9. ANALYZING THE IMPACTS OF UNOBSERVED NATIONAL CHARACTERISTICS ON ECONOMIC PERFORMANCE OF INFORMATION TECHNOLOGY BASED ON A PARTIAL ADJUSTMENT APPROACH WITH DYNAMIC AND VARIABLE SPEED OF ADJUSTMENT

Zhiguang ZHANG[1]
Haiqing HU[2]
Winston T. LIN[3]

Abstract

The long-debated issue of the productivity paradox of information technology has been the subject of academic research for several decades. But the studies have rarely examined the impact of national characteristics on the value of information technology. This paper applies a partial adjustment approach with different speed of adjustment to compare the impacts of unobserved national characteristics on the economic performance of information technology in developed and developing countries, in conjunction with the productivity paradox and the substitutability and complementarity of inputs. The conclusions are as follows. First, the impact of the selected unobserved national characteristics on the speed of adjustment varies in different countries and the speed of adjustment, in turn, affects the performance value of IT. Second, the productivity paradox may exist in a country regardless of whether it has a developed or developing economy, rejecting the notion that the productivity paradox exists only in developing countries, but not in developed countries. Third, the complementary and substitution relationships among traditional capital, traditional labor, and IT capital differ from country to country.

Keywords: dynamic adjustment; information technology value; the productivity paradox; nonlinear least squares
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[1] School of Economics and Management, Xi'an University of Technology, Xi'an, China. Corresponding author: zzg624@163.com.
[2] School of Economics and Management, Xi'an University of Technology, Xi'an, China.
[3] School of Management, State University of New York at Buffalo, Buffalo, USA.

1. Introduction

Whether investments in information technology (IT) promote productivity has been a controversial topic. Numerous studies on this topic have reached contradictory conclusions, especially with respect to the issue of the so-called productivity paradox. Some studies have acknowledged the existence of the productivity paradox and questioned the contribution of IT to productivity (Baily *et al*., 1988; Lin and Shao, 2006b; Roach, 1991). However, some studies at the firm level have provided evidence that IT investment has a positive effect on productivity, thereby contradicting the IT paradox (Arcelus and Arocena, 2000; Bresnahan, 2001; Brynjolfsson, 1993; Brynjolfsson and Hitt, 1996; Davamanirajan, Mukhopadhyay and Kriebel, 2002; Lee and Menon, 2000; Lin and Shao, 2000; Shao and Lin, 2001, 2002; Shu and Lee, 2003; Tsekouras *et al*., 2010; Lin and Chuang, 2013). In addition, other studies have claimed that the productivity paradox appeared in the 1980s but disappeared in the early 1990s (Brynjolfsson and Hitt, 1996; Hitt and Brynjolfsson, 1996). Thus, the business value of IT and the existence of the productivity paradox remain highly controversial issues. In particular, prior studies have focused primarily on firm-level data, and cross-country studies are lacking in the literature (Chen and Lin, 2009; Lin, 2009). Thus, more attention should be devoted to knowledge accumulation concerning macro-characteristics and IT value at the country level (Lin, Chen and Shao, 2015).

In fact, the conclusions are also inconsistent in country-level research. The study of Reuter (2010) reveals a significant relation between information technology and economic growth in the developed countries after the first half of the 1990s. The result of research conducted by Strauss and Samkharadze (2011) shows that information technology development has a determinant role in improving the growth of productivity in the developed countries. Dewan and Kraemer (2000) conclude that the productivity paradox is absent from the developed countries, but still exists in the developing countries; in contrast, Lin (2009), Chen and Lin (2009), and Lin and Chiang (2011) argue that the productivity paradox exists in both developing and developed countries. Moreover, a large volume of studies on particular countries has emerged. Examples of such studies include Martínez, Rodríguez and Torres (2010) on the US; Correa (2006) on the UK; Jorgenson and Motohashi (2005) on Japan; Khuong (2013) on Singapore; Jorgenson (2003) on the G7 economies; Erumban and Das (2016) on India. However, these studies lack comparisons between the developed countries and the developing countries. Chou, Shao and Lin (2012) and Shao and Lin (2016) point out that efficiency change has a negligible effect, and each country's IT industry exhibited a distinctive performance profile.

