Micro-macro linkages between ICT and sustainability:
ICT investment and its managerial and environmental impacts in Japan

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Toshiya Jitsuzumi, Hitoshi Mitomo, Hajime Oniki

Abstract

There exists a manifold of causal linkages between information and communications technologies (ICTs) and social sustainability. In this article, these linkages are classified into three areas: direct improvement of corporate productivity; changed behavior of people/organizations; and improved decision-making capabilities within society. The authors introduce a framework designed to analyze the first two of these three linkages, and present the results of a questionnaire survey.

Findings include a continuous growth trend of Japanese ICT investment with sectoral variations, which may explain the sectoral differences in micro-level benefits, and statistically significant evidence confirming ICTs' contributions to corporate operations and to environmental issues.

1. Introduction: Pro-sustainability roles of information and communications technologies

Information and communications technologies (ICTs) have come to be considered not only a tool for a new way of life and business, but also a foundation for the creation of a sustainable society. Until recently, ICT investment was evaluated purely as a business concern, i.e., based solely on its potential to streamline corporate operations, improve productivity and yield additional profits. However, since the United Nations Conference on Environment and Development (UNCED) in 1992 and the 3rd UN Conference on Climate Change (COP3) in 1997, "sustainability" has become one of the most pressing issues on the international as well as domestic agenda, and ICT investment is now seen as a promising way to improve social sustainability.

Although many firms have improved productivity, profitability and environmental performance by adopting ICTs, little empirical evidence suggests that these individual successes really contribute to macro-level productivity and societal sustainability. Indeed, macro-level statistics usually point to the opposite conclusion. As Solow[1] notes, "You can see the computer age everywhere but in the productivity statistics" (i.e., the well-known "productivity paradox").

The productivity paradox does not necessarily imply that ICTs cannot product macro-level contributions; on the contrary, the authors believe that a manifold of complex causal linkages are at work in the gap between micro-level impacts and macro-level contribution. We cannot also rule out the possibility that the paradox is a consequence of deficiencies in measurement and methodological tools.

A goal of the authors' research is to explain the linkages at work in the gap between ICTs' micro-level effects and macro-level contribution. To do this, the authors follow Mitomo and Oniki[2] in classifying possible linkages into three types:

a) Direct effects through improved corporate productivity:

As efficiency improvements imply "more output from the same input" (or equivalently, "less input for the same output"), ICTs can increase the efficiency with which natural resources and/or labor inputs are utilized or can reduce net demand for them. Abundant examples of this effect can be found, notably in the manufacturing sector where ICT-controlled machinery now works without the help of human staff and also acts to optimize production flows, or in the electronic-commerce sector where global business can be performed with minimum physical inputs. Reduced need for natural resources improves environmental sustainability, while increased per-capita output implies greater sustainability for economic prosperity. Moreover, ICTs further contribute to economic sustainability by expanding working opportunities for the handicapped and the aged, a particularly notable factor for nations such as Japan where the working-age population will begin to decline in the near future.

b) Indirect contributions through changed individual or organizational behavior:

ICT-related advances such as telework/telecommuting (T/T) not only help firms to increase productivity but can also alter employee commuting patterns, leading to net time savings for

[1] Robert M. Solow, 'We'd better watch out', *New York Times Book Review*, 1987, July 12, p.36.
[2] Hitoshi Mitomo and Hajime Oniki, 'Information technology for sustainable societies -- public policy perspectives in Japan: the case of telework', *The IPTS Report*, 1999, March, 32, pp. 24-31.

workers (see Mitomo and Jitsuzumi[3]) and reduced energy consumption and CO_2 emission. Similarly, the introduction of an Internet-EDI into a firm can affect the management of other companies through either a supply value chain or competitive pressures. Other examples of indirect ICT contributions include the development of telemetry devices to monitor the global environment and the emergence of computerized auction markets for CO_2 emission rights, each of which motivates firms and society to act in a more environmentally aware manner.

c) Internalized external effects through improved decision-making capabilities for society

In a democratic society, a collective choice can be sustained only with approval of the majority. Thus, before implementing a pro-sustainability policy (which usually hinders short-term interests for long-term objectives), the majority needs to understand all the externalities associated with individual decisions, i.e., how "selfish" decisions by individuals can affect the whole world. Policy makers seeking to disseminate information of this type to the public in an accurate and timely manner must rely on ICT applications, as must a public seeking to assimilate large volumes of such information. In this sense, societal sustainability can be improved only through the evolution of a knowledge-based society heavily endowed with ICTs not only in the business arena but also in everyday life.

