.527)	2.112 (3.530)	0.854 (1.201)	−0.103 (0.126)	35.448 (17.031)	140.672 (262)

Table 1 continued

Variables	Motor	Tran. eq.	Inst.	Rubber	Misc.	Trans.	Comm.
Transportation	−0.791 (0.362)	−0.706 (1.209)	–	0.996 (2.314)	−23.525 (10.584)	−0.077 (0.142)	–
Communication	– 115.622	353.197 (205)	1.467 (1.244)	– 0.211	−44.246 (62.574)	297.278 (184)	0.144 (0.171)

The number of observations is 53. The dependent variable is productivity growth. All coefficients are estimated by random-effect models. Standard errors are shown in parentheses. Constant terms are omitted

Data source: ICPA database

already established strong economic ties with the USA. Hence, it is of equal importance to construct the innovation input–output matrix for the integrated region of East Asia and the USA. The results are reported in Table 2.

The overall pattern of the matrix in this table seems to remain the same as before. Once again, the electrical machinery and communication sectors have no significant coefficients. In other sectors, however, statistical significance and sign conditions differ slightly from those in Table 1.

To see the difference more clearly, we calculated the innovation backward and forward linkages and examined their significance using a *Z* test. Table 3(a) shows the results.

Comparing the two samples, no difference exists in terms of statistical significance and sign condition. All other linkages show the same pattern between the two samples. Thus, even if the USA is added to the East Asian countries, the properties of innovation linkages remain almost the same. This implies that growth strategy in the East Asian region should not be significantly altered even if this strategy is extended to include the USA.

Surprisingly, the data show no significant innovation backward and forward linkages in the electrical machinery sector. This is probably because of the fact that, while this sector should have positive innovation backward and forward linkages in terms of commodity and technology linkages, it has received and exerted little influence in terms of innovation linkages. Obviously, the linkages in this sector are significantly related to process technologies in other sectors, but appear to be less related to product innovation. This result might reflect the fact that product innovation becomes more important than process innovation in terms of productivity growth.[16]

Regarding innovation backward linkages, transportation equipment has positive effects. This is reasonable, because this sector requires a variety of technology components to complete its products. Hence, its innovation backward linkages result in positive effects.

Regarding innovation forward linkages, the chemical and primary metal sectors have strong effects, with no innovation backward linkages. However, while the chemical sector exerts positive effects, the primary metal sector negatively contributes to other sectors' innovation. This is probably because innovation in materials first leads to the replacement of current products using primary metal. In the short run, this substitution effect dominates. However, in the longer run, this innovation is fully incorporated into new products, leading to more TFP growth. Therefore, we expect that with a longer time

[16] In this context, process innovation refers to technical change in production technologies for a given product, while product innovation means technical change in that product.

Table 2 Innovation input–output matrix (Γ') (with the USA)