The mis-measurement is considered an important cause for the productivity paradox (Melville, Gurbaxani and Kraemer, 2007; Lin, 2009). Different methodologies have been used in researches on the business value of IT at the firm or country level. Most studies have used the traditional regression-analysis approach (Dewan and Kraemer, 2000; Hitt and Brynjolfsson, 1996; Tam, 1998), and the statistical correlation approach has also been applied to measure the relationship between IT investment and performance measures, such as profitability (Dos Santos, Peffers and Mauer, 1993). To avoid an aggregation problem at the firm level, Mukhopadhyay, Rajiv and Srinivasan (1997) use the Generalised Method of Moments (GMM) procedure to assess the impact of IT on both process output and quality. Moreover, some researchers have used non-parametric data envelopment analysis (DEA), proposed by Charnes, Cooper and Rhodes (1978), which is a linear programming method that can consider many inputs and outputs simultaneously to measure the efficiency of IT (*e.g.,* Park and Lesourd, 2000; Shao and Lin, 2002). The parametric timevarying stochastic frontier production (SFP) approach has also been applied (Chen and Lin, 2009; Lin, 2009; Lin and Chiang, 2011; Lin and Shao, 2000, 2006a, b; Shao and Lin, 2000, 2001). Lee (2006) develops a stochastic frontier model with group-specific temporal variations in technical efficiency, which allows group-specific patterns of temporal change in technical inefficiency to be analyzed without imposing any specific form of temporal pattern (Lee, 2010).

In a recent study, Lin, Chuang and Choi (2010) develop a partial adjustment (PA) approach and a performance measure, based on the theory of PA, to assess and measure the business value of IT. The approach has a strong theoretical foundation, *i.e.*, is based on a powerful theory called the theory of partial adjustment, and the proposed approach and its companion measure of performance are simple and easy to apply empirically. As an extension of Lin, Chuang and Choi (2010), this paper assumes that the speed of adjustment is dynamic and variable, and is a linear function of some selected unobserved national characteristics.

Therefore, the paper aims to simultaneously investigate four important issues, namely, the business value of IT, the productivity paradox, the substitution and complementarity of IT capital for both traditional capital and labor, which is another important issue related to the value of IT and the productivity paradox, and the impacts of unobserved national characteristics on the business value of IT in developed countries and developing countries. The PA model with dynamic and variable speed of adjustment based on the theory of PA is significantly different from the previous approach. Within the PA framework, unobserved factors can cause the speed of adjustment to change gradually, and thus, affect the economic performance of information technology.

The rest of this paper is organized as follows. Section 2 describes the theory of partial adjustment, the proposed partial adjustment approach and the performance measure. Section 3 explains the data, variables and data source. Section 4 reports the empirical results, and discusses the results. Finally, Section 5 concludes the study with some remarks and potential extensions.

2. Theory, Research Methodology and Research Models

2.1 The Partial Adjustment Approach with Dynamic and Variable Speed of Adjustment

With the changing economic situation, current economic behavior may frequently be inconsistent with the long-run equilibrium, and the economic unit (firm or country) may make planned adjustments to the long-run equilibrium from time to time. Because of certain limiting factors, such as technological rigidities, institutional imperfection, and limitations from the market and management, the observed output cannot completely adjust to the desired output, but can only partially adjust. The theory of PA is put forward by Nerlove (1958) in rationalizing the Koyck model to explain the phenomenon of distribution lags and is later extended and applied by other researchers (*e.g.*, Lin, 1979, 1986, 1988, 2005; Lin and Chen, 1998; Lin, Chen and Chatov, 1987; Lin, Chuang and Choi, 2010). The theory assumes that a change in the actual (observed) output is only a portion of the desired change. Represented symbolically, the theory states:

$$Y_{jt} - Y_{j,t-1} = \delta_j (Y_{jt}^* - Y_{j,t-1}) \tag{1}$$

where: Y_{jt} is the actual (observed) output for a decision-making unit (DMU) j at time t, $Y_{j,t-1}$ is the actual (observed) output at time t-1, Y_{jt}^{*} is the desired (ideal or maximum) output at time t, δ_j represents the constant speed of adjustment, and $0 \le \delta_j \le 1$. If the speed of adjustment is 0, then there is no adjustment at all, and the closer δ_j is to 1, the higher the speed of adjustment is to the desired level. Thus, if the speed of adjustment is 1, it reaches full adjustment; however, it is practically and technologically impossible for the speed of adjustment to be complete; rather, it is only partial (*e.g.*, Lin, 1979, 1986; Lin, Chuang and Choi, 2010; Nerlove, 1958). Hence, δ_j lies between 0 and 1 in practice. The model satisfying Eq. (1) is called the PA approach with a constant speed of adjustment.