Fig. 1 shows how these three causal paths may contribute to sustainability in the case of T/T, an ICT-related business application.

Fig. 1 ICTs and sustainability: the case of T/T

Expanding the scope of Mitomo and Oniki's work to focus on T/T, the authors have initiated a research project which covers ICT business applications in general. This research deals with the first and second of three contribution channels. We set the following three objectives: a) to confirm that ICTs in Japan contribute to productivity, profitability, and environmental friendliness at the firm level;

[3] Hitoshi Mitomo and Toshiya Jitsuzumi, 'Impact of telecommuting on mass transit congestion: the

b) to identify the causal relationship associated with micro-macro linkages between ICT investment of individual firms and macro-level contributions; and c) to recommend some policy options for the government from a sustainability viewpoint.

Since Solow's[4] initial work, a considerable number of studies have examined the relationship between technology and economic growth. Meanwhile, both Stiglitz[5] and Faucheux[6] have considered the impact of technological development on sustainability. However, all of this work is very abstract in nature; none of it explicitly mentions ICTs. As a general-purpose technology (GPT) which "initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many Hicksian and technological complementarities"[7], ICTs can contribute to sustainability through more channels than other technologies. We firmly believe that this distinctive feature makes ICTs worthy of special attention. On the other hand, Brynjolfsson & Hitt[8] and Shafer & Byrd[9] focus on ICTs' impacts on individual firms and try to measure them quantitatively. However, their focus is only on private benefits to ICT-adopting firms; they do not address spillover effects or externalities such as ICTs' impact on the environment. None of these studies, as currently structured, can provide any conclusions concerning ICTs and sustainability.

The authors thus designed this research as a significant departure from these previous approaches, in order to explicitly focus on the relationships between ICT and sustainability using individual company

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Tokyo case', *Telecommunications Policy*, 1999, 23, pp. 741-51.

[4] Robert M. Solow, 'A contribution to the theory of economic growth', *Quarterly Journal of Economics*, 1957, February, 70, pp.65-94; 'Technical change and the aggregate production function', *Review of Economics and Statistics*, 1957, August, 39, pp. 312-20.

[5] Joseph E. Stiglitz, 'Growth with exhaustible natural resources: efficient and optimal growth paths', *Review of Economic Studies*, 1974, Symposium Volume, pp. 123-37.

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[9] Scott M. Shafer and Terry A. Byrd, 'A framework for measuring efficiency of organizational investments in information technology using data envelopment analysis', *Omega*, 2000, 28, pp. 125-41.

data collected from across Japan.

This paper, as a first output of our research, seeks to introduce a model which we will use to illustrate a possible micro-macro causal linkage, to address the challenges of our research effort and to elaborate upon some preliminary findings from our questionnaire survey.

2. Towards a general framework

2.1. A preliminary framework

In this section, we introduce a research framework which describes a micro-macro causal linkage based on certain behavioral assumptions about corporate decision-making (Fig. 2).

Fig. 2 Assumed micro-macro causal linkage

First of all, we assume that a firm reacts to an exogenous change primarily through strategic investments designed to realize product innovations and/or process innovations, a classification used in many previous studies. For example, as Stoneman[10] explains, "product innovation [relates] to the generation, introduction and diffusion of a new product (with the production process being unchanged)" and "process innovation … to the generation, introduction and diffusion of a new production process (with the products remaining unchanged)." When these innovations function as expected then, by following direct and indirect causal routes, a firm can streamline its operations, generate more profit, and possibly reduce its environmental burden (i.e., micro-level impacts). Once a certain player accrues these advantages, competition drives other firms to follow suit. Over time, what was once an exceptional improvement at a single company becomes a macro-level trend affecting an entire nation (i.e., a macro-level impact), which in turn produces another wave of exogenous challenges to corporate management.