Variables	Chem.	Petro.	Leather	Clay	P. metal	F. metal	Machine	Electrical
Chemical	−0.082 (0.192)	−0.155 (0.136)	0.784 (0.309)	0.577 (0.368)	3.738 (2.107)	4.248 (10.908)	−3.301 (20.492)	2.764 (6.967)
Petroleum	17.518 (7.086)	0.407 (0.126)	−0.153 (1.124)	–	–	−0.137 (0.197)	–	–
Leather	20.913 (8.083)	–	0.138 (0.108)	–	–	–	–	–
Clay glass	−3.151 (1.662)	−9.753 (4.798)	−1.068 (2.409)	−0.251 (0.169)	−2.864 (2.817)	−79.588 (58.218)	20.326 (14.230)	−1.571 (23.405)
Primary metal	–	3.595 (24.938)	–	18.272 (13.184)	0.270 (0.149)	3.899 (1.941)	2.293 (5.749)	342.843 (824)
Fabricated metal	7.651 (10.546)	–	–	2.527 (4.034)	−0.015 (0.831)	0.206 (0.140)	13.743 (5.763)	71.777 (51.179)
Machinery	−0.851 (1.014)	–	2.947 (1.902)	−2.716 (1.974)	−0.896 (0.370)	0.680 (0.620)	0.009 (0.182)	0.950 (2.069)
Electrical machinery	12.181 (39.365)	–	3.382 (11.855)	−78.772 (222)	24.512 (22.762)	−1.126 (0.689)	2.382 (1.675)	0.140 (0.189)
Motor vehicle	4.807 (3.117)	–	0.912 (0.502)	1.885 (1.013)	1.679 (2.825)	0.880 (0.971)	0.596 (0.772)	0.178 (0.654)
Transportation equipment	–	–	–	−29.489 (49.358)	8.224 (9.661)	190.806 (187)	1.684 (2.998)	23.894 (123)
Instrument	0.618 (0.610)	–	−1.067 (1.844)	−1.631 (3.713)	193.623 (97.190)	−1.754 (1.512)	−0.526 (0.231)	−3.072 (2.229)
Rubber	−17.285 (6.807)	–	−64.012 (45.548)	4444.790 (10,798)	577.593 (1281)	−46.008 (45.009)	−3.179 (19.550)	−42.447 (225)
Misc. manufacturing	0.847 (1.456)	−0.272 (18.113)	−0.280 (1.529)	0.933 (0.802)	2.364 (6.437)	0.511 (0.428)	−1.300 (0.986)	15.565 (45.006)
Transportation	–	–	–	−47.833 (55.587)	2.715 (10.809)	−266.441 (213)	−7.478 (3.401)	−113.100 (138)
Communication	6.910 (10.677)	–	21.469 (13.860)	4.444 (2.088)	−12.869 (11.735)	66.259 (23.963)	−0.657 (6.109)	0.026 (0.482)

Variables	Motor	Tran. eq.	Inst.	Rubber	Misc.	Trans.	Comm.
Chemical	137.270 (94.429)	–	–	−0.312 (2.071)	18.825 (6.286)	–	2211.040 (1417)
Petroleum	–	–	–	–	–	–	–
Leather	0.551 (2.819)	–	–	–	13.657 (4.737)	–	–
Clay glass	–	–	22.374 (21.255)	–	525.281 (1006)	–	114.600 (255)
Primary metal	−20.827 (15.064)	–	–	–	–	–	−27,165 (26,678)
Fabricated metal	6.322 (7.737)	240.935 (184)	–	44.180 (15.411)	0.051 (0.416)	158.022 (170)	−399.937 (356)
Machinery	0.516 (0.428)	0.030 (0.194)	0.497 (0.331)	−29.293 (17.296)	0.506 (0.438)	−0.114 (0.176)	0.188 (6.088)
Electrical machinery	−3.457 (13.900)	–	−23.268 (10.275)	196.797 (131)	−0.780 (0.867)	–	0.256 (0.251)
Motor vehicle	0.132 (0.133)	−3.445 (10.284)	2.594 (2.868)	0.499 (0.418)	2.774 (1.066)	4.950 (9.492)	3.317 (20.069)
Transportation equipment	0.048 (0.342)	0.212 (0.118)	–	−1.337 (2.075)	2.303 (8.420)	0.966 (0.844)	–
Instrument	6.923 (10.207)	27.058 (39.817)	−0.186 (0.138)	−0.126 (10.652)	−5.043 (5.245)	25.527 (36.870)	−3.745 (3.449)
Rubber	–	–	–	−0.396 (0.220)	−6.435 (2.055)	–	103.231 (318)

Table 2 continued

Variables	Motor	Tran. eq.	Inst.	Rubber	Misc.	Trans.	Comm.
Misc. manufacturing	−1.868 (2.796)	6.039 (15.051)	1.763 (2.765)	0.506 (1.071)	−0.055 (0.101)	29.762 (13.928)	171.921 (200)
Transportation	−0.529 (0.347)	−0.645 (1.006)	–	1.320 (2.132)	−20.209 (9.255)	0.001 (0.120)	–
Communication	–	347.673 (175)	1.526 (1.016)	–	−34.053 (53.830)	166.939 (159)	0.162 (0.140)

The number of observations is 72. The dependent variable is productivity growth. All coefficients are estimated by random-effect models. Standard errors are shown in parentheses. Constant terms are omitted

Data source: ICPA database

lag, the innovation in the primary metal sector would positively affect TFP growth in other sectors.