Clearly, the original theory of PA assumes that the speed of adjustment δ_j (the ratio of the actual change ($Y_{jt} - Y_{j,t-1}$) to the desired ($Y_{jt}^{*} - Y_{j,t-1}$) in Eq. (1) is a fixed value rather than a policy-influenced and market-determined variable; however, this assumption does not conform to reality and is not without criticism (Lin, 1986; Lin, Chuang and Choi, 2010). In reality, the speed of adjustment should be influenced by macroeconomic variables, unobserved or observed, at the country level. Specifically, it should be a function of a series of national characteristics; that is, $\delta_{jt} = g(Z_{jt}, \alpha_j)$, where Z_{jt} represents a broad set of observed and/or unobserved macroeconomic factors that explain the speed of adjustment and α_j is a vector of unknown coefficients.

Accordingly, in line with Lin (1986) and Lin and Kao (2014), the PA approach with dynamic and variable speed can be developed by rewriting Eq. (1) as

$$Y_{jt} = g(Z_{jt}, \alpha_j) Y_{jt}^{*} + [1 - g(Z_{jt}, \alpha_j)] Y_{j,t-1} + W_{jt} \tag{2}$$

Obviously, Eq. (2) indicates that the observed output is a weighted average of the desired output and the past period's actual outputs, with weights $g(\bullet)$ and 1- $g(\bullet)$, respectively, plus the random error W_{jt}. In contrast to the constant speed of adjustment approach, the speed of adjustment in the dynamic and variable speed of adjustment approach varies from year to year, clearly reflecting the impact of macroeconomic conditions (unobserved national characteristics in this research) on the adjustment of outputs. Again, the dynamic and variable speed of adjustment δ_{jt} must also lie between 0 and 1. The stochastic disturbance term W_{jt} is assumed to distribute according to $N(0, \sigma_w^2)$.

Following the research of Lin and Kao (2014), we represent the desired output with a production function, as arranged in the SPF approach, denoted by $Y_{jt}^{*} = f(X_{jt}, \beta_j)$, where X_{jt} is a vector of the inputs of production at time t and β_j is a vector of unknown coefficients. By introducing the production function, Eq. (2) can be rewritten as follows:

$$Y_{jt} = g(Z_{jt}, \alpha_j) f(X_{jt}, \beta_j) + [1 - g(Z_{jt}, \alpha_j)] Y_{j,t-1} + W_{jt} \tag{3}$$

Lin, Chuang and Choi (2010) propose $\delta_j f(X_{jt}, \beta_j)$ as a measure of performance with constant speed. Similarly, we can employ $PM_{jt} = g(Z_{jt}, \alpha_j) f(X_{jt}, \beta_j)$ as a performance measure in the PA approach with dynamic and variable speed of adjustment expressed by Eqs. (3). Obviously, the performance measure contains two parts: (i) the dynamic speed of adjustment $g(Z_{jt}, \alpha_j)$, which is highly related the chosen unobserved national characteristics; and (ii) the desired outputs $f(X_{jt}, \beta_j)$, which is subject to the chosen production function, input factors X_{jt}, and the unknown coefficients β_j. A change in unobserved national characteristics may lead to a change in the speed of adjustment and, thus, to a change in PM_{jt}. Similarly, a change in X_{jt} may cause the desired output to change, thereby resulting in a change in PM_{jt}. The PM_{jt} measure has the same physical units as Y_{jt} (Lin, Chuang and Choi, 2010; Lin and Kao, 2014).

If the estimates of α_j and β_j are expressed by $\hat{\alpha}_j$ and $\hat{\beta}_j$, respectively, then the estimated value of PM_{jt} is given by

$$PV_{jt} = PM_{jt} = g(Z_{jt}, \hat{\alpha}_j) f(X_{jt}, \hat{\beta}_j) \tag{4}$$