[10] Paul Stoneman, 'Introduction', in Paul Stoneman (ed), *Handbook of the Economics of Innovation and Technological Change*, Blackwell Publishers, Ltd., Oxford, UK, 1995, pp. 1-13.

In general, if some sectors or nations are similarly configured for decision-making purposes, they may experience similar outcomes/impacts from ICT investment. Thus, the objective of this model is to clarify the differences in ICTs' macroeconomic impacts between Japan and the US, as well as to explain why Japan has yet to enjoy the emergence of a "New Economy" in spite of heavy ICT investment in recent years. In addition, the model allows us to analyze how ICT impacts will be influenced by various factors: these include initial surrounding conditions, firm characteristics, firms' "proximity" to ICT, managers' attitude toward exogenous changes, resource allocation between the two types of innovations, and competitors' reactions.

Using this framework in conjunction with actual data from Japan, we can check the applicability to a Japanese setting of prior studies' conclusions, most of which were drawn from US or European data. For example, Barras[11] notes that a product innovation increases employment and a process innovation displaces it; and if so, sectoral differences concerning the order of occurrence in, and the relative magnitude of, these two innovations can lead to remarkable differences in ICTs' macro-level impact, especially on the unemployment rate. On the other hand, Brynjolfsson & Hitt[12] mention that for ICT investment to yield the greatest benefits, it must be coupled with other complementary investments as well as new strategies, new business processes and new organizational structures. If this is the case, the heterogeneity of management styles between Japan and the US may explain the difference in relative economic performance.

2.2. Key Issues

When conducting systematic research on ICTs' impact or assessing from economic or statistical perspectives the validity of previous studies' conclusions, one faces a range of complex problems. Below, we introduce three of the most critical.

First, before assessing ICTs' impact, we must identify the functional and mutual relationships associated with ICTs. Sometimes categorized as an enabling technology or a GPT, ICTs have been

[11] Richard Barras, 'Towards a theory of innovation in services', *Research Policy*, 1986, 15, pp. 161-73.
[12] Erik Brynjolfsson and Lorin Hitt, 'Beyond the productivity paradox: computers are the catalyst for bigger changes', *Communications of the ACM*, 1998, August; 'Information technology and

said to be "…changing product design, production, marketing, finance, and the organization of firms."[13] Here, we must understand that causal relationships for ICTs involve far greater complexities and difficulties than for other kinds of investments. The more elaborate the ICT applications we examine, the more complex the web of causal relationships, and the greater the effort needed to identify a valid path on which to proceed. Another obvious source of difficulty is the existence of interrelatedness (i.e., complementarity and network-externality among related technologies), a key characteristic of GPTs as well as information goods/services.

Second, after identifying causal relationships, we have to consider how to measure the value and scale of ICTs and their degree of usefulness or contribution. On the input side, because most ICT goods and services are traded in a market with many suppliers, it seems valid to assume that pricing properly reflects the nominal amount of ICT; in reality, however, rapid technological advances and the lack of quality-adjusted deflators make nominal pricing quite difficult to interpret. Moreover, the presence of a fixed-cost-dominating structure drives many ICT industries to employ a mark-up pricing principle; here, prices become not only irrelevant to marginal costs but also very unstable because mark-up rates must be influenced by exogenous factors which are uncontrollable by nature (for example, policy settings or industrial structures). In such a case, nominal values do not reflect the scale of ICT investment, and become less useful for analytical purposes. The output side poses additional problems. In many cases, ICTs' usefulness can be evaluated only in qualitative terms, in which case subjective judgments are unavoidable. The need to manage both qualitative and quantitative data can be another source of uncertainty. Given these uncertainties, it is far from easy to measure the scale of ICTs and their effects.