The remaining significant sectors are rubber and transportation, with both sectors having innovation backward and forward linkages. Particularly, the rubber sector has positive effects on both linkages, indicating that this sector is a key to innovation in our dataset. The transportation sector exerts positive innovation backward linkages, but its effects on innovation forward linkages are negative. Because transportation requires a variety of technology components, the positive backward linkages are reasonable. However, its negative innovation forward linkages imply that an improvement in transportation services exerts substitution effects on other sectors, at least in the short run. Therefore, facilitating innovation in this sector might cause a short-run productivity slowdown.

Finally, note that the communication sector has no significant innovation backward or forward linkages. However, in our alternative empirical analysis that used simple TFP growth data as explanatory variables, the communication sector generated positive innovation forward linkages. This result is consistent with the fact that the IT revolution contributed to positive economic growth (see, for example, Brynjolfsson and Hitt 1996). The difference arises because the four sectors (i.e., petroleum, leather, transportation equipment, and transportation) do not invest in communication technology in our dataset. Therefore, Table 3(a) does not take into account the effects of these sectors in the regression analysis. Non-adjusted data might be more realistic in evaluating innovation linkages in the sectors, because most of the sectors receive some spillover effects from communication technology, even although some of the sectors do not make R&D investments in communication technology. It is important to note this when interpreting the innovation linkage results. Although we cannot discuss this in detail because of space limitation, we show the alternative regression analysis results for innovation backward and forward linkages in Table 3 (b).

3.3 Evaluating growth strategies

Given these estimates of innovation linkages, we are now in a position to compare the magnitudes of such linkages in the balanced and unbalanced growth strategies. To achieve this, the difference in innovation forward linkages across the sectors must be tested. We calculated the Z statistics for the pairwise difference between two sectors in

Table 3 Innovation backward and forward linkages

Sector	Without USA		With USA	
	Backward	Forward	Backward	Forward
(a)				
Chemical	55 (36,491)	1800*** (50)	50 (26,723)	2375*** (44)
Petroleum	10 (32)	18 (33)	−6 (30)	18 (31)
Leather	−69 (49)	45 (48)	−37 (51)	35 (49)
Clay and glass	3396 (10,559)	662 (10,522)	4313 (10,841)	584 (10,801)
Primary metal	1014 (1168)	−30,767*** (1170)	798 (1286)	−26,815*** (1285)
Fabricated metal	−361 (310)	183 (332)	−128 (277)	145 (295)
Machinery	30* (16)	−38 (35)	25 (15)	−28 (34)
Electrical machinery	29 (978)	25 (993)	298 (866)	132 (878)
Motor vehicle	86 (94)	19 (96)	125 (95)	22 (98)
Transportation equipment	604** (302)	181 (303)	618** (252)	197 (259)
Instrument	12 (32)	319*** (29)	5 (27)	237*** (24)
Rubber	234* (139)	4414*** (148)	212* (123)	4946*** (134)
Misc. manufacturing	499 (1066)	248 (1089)	497 (987)	226 (1008)
Transportation	636** (274)	−803*** (274)	386* (231)	−452* (237)
Communication	−29,123 (36,675)	747 (36,490)	−24,964 (26,843)	568 (26,722)
(b)				
Chemical	0.539 (0.836)	2.031*** (0.705)	0.529 (0.730)	1.729*** (0.617)
Petroleum	0.307 (0.518)	0.620* (0.373)	−0.074 (0.490)	0.906*** (0.308)
Leather	0.805*** (0.233)	2.184*** (0.812)	0.785*** (0.246)	2.027*** (0.618)
Clay and glass	0.711** (0.295)	−0.530 (0.807)	0.585* (0.302)	−0.682 (0.732)
Primary metal	0.735** (0.318)	−0.418 (0.873)	0.578** (0.275)	−0.100 (0.724)
Fabricated metal	0.403* (0.224)	2.602** (1.204)	0.441** (0.192)	2.649** (1.047)
Machinery	0.313 (0.296)	−0.424** (1.204)	0.357 (0.273)	−0.521 (0.938)
Electrical machinery	0.733 (0.516)	−0.251 (0.598)	0.726 (0.472)	−0.126 (0.528)
Motor vehicle	0.142 (0.235)	3.786*** (0.984)	0.205 (0.206)	3.153** (0.858)
Transportation equipment	0.037 (0.374)	0.339 (0.664)	0.224 (0.301)	0.458 (0.568)
Instrument	1.120*** (0.402)	−0.932 (0.620)	0.814** (0.342)	−0.857 (0.514)