PV_{jt} is considered a monetary gain. In addition, to compare and rank the performance of IT in individual DMUs (countries in this research), we use the average performance value APV_j given by

$$APV_j = \sum_t PV_{jt} / n \tag{5}$$

To compare with others obtained by DEA or the SPF approach, Lin, Chuang and Choi (2010) propose a ratio or index concept by dividing the performance value by the relevant observed output (denoted by Y_{jt}^{Δ}); that is,

$$PR_{jt} = PV_{jt} / Y_{jt}^{\Delta} \tag{6}$$

where: $Y_{jt}^{\Delta} = \ln Y_{jt}$ for the CES production function to be employed in this paper. It is obvious that PR_{jt} lies between 0 and 1.This approach facilitates easy comparisons with the productive efficiency measure from DEA and the SPF approach (Chen and Lin, 2009; Lin, 2009; Lin and Chiang, 2011; Lin and Shao, 2000, 2006a, b). The corresponding average $PR_{jt} (APR_j)$ can be defined as

$$A\mathrm{P}R_j = \sum_t PR_{jt} / n \tag{7}$$

By establishing the PA approach with dynamic and variable speed of adjustment, we have relaxed the assumption of constant speed of adjustment to allow the speed of adjustment to vary with time t. Simultaneously, the impact of unobserved national characteristics on changes in actual output and IT value can be studied synthetically.

2.2 Research Models and Estimation Method

In order to assess the IT value and analyze the substitutability and complementarity of inputs such as ordinary capital, ordinary labor, and IT capital with the PA model, in which the speed of adjustment is dynamic and variable as affected by the unobserved national characteristics, the CES production function will be employed to express the desired outputs $f(X_{jt}, \beta_j)$.

We can see from Eqs. (3) that the actual change in output ($Y_{jt} - Y_{j,t-1}$) depends on three effects: the functional form of the production function (CES considered in this paper); the inputs entered into the production function; and the so-called unobserved national characteristics entered into the speed of adjustment function, which are largely policy-oriented at the country level (Lin, 1986; Chen and Lin, 2009).

As stated earlier, because of the shifts in economic conditions and public policies, the speed of adjustment function is constantly affected by a series of policy-influenced and market-determined variables (Lin, 1986). Thus, the changes of economic conditions and government policies (national characteristics) affect the speed of adjustment. Following Chen and Lin (2009), the national characteristics that become the elements of the Z_{jt} vector in the speed of adjustment function δ_{jt} are country-specific national characteristics represented by (i) $TRIM_{jt}$, which is the ratio of foreign-exchange reserves to imports; (ii) UER_{jt}, which is the unemployment rate; (iii) R_{jt}, which is government bond yields; (iv) $IFLA_{jt}$, which is the inflation rate; and (v) PCC_{jt}, which is per capita consumer expenditure. The national characteristics in this paper are defined as expected, desired or unobserved variables in order to allow for the impact of expectations. The unobserved variables are quantified by a distributed lags scheme. The distributed lags scheme is a third-order autoregressive process, which is a weighted average of three past actual values. There are also different sets of the weight of past actual values, but the third-order autoregressive process with the weights of 1/2, 1/3 and 1/6 may be more rational (Lin, 1986). Thus, incorporating the five expected or unobserved national characteristics, namely, $TRIM^*_{jt}$, UER^*_{jt}, R^*_{jt}, $IFLA^*_{jt}$ and PCC^*_{jt}, the counterparts of the observed national characteristics and the CES functions leads to two research models in two cases (two-factor and three-factor) as follows:

Model 1: The two-factor case, dynamic and variable speeds with national characteristics.

$$\ln Y_{jt} - \ln Y_{j,t-1} = (\alpha_{j0} + \alpha_{j1} TRIM^*_{jt} + \alpha_{j2} UER^*_{jt} + \alpha_{j3} R^*_{jt} + \alpha_{j4} IFLA^*_{jt} + \alpha_{j5} PCC^*_{jt})$$
$$* (\beta_{j0} + \beta_{j1} \ln K_{jt} + \beta_{j2} \ln L_{jt} + \beta_{j2} (\ln K_{jt} - \ln L_{jt})^2 - \ln Y_{j,t-1} + W_{jt}$$

Model 2: The three-factor case, dynamic and variable speeds with national characteristics

$$\begin{aligned}\ln Y_{jt} - \ln Y_{j,t-1} = (&\alpha_{j0} + \alpha_{j1} TRIM^*_{jt} + \alpha_{j2} UER^*_{jt} + \alpha_{j3} R^*_{jt} + \alpha_{j4} IFLA^*_{jt} + \alpha_{j5} PCC^*_{jt})\\ &*(\beta_{j0} + \beta_{j1}\ln K_{jt} + \beta_{j2}\ln L_{jt} + \beta_{j3}\ln I_{jt} + \beta_{j4}(\ln K_{jt} - \ln L_{jt})^2\\ &+ \beta_{j5}(\ln L_{jt} - \ln I_{jt})^2 + \beta_{j6}(\ln K_{jt} - \ln I_{jt})^2 - \ln Y_{j,t-1} + W_{jt}\end{aligned}$$