Finally, when establishing the linkages between macro-level impacts and individual success stories of ICT introduction, we have to tackle the productivity paradox. Specifically, aggregate economic time-series data as well as standard economic tools (such as production functions or TFP) seem to indicate that ICT investment has made little contribution to (labor) productivity. A number of studies have attempted to explain this paradox. Some authors seem to agree that the paradox arises from the

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organizational design firm level evidence', *MIT, Stanford and Wharton Working Paper*, 1998, January.

inability of statistical data to incorporate two factors: the dramatic advances in the quality of ICTs and the simultaneous massive decline in ICT pricing. At the same time, David[14] identifies a time factor, insisting that it takes a long time for a new technology such as ICT to exhibit full benefits for production. Brynjolfsson[15] mentions the possibility that while ICTs do produce a positive impact for user firms, such gains come entirely at the expense of others. Here again, it is intrinsically difficult to obtain information on the macro-level usefulness of ICT goods and services.

3．Measuring the micro-macro linkages

In order to tackle the above-mentioned issues, the authors in April 1999 initiated a research project, with substantial support from the Ministry of Posts and Telecommunications, entitled "Project on Information and Communication Technology for Japan" [PICTJ]. Structured as a significant departure from earlier studies that took the form either of case studies of cutting-edge firms or of analyses based on aggregated statistical figures; PICTJ was designed as a theoretical as well as statistical research effort using cross-sectional datasets of individual companies sampled from across the entire Japanese industrial sector.

Below, we elaborate upon some preliminary findings of our first questionnaire survey, designed to clarify the status quo of ICTs among Japanese firms. In mid-January 2000, we distributed questionnaires to 3,321 firms (i.e., every publicly listed firm in Japan) and received 195 responses. Despite the relatively low response rate, the respondents' composition reflects Japan's industrial structure quite well.[16] In order to better identify sectoral variations, we classified respondents into three groups: the manufacturing sector (consisting of manufacturing firms); the infrastructure sector (transport, public utilities, and communications firms); and the application sector (all remaining

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[13] Lipsey, et al., *op cit*, ref 7.

[14] Paul A. David, 'The dynamo and the computer: an historical perspective on the modern productivity paradox', *American Economic Review, Papers and Proceedings*, 1990, 80, 2, pp.355-61.

[15] Erik Brynjolfsson, 'The productivity paradox of information technology: review and assessment', *Communications of the ACM*, 1993, December, pp. 66-77.

[16] Out of 11 sectors, only three -- construction, transportation, and public utilities -- generate significant ($p<0.05$) over-representation.

industries), based on their respective characteristics.

It should be stressed that, at this stage of PICTJ, none of the previously mentioned key issues has been fully considered; consequently, none of the findings put forward in the following section should be taken as final. We plan to address these key issues in the next stage of our PICTJ research, in which we will conduct an additional questionnaire survey and interview some corporate managers.

3.1. Overall trend of ICT investment in Japan

The sample indicates a steady and continuous growth trend for ICT investment, a finding consistent with other statistical studies such as the MPT's[17]. For example, 78.9% of personal computers used at sample firms are now connected to some form of network (e.g., LAN, intranet, or extranet). The proportion of networked PCs is lowest in the infrastructure sector (68.9%) and highest in the manufacturing sector (82.8%). For newly installed PCs (i.e., purchased during fiscal 1998), the corresponding figures rise by 5 to 12 points. Moreover, 35.4% of the sample firms plan a relative increase in ICT-related investment, while only 9.0% plan such an increase in non-ICT investment.

Other figures suggest that most companies consider ICT investment as a means to facilitate process innovation rather than product innovation, and that the infrastructure sector places the most emphasis on process innovation while the application sector places the least (Table 1).

Table 1 Purpose of ICT investment

3.2. Relationship between ICT investment and its impacts

As discussed in section 2.2, we face numerous difficulties in seeking to evaluate quantitatively the scale of ICT investment and its contributions, inasmuch as both quantitative and qualitative information must be assessed. At this stage of research, we propose one potential measure allowing both kinds of information to be used in a coordinated and easy-to-handle manner.