Table 3 continued

Sector	Without USA		With USA	
	Backward	Forward	Backward	Forward
Rubber	0.645 (0.403)	−2.224** (0.959)	0.562 (0.374)	−2.211*** (0.846)
Misc. manufacturing	0.167 (0.223)	1.495* (0.856)	0.311 (0.196)	0.739 (0.692)
Transportation	0.592** (0.286)	−2.263*** (0.730)	0.383 (0.272)	−1.279** (0.636)
Communication	0.196 (0.765)	1.429*** (0.408)	0.363 (0.586)	0.905** (0.359)

*, **, and *** Significance level at 10, 5, and 1 %, respectively

Standard errors are shown in parentheses

innovation forward linkages. Tables 4 and 5 show the results in the samples without and with the USA, respectively.

These tables clearly suggest that many pairs of sectors are statistically different in innovation forward linkages. In particular, innovation forward linkages of the chemical, primary metal, instrument, rubber, and transportation sectors are significantly different from those of many other sectors. These sectors also exert strong innovation forward linkages in Table 3. Thus, sectors with significant innovation forward linkages tend to be differentiated from many other sectors in the pairwise difference of innovation forward linkages.

These results imply that an unbalanced growth strategy should be pursued in both regions. Suppose some kind of unbalanced growth strategy is chosen to be implemented in these regions. The next question to arise is which sectors should become the targets of this unbalanced strategy. In development strategy, Hirschman (1958) suggested that investment should be promoted in the sectors that induce more investment in other sectors. In the innovation input–output analysis, this implies that sectors that induce more innovation should be subsidized to increase productivity growth. In other words, sectors with high innovation forward linkages should become the targets. If we select sectors based on the 5 % significance level, then the target sectors are chemical, instrument, and rubber, and the primary metal sector is excluded because of its negative sign. Additionally, in our alternative regression analysis, the communication sector generated strong innovation forward linkages.

To further characterize these sectors, Table 6 lists the growth rate and volatility of these sectors. As the average growth rates for the 15 sectors are 1.54 and 1.72 % for with and without the US samples, respectively, only the communication sector achieves higher productivity growth than the average in both regions. The instrument sector achieves higher growth than the average in the East Asian region, but slightly lower growth than the average in the integrated region. Therefore, the core sector becomes communication in both regions. The other sectors—chemical, instrument, and rubber—are characterized as bottleneck sectors owing to their lower growth rates.

The growth strategy should maintain the current growth rates of the core sectors, while promoting more productivity growth in the bottleneck sectors. In the case of core sectors, more emphasis might be placed on removing current trade barriers and facilitating trade liberalization in the target region to boost innovation in the region as a whole.

Table 4 *Z* **tests for pairwise differences in innovation forward linkages (without the USA)**