The chosen unobserved national characteristics help us analyze the impacts of expectations associated with the unobserved macroeconomic factors on the change in the actual outputs Y_{jt}. Moreover, the chosen expected or unobserved national characteristics reflect economic activities at the country level, such as PCC (Chen and Lin, 2009; Lin, 1992), government bond yields (Chen and Lin, 2009), and TRIM (Chen and Lin, 2009; Lin, 1999; Lin and Chen, 1998); moreover, UER and IFLA are essential in the Keynesian theory at the macroeconomic level. As noted above, Chen and Lin (2009) have studied the impacts of the five national characteristics on IT value with a two-equation SPF model, which is based on production theory. The approach used in this paper is called the PA approach with dynamic and variable speed of adjustment, which is different from the SPF approach. Under the PA approach, the impact of the unobserved national characteristics on IT value can be measured, and their effects on the changes in the actual output used to reflect the country's economic growth can be examined. Thus, it is interesting to compare the impacts of the five national characteristics on IT value under the two different approaches.
The estimation task is conducted using EVIEWS 5.0, a computer package used for econometric analysis, forecasting, and simulation.

3. Data

The data used in this study cover 12 economies for the period from 1993 to 2010. To analyze the productivity paradox in depth, we divided the 12 economies into two groups (Lin, 2009; Lin and Chiang, 2011): Group 1 (GP1), which comprises ten developed and newly developed economies, namely, Australia (AU), Canada (CN), France (FR), Japan (JP), Italy (IL), the United Kingdom (UK), the United States (US), Hong Kong (HK), South Korea (SK), and Singapore (SG); and Group (GP2) which comprises two developing countries, namely, China (CH) and Thailand (TL).

The variables related to this research are defined as follows: the actual outputs Y_{jt} is represented by GDP_{jt} (Chen and Lin, 2009; Lin, 2009; Lin and Chiang, 2011; Lin and Shao, 2000, 2006a, b; Lin, Chuang and Choi, 2010); $capital_{jt}$ is defined as the gross fixed capital formation of country j at time t, $labour_{jt}$ is defined as the total labor cost of country j at time t, IT $investments_{jt}$ is defined as IT hardware $spending_{jt}$ + IT software $spending_{jt}$+other office $equipment_{jt}$, and information systems (IS) is defined staffing $cost_{jt}$, which is the spending on computer services (Chen and Lin, 2009; Lin, 2009; Lin and Kao, 2014). Then, the production factors in the CES functions are computed as follows: K_{jt}=$capital_{jt}$-IT $investment_{jt}$ L_{jt}=$labour_{jt}$-IS staffing $cost_{jt}$, and I_{jt} (IT capital) =IT $spending_{jt}$ +3*IS staffing $cost_{jt}$ (Brynjolfsson and Hitt, 1996; Chen and Lin, 2009; Hitt and Brynjolfsson, 1996; Lin, 2009; Lin and Chiang, 2011; Lin and Shao, 2000, 2006a, b; Lin, Chuang and Choi, 2010).

The data on the above variables and the five national characteristics are collected from the following sources: the yearbook of each country, the United Nations Common Database, International Financial Statistics, International Marketing Data and Statistics, European Marketing Data and Statistics, and Digital Planet 2002, 2004, 2006, and 2008, the Global Information Economy. The IT data for the years 2009 and 2010 are the projected values from Digital Planet 2008. All the data used are transformed into millions of constant U.S. dollars in 1995 or in the form of ratios (indexes).

4. Results and Discussion

4.1. The Individual Analytical Results

The individual analytical method could be used to address the issues of the value of IT and the productivity paradox for individual countries, as in Lin (2009), Chen and Lin (2009), Lin, Chuang and Choi (2010), and Lin and Chiang (2011). Table 1 compares the APR_j for the individual countries and different groups in detail. Hence, the IT value and so-called productivity paradox can be analyzed in more depth.