[17] Ministry of Posts and Telecommunications, *The 1999 White Paper -- Communications in Japan*, MPT, Tokyo, 1999.

Specifically, we employ a principal component analysis (PCA), which is nonparametric and dispenses with precise model construction, as a convenient tool to summarize a number of information sets with different natures. PCA involves a mathematical procedure, eigenvector analysis, that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables (principal components). The first principal component accounts for as much of the variability in the original data as possible, and each succeeding component accounts for as much of the remaining variability as possible. Applying this PCA method on input-related elements of our dataset, we derive an "ICT introduction index" measuring the scale of ICT investment. On the output side, we obtain an "operational impact index" which summarizes impacts on corporate operations, and an "environmental impact index" which reflects a reduction of environmental burden. Each of these indices is the first principal component built on 6, 16 and 6 kinds of data elements, respectively.

Plotting these indices in a two-dimensional diagram, we find a significant positive correlation between the ICT introduction index and the operational impact index, and between the ICT introduction index and the environmental impact index (Fig. 3, Fig. 4).[18] The PCA scores also show that the ICT index has less explanatory power for environmental contributions. Given that both the operational and environmental impact indices capture the micro-level impacts described in Fig. 2, these results imply that ICT investment makes a significantly positive but uneven contribution towards different areas of micro-level contribution.

Fig. 3 ICT introduction and its operational impacts

Fig. 4 ICT introduction and its environmental effects

Finally, our questionnaire indicates that, although less than 14% of the sample took environmental issues into consideration when making ICT investment, many firms subsequently noticed some environmental impact from ICTs. For example, 58% of respondents recognized a reduction in paper disposal, whereas more than a quarter pointed to an increase in energy consumption and industrial

[18] The relationships are statistically significant, the former at the 1% significance level and the latter at

waste. This gap (i.e., pre-investment vs. post-investment) may imply the existence of externalities for ICT investment. If so, some degree of policy intervention on behalf of ICT investment, such as subsidies for the adoption of environmentally friendly (or "sustainability friendly") ICTs, could theoretically be justified.

4. Conclusion and agenda for further analysis

As the complex web of cause and effect outlined above suggests, any analysis of ICTs and their impact on the overall economy clearly touches on a vast number of issues. Indeed, one can imagine literally hundreds of related issues -- research efforts such as this paper can address only a small portion of them.

In this paper, we have presented a possible model of causal linkages between ICT investment and macro-level impacts which has yet to be empirically verified, along with some preliminary findings derived from our questionnaire. Although no concrete conclusions can yet be presented, we conclude with the following two inferences:

- ✓ The questionnaire results indicate some sectoral variation concerning the weight between process and product innovations as objectives of ICT introduction. If ICTs for process innovation may negatively affect employment at least in the short term, considering the long-term employment system common in Japan, firms that place greater emphasis on process innovation may not enjoy the full benefits of ICTs. If so, this variation may provide some clues explaining why some sectors enjoy clear contributions from ICT investment while others do not.
- ✓ The uneven micro-level contribution of ICTs, as indicated in Figs. 3 and 4, implies the existence of impact-related variation in ICTs. Moreover, if a time factor affects different kinds of ICT contributions unevenly, the so-called "productivity paradox" may be much more complex than previously considered. In such a case, of course, our assumed framework linking

the 5% level.

ICT investment to a sustainable society needs further elaboration.

We must again stress that the foregoing represents only a very initial analysis of the role of ICT investment in Japan, one based on individual sample data and addressing such issues as the impact of ICT investment on corporate operations and environmental issues. As with any analytical report which examines a phenomenon as young and complex as ICTs, our findings generate more questions than answers. These questions form the basis of our future research agenda, which may include a thorough survey of the literature, more data analysis, interviews with corporate managers, construction of a theoretical model, and empirical verifications. We firmly believe that further efforts along these lines will furnish a significant amount of new data potentially useful to policy makers seeking to learn more about the current status and likely future directions of ICT usage in Japan.

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