Variables	Petro	Leather	Clay	P metal	F metal	Machine	Elec	Motor	Trans eq	Instru	Rubber	Misc.	Trans	Com
Chemical	29.8***	25.5***	0.1	27.8***	4.8***	30.1***	1.8**	16.4***	5.3***	25.8***	−16.7***	1.4	9.3***	0.3E−01
Petroleum	–	−0.4	−0.6E−01	26.3***	−0.5	1.1	−0.7E−02	−0.9E−02	−0.5	−6.9***	−29.0***	−0.2	3.0***	−0.2E−01
Leather		–	−0.6E−01	26.3***	−0.4	1.4	0.2E−01	0.2	−0.4	−4.9***	−28.0***	−0.2	3.0***	−0.2E−01
Clay and glass			–	3.0***	0.5E−01	0.7E−01	0.6E−01	0.6E−01	0.5E−01	0.3E−01	−0.4	0.4E−01	0.1	−0.2E−02
Primary metal					−−25.4***	−26.3***	−20.1***	−26.2***	−25.6***	−26.6***	−29.8***	−19.4***	−24.9***	−0.9
Fabricated metal					–	0.7	0.2	0.5	0.3E−02	−0.4	−11.6***	−0.6E−01	2.3**	−0.2E−01
Machinery						–	−0.6E−01	−0.6	−0.7	−7.8***	−29.2***	−0.3	2.8***	−0.2E−01
Electrical machinery							–	0.6E−02	−0.2	−0.3	−4.4***	−0.2	0.8	−0.2E−01
Motor vehicle								–	−0.5	−3.0***	−24.9***	−0.2	2.8***	−0.2E−01
Transportation equip									–	−0.5	−12.5***	−0.6E−01	2.4**	−0.2E−01
Instrument										–	−27.1***	0.7E−01	4.1***	−0.1E−01
Rubber											–	3.8***	16.7***	0.1
Misc. manufacturing												–	0.9	−0.1E−01
Transportation														−0.4E−01

Z statistics are reported in the table

*, **, and *** Significance level at 10, 5, and 1 %, respectively

Table 5 ***Z*** **tests for pairwise differences in innovation forward linkages (with the USA)**

Variables	Petro	Leather	Clay	P metal	F metal	Machine	Elec	Motor	Trans eq	Instru	Rubber	Misc.	Trans	Com
Chemical	44.6***	35.4***	0.2	22.7***	7.5***	43.3***	2.6**	22.0***	8.3***	42.6***	−18.2***	2.13**	11.7***	0.7E−01
Petroleum	–	−0.3	−0.5E−01	20.9***	−0.4	1.0	−0.1	−0.4E−01	−0.7	−5.6***	−35.8***	−0.2	2.0**	−0.2E−01
Leather		–	−0.5E−01	20.9***	−0.4	1.1	−0.1	0.1	−0.6	−3.7***	−34.4***	−0.2	2.0**	−0.2E−01
Clay and glass			–	2.5**	0.4E−01	0.5E−01	0.4E−01	0.5E−01	0.3E−01	0.3E−01	−0.4	0.3E−01	1.0E−01	0.6E−03
Primary metal				–	−20.4***	−20.8***	−17.3***	−20.8***	−20.6***	−21.0***	−24.6***	−16.6***	−20.2***	−1.0
Fabricated metal					–	0.6	0.1E−01	0.4	−0.1	−0.3	−14.8***	−0.8E−01	1.6	−0.2E−01
Machinery						–	−0.2	−0.5	−0.9	−6.4***	−36.0***	−0.3	1.8*	−0.2E−01
Electrical machinery							–	0.1	−0.7E−01	−0.1	−5.4***	−0.7E−01	0.6	−0.2E−01
Motor vehicle								–	−0.6	−2.1**	−29.7***	−0.2	1.8**	−0.2E−01
Transportation equip									–	−0.2	−16.3***	−0.3E−01	1.9**	−0.1E−01
Instrument										–	−34.6***	0.1E−01	2.9***	−0.1E−01
Rubber											–	4.6***	,19.8***	0.2
Misc. manufacturing												–	0.7	−0.1E−01
Transportation													–	−0.1E−01

Z statistics are reported in the table

*, **, and *** Significance level at 10, 5, and 1 %, respectively

Table 6 Average growth rate and volatility

Sector	Without USA		With USA	
	Growth	Variance	Growth	Variance
Sector average	0.017	0.003	0.015	0.002
Chemical	0.013	0.007	0.011	0.005
Petroleum	0.010	0.006	0.009	0.006
Leather	0.008	0.002	0.007	0.001
Clay and glass	0.013	0.002	0.012	0.002
Primary metal	0.006	0.002	0.007	0.001
Fabricated metal	0.009	0.001	0.008	0.001
Machinery	0.018	0.001	0.023	0.001
Electrical machinery	0.042	0.004	0.044	0.003
Motor vehicle	0.016	0.001	0.012	0.001
Transportation equipment	0.013	0.002	0.010	0.002
Instrument	0.020	0.004	0.017	0.003
Rubber	0.012	0.004	0.013	0.003
Misc. manufacturing	0.005	0.001	0.006	0.001
Transportation	0.005	0.002	0.005	0.001
Communication	0.066	0.007	0.048	0.006