Table 1

Comparison of APVjs without/with IT (Model 1 vs. Model 2): Does IT in the Presence of Unobserved Characteristics Enhance (E) or Reduce (R) the APVjs ?

Country	Without IT	Ranking	With IT	Ranking	E or R	%
AU	0.3951	6	0.5098	3	E	29.03
CN	0.3609	8	0.4277	7	E	18.51
FR	0.6453	3	0.5784	2	R	-10.37
IL	0.6571	2	0.3930	11	R	-40.19
JP	0.3174	9	0.4006	10	E	26.21
UK	0.6242	4	0.6102	1	R	-2.24
US	0.2894	11	0.4198	8	E	45.06
HK	0.5083	5	0.3488	12	R	-31.38
SK	0.6694	1	0.4304	6	R	-35.70
SG	0.3080	10	0.5081	4	E	64.97
AVG of GP1	0.4775		0.4627		R	-3.10
CH	0.2690	12	0.4831	5	E	79.59
TL	0.3775	7	0.4180	9	E	10.73
AVG of GP2	0.3233		0.4506		E	39.38
AVGW	0.4518		0.4607		E	0.57

Notes: (i) AVG and AVGW stand for group average and overall average, respectively.
(ii) GP1 represents Group 1, composed of Australia (AU), Canada (CN), France (FR), Japan (JP), Italy (IL), the United Kingdom (UK), the United States (US), Hong Kong (HK), South Korea (SK), and Singapore (SG); GP2 represents Group 2, consisting of China (CH) and Thailand (TL). The division of groups follows the income criterion as provided by the World Bank (see Lin 2009; Lin and Chiang 2011).
(iii) UNC stands for national characteristics.

Now, we see from Table 1, the average of the APR_j of Group 1 (developed countries) in the absence of IT is 0.4775, in comparison with 0.4627 in the presence of IT, representing a 3.10% decrease and suggesting the existence of the productivity paradox in the developed countries. By contrast, the averages of the APR_j of Group 2 (developing countries) represent a 39.38% increase (0.3233 without IT versus 0.4506 with IT), suggesting the absence of the productivity paradox in the developing economies. Thus, the argument of Dewan and Kraemer (2000) and Lee, Gholami and Tan (2005) claims that the productivity paradox exists only in the developing economies and not in the developed countries is not supported by our empirical evidence. Furthermore, the average of 0.4581 without IT versus 0.4607 with IT of the APR_j of all 12 economies indicates an increase of approximately 1.97%. This empirical evidence seems to support the argument that the productivity paradox has disappeared (Brynjolfsson and Hitt, 1996; Hitt and Brynjolfsson, 1996; Lin and Shao, 2000).

Carefully inspecting the APR_j s for the individual countries, we can draw some conclusions. Among the developed countries, there are three countries, namely, FR (France), IL (Italy), and UK (United Kingdom), where the appearance of IT decreases their APR_j (0.6453, 0.6571 and 0.6242, respectively, in the absence of IT in comparison with 0.5784, 0.3930, and 0.6102 in the presence of IT, representing a decrease of 10.37%, 40.19%, 2.24%, respectively). Similarly, there are also two developed economies, HK (Hong Kong) and SK (South Korea), where the APR_j s without IT are 0.5083 and 0.6694, respectively, and their counterparts with IT are 0.3488 and 0.4304, a decrease of 31.38% and 35.70%. In the other five developed countries and two developing economies, the IT investments have a positive effect on the performance measurement. These empirical results show that the productivity paradox may occur in a country regardless of whether it is a developed or developing country. This finding contradicts conventional wisdom (Brynjolfsson and Hitt, 1996; Hitt and Brynjolfsson, 1996; Lin and Shao, 2000) and the conclusion that the productivity paradox exists only in developing countries but not in developed countries (Dewan and Kraemer, 2000). The conclusions, however, support the viewpoint by other authors, such as Lin (2009), Chen and Lin (2009), and Lin and Chiang (2011) adopting the SPF approach and Lin, Chuang and Choi (2010) adopting the PA approach.

