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Productivity Growth in the Public Accounting Industry: The Roles of Information Technology and Human Capital

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SUMMARY: In this paper we decompose productivity growth into four components: efficiency change, technical progress, information technology (IT) capital accumulation, and human capital accumulation. We analyze data on the operations of 51 public accounting firms in Taiwan for the years 1993 and 2003, and find that productivity growth was driven primarily by the accumulation of IT capital and human capital. We also find that the difference in productivity growth between Big 4 and non-Big 4 accounting firms is attributable to technical progress and, especially, IT capital accumulation. Further, our multiple regression results indicate that accounting firms that had high growth in non-audit services (NAS) during the 11-year period enjoyed significantly higher productivity growth through greater IT capital and human capital accumulation than firms that remained focused on traditional audit services.

Keywords: productivity growth; efficiency change; technical progress; IT capital accumulation; human capital accumulation; Big 4; non-audit services.

INTRODUCTION

The audit market has witnessed intense competition in the last two decades, a period which featured a growing number of global networks and alliances (AICPA 2008) and increasing pressure on public accounting firms to control costs (see, e.g., Johnstone et al. 2004).[1] In this competitive environment, public accounting firms invested in information technology (IT) and human capital in an effort to boost productivity (i.e., revenues per employee) and facilitate service

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[1] Even after the demise of Arthur Andersen, no evidence was found linking audit market concentration to impairment of competition in the U.S. (GAO 2003).

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delivery (Janvrin et al. 2008). This paper examines dynamic shifts in the productivity of accounting firms and evaluates the contributions of IT and human capital in the productivity growth of public accounting firms.

Investment in IT has been identified as a key driver of productivity improvement among public accounting firms (Banker et al. 2002). IT enables public accounting firms to automate their routine auditing tasks and improve work collaboration and communication within audit teams, which in turn may enhance their service delivery (Banker et al. 2002; Bierstaker et al. 2001; Manson et al. 2001; Janvrin et al. 2008). Furthermore, public accounting firms are often hired to help integrate company information systems that may have grown in an uncoordinated manner, or to help implement complete systems incorporating office automation and automated warehousing (Banker et al. 2002). Due to their experience with these information systems and related services, public accounting firms which make use of sophisticated IT to provide these services may be rewarded with significant gains in productivity (Melville et al. 2004; Shin 2006; Chari et al. 2008).

For public accounting firms, the employment of high-quality human resources is considered just as important as investment in IT (O'Keefe et al. 1994; Blokdijk et al. 2006). The quality of human resources is typically measured in terms of education level and work experience (Hall and Jones 1999; Psacharopoulos 1994; Klenow and Rodriguez-Clare 1997). It is generally held that both college education and work experience are indispensable to the build-up of expertise in the auditing profession (Bonner and Pennington 1991; Hitt et al. 2001). Since professional services provided by public accounting firms are complex, they require both technical knowledge and tacit managerial knowledge (Tan and Libby 1997), which are acquired through advanced education and work experience (Bonner and Pennington 1991). Therefore, professionals with higher education levels and more experience in the field constitute greater human capital for public accounting firms. This human capital, in turn, should produce higher-quality services for clients and thereby contribute to the productivity growth of public accounting firms (Bröcheler et al. 2004).

Even though IT and human capital may have a significant impact on the productivity of public accounting firms, little empirical work has been done to examine the relation between these two productive factors and productivity growth in the context of public accounting firms. Banker et al. (2002) investigate the effect of IT on a public accounting firm's productivity in the U.S., while Bröcheler et al. (2004) use data from the Dutch audit market to examine the relationship between human capital and audit firm performance. However, they do not investigate both factors simultaneously in a single study. To address this gap in the literature, we adapt the framework proposed by Henderson and Russell (2005) and include IT capital and human capital as factors to further decompose productivity growth into four distinct components—efficiency change, technical progress, IT capital accumulation, and human capital accumulation.[2] The method proposed by Henderson and Russell (2005) enables us to identify and evaluate the individual contributions of these four potential drivers of productivity growth among public accounting firms.

Further, non-audit services (NAS) have grown significantly over the past three decades. While Simunic (1984) examines the synergies public accounting firms may achieve from providing NAS, subsequent studies focus on the possible compromise of auditor independence related to NAS provision (e.g., Frankel et al. 2002; Ashbaugh et al. 2003; Chung and Kallapur 2003; Larcker and Richardson 2004; Krishnan et al. 2005; Francis and Ke 2006). With only a few notable exceptions (Banker et al. 2005; Knechel et al. 2009; Knechel and Sharma 2010), studies on the audit production function and efficiency (e.g., Simunic 1980; O'Keefe et al. 1994; Dopuch et al. 2003) do not evaluate the association between NAS and the efficiency and productivity of public accounting

[2] Efficiency change refers to the change in relative efficiency between two periods, whereas technical progress is the shift in production frontier between the two periods.

firms. Thus, the effect of NAS on productivity growth and its contributing components warrants further investigation. In this paper, we investigate the effects of the increase in the relative importance of NAS in recent years on productivity growth and its components.