Innovation can diffuse without commodity trade, but its linkages will be magnified if it is actually purchased. For example, trade restrictions during the Edo era and in World War II blocked the import of foreign commodities to Japan, with negative impacts on productivity growth. The removal of foreign import restrictions after the Meiji restoration and again after World War II provided the spur for economic growth. Hence, trade barriers that impede commodity and innovation flows should be removed for the purpose of promoting innovation. In the case of bottleneck sectors, more policy intervention is needed to promote productivity growth by subsidizing R&D investment.

Among the targets of unbalanced growth strategy, only the rubber sector has both significantly positive innovation backward linkages and has low growth rates. Thus, the innovation backward linkages seem to exert a negative effect on productivity growth among the target sectors. This occurs because high innovation backward linkages are sensitive to productivity changes in other sectors. When other sectors enjoy positive growth, sectors with high innovation backward linkages also experience a positive effect. Conversely, in the case of productivity decline, the productivity of those sectors is negatively affected. Over the 20 years of data, these sectors may have experienced even more negative effects. Thus, paradoxically, sectors with high innovation forward and backward linkages tend to become bottlenecks.

As we have seen, an unbalanced growth strategy that aims to improve productivity growth in this core and bottleneck sectors should be implemented. However, because the coverage of the strategy extends beyond national boundaries, it would be difficult to implement. In particular, without policy coordination across the countries, an innovation promoting unbalanced strategy cannot be put into practice. For example, it cannot be expected for one country to subsidize R&D investment in another country unless that R&D is undertaken by domestic firms. However, the country can indirectly subsidize R&D in another country by removing trade barriers. In turn, such indirect subsidization has positive repercussions in domestic sectors. Policy coordination in implementing a growth strategy will always involve practical difficulty, but the difficulty can be avoided with a proper understanding of the innovation input–output matrix and innovation linkages in the target region.

4 Concluding remarks

This paper developed the underlying theoretical model for an innovation input–output matrix and derived the implications for growth strategy. Our empirical investigation in four countries—the USA, Japan, Korea, and China—revealed that innovation linkages are sometimes negative but quite a few sectors show positive and significant innovation linkage effects. The estimated innovation linkages of the two regions—the East Asian region and the integrated region of East Asia and the USA—showed similar patterns.

The empirical tests favored an unbalanced growth strategy, and communication is identified as a core sector, while chemical, instrument, and rubber are bottlenecks. In particular, rubber showed lower growth with positive and significant innovation backward linkages. This result implies that sectors having both high innovation backward and forward linkages are likely to become bottlenecks in the process of economic growth.

The unbalanced growth strategy should place more emphasis on removing current trade barriers and facilitating trade liberalization in the core sectors of the target region. In the case of bottleneck sectors, more policy intervention is needed to promote productivity growth by subsidizing R&D investment. Although a practical difficulty always exists in implementing a growth strategy across national boundaries, policy coordination still seems feasible as long as the findings from the innovation input–output matrix are shared.

This paper is a first attempt at providing a theoretical justification for innovation input–output analysis with simple quantitative analysis. More theoretical and empirical studies are needed. In particular, this paper assumes that some common innovation linkages have existed across the East Asian region for over 20 years (1980–2000). This assumption is quite bold, but it is necessary owing to the limited number of observations. Construction of the innovation input–output matrix without the need for such an assumption remains an important challenge for future research. In addition, this paper focuses exclusively on TFP growth and does not address factor growth, such as physical and human capital accumulation patterns. The impact of these growth drivers on the estimation of innovation linkages should also constitute a future research agenda, as this would deepen our understanding of the properties of regional innovation systems, ultimately leading to more effective growth policy.

Abbreviations

TFP: total factor productivity; R&D: research and development; OECD: Organization for Economic Co-operation and Development; DRAM: dynamic random access memory; PC: personal computer; ICPA: International Comparison of Productivity among Asian Countries; RIETI: Research Institute of Economy, Trade and Industry; IT: information technologies.

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Competing interests

The author declares that he has no competing interests.

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