Some countries need special attention. The APR_j s of the UK and FR without IT/with characteristics rank fourth and third, respectively, among the 12 countries; however, their APR_j s in the presence of IT rank first and second, respectively, though both counties face the same fate of R. Another developed country, SK (South Korea), has an APR_j that ranks first in the absence of IT, owing to a higher average speed of adjustment (0.6683) caused by unobserved national characteristics; however, its ranking regressed to sixth in the presence of IT because of a lower speed of adjustment (0.4300), with a drop of 35.70% in its APR_j . Finally, for CH (China) and the US (United States), the largest developing country and the largest developed country, respectively, their APR_j rank the last and second to last in the absence of IT, respectively. However, the contributions by IT investments lead to their rankings to improve to the fifth and eighth, with a growth of 79.59% and 45.06%, respectively. Obviously, the speed of adjustment caused by unobserved national characteristics has a significant effect on the established performance measurement (see Eqs. (5)-(8)) based on the PA approach), and the IT capital appearing in the production function affects the desired output (Lin, Chuang and Choi , 2010) and thus the performance measurement. Consequently, the IT and unobserved national characteristics may be complementary in improving the performance of an individual country. Consider CN (Canada) as an example. Its APR_j increased from 0.3609 to 0.4277 because of the appearance of IT, a net increase of 18.51%; however, part of this increase is due to the improved adjustment speed, mostly due to unobserved national characteristics, and part of the increase resulted from IT investment. However, the phenomenon of complementarity is not guaranteed to occur in a country because the adverse phenomenon of substitutability between IT and unobserved characteristics may prevail in the country (*e.g.,* IL and SK). This finding seems to be consistent with the conclusion of Lin, Chen and Shao (2015), although basic research theories, approaches, models and forms of selected national characteristics are different between the present study and the work of Lin, Chen and Shao (2015).

4.2. Analyzing Relations with Respect to the Substitutability and Complementarity of Inputs

The relationships of substitution and complementarity among ordinary capital, ordinary labor, and IT capital are an important but complex issue with respect to IT value (Chen and Lin, 2009; Lin and Chuang, 2013), and they have received some attention by several researchers (Chen and Lin, 2009; Dewan and Min, 1997; Lin and Shao, 2006b). Table 2 describes the phenomena of substitution and complementarity within the countries considered in this research in the two-factor model (Model 1) and three-factor model (Model 2). Let us first analyze the relationships regarding substitution and complementarity between ordinary capital (K) and ordinary labor (L) in the absence of IT. In the developed countries, the substitution parameters of AU, CN, FR and the UK are p=0.2984, 0.7559, 0.8520 and 1.3124, respectively, which are all higher than zero. These results clearly imply that the ordinary capital and labor in these developed countries are substitutable. The substitution parameters of the other six developed countries (JP, IL, the US, HK, SK and SG) are negative, suggesting that ordinary capital and labor are complementary in these developed countries. In the two developing economies, ordinary capital and labor are substitutable for CH with p =4.6752 and complementary for TL with p =-1.0069, which are both close to -1.0.

Table 2

The Substitution Parameter of CES Production Function Estimated by Nonlinear Least Squares

Cty	Two factor (model 1) ()	Three factor (model 2)		
	p	p_1	p_2	p_3
AU	0.2984	0.0567	0.0737	0.0948
CN	0.7559	0.0256	-0.4271	-0.8026
FR	0.852	4.0669	0.5602	-1.0139
JP	-0.261	-0.0019	0.1093	0.1568
IL	-0.124	-0.1591	-0.0459	0.0166
UK	1.3124	15.1613	-0.0172	37.3922
US	-1.2838	-1.1084	-0.5534	0.2972
CH	4.6752	0.1312	0.0617	0.0659
HK	-1.173	6.0981	0.8074	0.4853
SK	-0.3621	-0.0615	-0.1594	-0.0852
SG	-1.1768	-0.2047	0.3223	0.8723
TL	-1.0069	106.0258	3.4835	4.6082

However, by introducing IT capital as a production factor into the production process, the substitution between K and L, between L and I, and between K and I begin to change. For example, in both HK and TL, ordinary capital and labor are complementary in the absence of IT, but they become substitutable in the presence of IT. The relationships with respect to substitution and complementarity among K, L, and I in all 12 countries considered in this paper can readily be observed. The substitution parameters (p_1, p_2 and p_3) in the economies of AU (Australia), CH (China), HK (Hong Kong), and TL (Thailand) are all higher than zero, implying that K, L, and I in these countries are pairwise substitutable. Thus, for these four economies, the empirical evidence seems to confirm the conclusion of Dewan and Min (1997), who claimed that the input factors K, L and I are pairwise substitutable. In fact, however, this phenomenon was not found in other countries in our sample because the values of the three substitution parameters show mixed by positive and negative signs. In particular, the three inputs are pairwise complementary for SK (South Korea) because p_1=-0.0615, p_2=-0.1594, and p_3=-0.0852 are all negative.

Accordingly, the empirical evidence does reject the notion that (K, L, and I) are pairwise substitutable (Dewan and Min, 1997). These findings are consistent with those of Lin and Chuang (2013) at the firm level and Chen and Lin (2009) at country level.

4.3. The Wilcoxon Signed-rank Test Result

The Wilcoxon signed-rank test, also known as the Wilcoxon matched pairs test, is a non-parametric test used to test differences in paired data. Here, the non-parametric method can be used to examine whether the differences in PR_{jt} (see Eq. (7)) from two different models - Model 2 with IT and Model 1 without IT - across countries and through time are significantly different from zero (Lin, 2009; Lin and Chiang, 2011; Lin and Shao, 2006a; Lin, Chuang and Choi , 2010).

For this purpose, we define PR_{jt} as the PR' of country j at time t in the presence of IT (*i.e.,* from Model 2), PR_{jt} as the PR of country j at time t in the absence of IT (*i.e.,* from Model 1), and d_{jt} as PR'-PR. The hypothesis is H_0: d_{jt}=0 against H_1: $d_{jt} \neq 0$. We then rank the differences by their absolute value $\left|d_{jt}\right|$ in an increasing order and assign the ranks 1, 2…, N to the ordered differences, where N=m×n. We use W^+ to denote the sum of the ranks corresponding to the positive differences, W^- to define the sum of the ranks corresponding to the negative differences, and W^*=min (W^+, W^-). Finally, we compute the observed value of the test statistic by applying $Z^* = [W^* - \mu(W^*)]/\sigma(W^*)$, where: $\sigma(W^*) = \sqrt{N(N+1)(2N+1)/24}$ and $\mu(W^*) = N(N+1)/4$.

In this paper, W^+=9021, W^-=14415, $\mu(W^*)$=11718, $\sigma(W^*)$=919.59, and as a result, $\left|Z^*\right|$ =2.9328, which is higher than the critical value of 2.575 at the 1% level of significance. Thus, we reject the null hypothesis, meaning that the differences in the performance values with and without IT across different countries and through time are significantly different from zero.

5. Concluding Remarks

This paper applies the PA approach proposed by Lin, Chuang and Choi (2010) to jointly investigate the business value of IT, the productivity paradox, and the relations of complementarity and substitution among three input factors (K, L and I), where the speed of adjustment is dynamic and variable rather than fixed. Thus, this paper represents an extension to the PA approach with constant speed (Lin, Chuang and Choi, 2010) and an application of the PA approach with dynamic and variable speed of adjustment, in contrast to the CES stochastic production frontier approach (Chen and Lin, 2009). The adjustment speed is the function of a set of unobserved (expected) national characteristics, incorporating the three-factor CES function, thereby enabling us to analyze the complementarity and substitution relations of the inputs.

There are several potential extensions for future research. First, for the purpose of comparisons, one possible extension is to replace CES with the CD function and the BC and BT transformations as the representative of the desired output. In so doing, the business value of IT and the productivity paradox using the PA approach with dynamic and variable speed under the CD, BC and BT specifications can be investigated. Second, obviously, our empirical evidence suggests that selective expected national characteristics have significant effects on the speed of adjustment and, thus, the value of IT. There is great flexibility in choosing different national characteristics. For example, the five policy-oriented variables growth options (GO), external balances (EB), national savings (NS), return on assets (ROA) and vertical integration (VI) studied in the research of Lin and Chiang (2011) may be considered. A third extension is a firm-level study equipped with certain firm characteristics in the PA approach with dynamic and variable speed of adjustment. A final and important extension concerns the use of simultaneous equation modeling methods, as suggested in Lin (2009). However, the simultaneous equation models may face considerable difficulty and challenges in estimation because such models are nonlinear.

The empirical results show that the business value of information technology is not only affected by the investments of information technology, but also, and even more, by the national characteristics. However, we have not pinned down the way how the national characteristics affect the business value of information technology. Also, as another limitation, the results might not explain the reason why some developed countries benefit from information technology and it does not exist the phenomenon of productivity paradox, but some others are not. This is beyond the scope of our research and we leave it for future work. The last and most important limitation is due to data unavailability and, hence, can be addressed by future research, once more data become available.

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