We analyze data on revenues, employees, IT expenditures, and human capital in 1993 and 2003 for a sample of 51 public accounting firms in Taiwan, and find that public accounting firms experienced an average of 51.1 percent growth in productivity. Of this growth, 0.2 percent came from efficiency improvement, 6.3 percent from technical progress, 30.2 percent from IT capital accumulation, and 14.3 percent from human capital accumulation. That is, the observed productivity gains were driven primarily by the accumulation of IT capital and human capital rather than by technical progress. In addition, we find a significant difference in productivity growth between Big 4 and non-Big 4 firms, caused primarily by greater technical progress and IT capital accumulation among the Big 4 accounting firms. Finally, by regressing productivity growth and its four components on the proportion of revenue from NAS and changes in the proportion of revenue from NAS, we find that Taiwanese public accounting firms that had greater growth in NAS enjoyed higher productivity growth than their peers because these firms accumulated higher IT and human capital than their peers over our sample period.

Our study contributes to the accounting literature by investigating the role of IT capital accumulation and human capital accumulation in the labor productivity growth of public accounting firms. Our adoption of Henderson and Russell's (2005) quadripartite decomposition of productivity growth in public accounting firms complements the studies of Bröcheler et al. (2004) and Banker et al. (2002) by identifying the relative contributions of IT capital accumulation and human capital accumulation to productivity improvement.[3] In addition, most prior research concerns the effect of NAS provision on auditor independence; our study extends this line of research by examining the effects of NAS on IT and human capital accumulation and hence productivity growth. Such an extension may contribute to policy deliberation on the prohibition of NAS provision.[4] Finally, with the accelerating globalization of business, accounting researchers have increasingly conducted research in international contexts (DeFond and Francis 2005; Simunic 2006). Our study contributes to this dimension by documenting empirical evidence from public accounting firms outside the U.S.

The rest of the paper is organized as follows. The next section reviews prior literature regarding productivity of public accounting firms and the effects of NAS provision on productivity, followed by an overview of the audit market in Taiwan. We then briefly describe the decomposition of productivity growth, and discuss the empirical estimation and results. Descriptions of data and sample selection, measurement of variables, and robustness checks are also included in this section. The final section presents our conclusions.

PRIOR LITERATURE

Following the seminal work of Simunic (1980), numerous studies have investigated production processes involved in the provision of auditing services. O'Keefe et al. (1994) first present a model of audit production that treats auditor effort (e.g., hours disaggregated by rank) as input and the level of assurance obtained as output. Based on this model, they investigate the production of audit services by using regression analysis to evaluate the influence of engagement characteristics

3 In this regard, our study also sheds light on prior work on efficiency measurement of Taiwanese accounting firms since most prior studies analyze only the efficiency of accounting firms in Taiwan and fail to identify underlying drivers of productivity growth (e.g., Cheng et al. 2000).

4 Our study addresses the association between productivity growth and NAS, and does not simultaneously examine the possible effect of NAS on audit quality. See Knechel and Sharma (2010) for a discussion on the effect of NAS provision on audit efficiency and effectiveness.

on audit hours spent on an engagement. Subsequent to O'Keefe et al. (1994), Hackenbrack and Knechel (1997) further disaggregate labor hours by the type of audit activities performed, e.g., audit planning, substantive testing, and internal control evaluation, and find that client-specific characteristics have a significant impact on task assignment patterns and resource allocation decisions.

Recently, some studies extend the audit production literature by examining relative efficiency in audit production using efficiency frontier techniques such as data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Dopuch et al. (2003) find that the average audit is produced at about an 88 percent efficiency level relative to the most efficient audits in their sample. Further, Knechel et al. (2009) develop a modified audit production framework that uses labor cost as input, and hours spent on evidence-gathering activities that determine the level of assurance as output, and find that audits are more efficient for clients that are larger, have a December year-end, and are highly automated. They also find that audits are less efficient when the auditor relies on internal controls, when tax services are provided, and when the client has subsidiaries.

The production function for audit engagements has been estimated in previous studies. However, relatively little research has been done on the estimation of the production function using firm-level data on outputs and inputs. Banker et al. (2003) were the first in accounting research to estimate the production function of public accounting firms. Analyzing a balanced panel of annual survey data for 64 of *Accounting Today*'s top 100 public accounting firms for the period 1995–1999, they find that public accounting firms improved their productivity in delivering services over the period 1995–1999. Recently, Banker et al. (2005) further extend their previous study by decomposing the productivity growth of public accounting firms into efficiency change and technical progress. They document that productivity growth of public accounting firms is attributable to technical progress rather than improvement in efficiency.

Some prior studies have focused on the important roles played by IT capital and human capital. Banker et al. (2002) explore the impact of IT implementation on the production function of an international public accounting firm. They find that the accounting firm's productivity is positively associated with its IT implementation. In contrast, Bröcheler et al. (2004) use data on 1,693 Dutch audit firms to examine the relationship between human capital and audit firm performance. They observe that human capital (measured by level of education and work experience) has a positive influence on audit firm performance. While these two studies have provided insights into the roles played by IT and human capital in the productivity growth of accounting firms, they do not incorporate IT and human capital simultaneously in the specification of their estimation models. Therefore, they do not identify and evaluate the relative contributions of IT and human capital on the productivity of public accounting firms.

Another line of research examines the effects of the increase in the relative importance of NAS on public accounting firms. Simunic (1984) suggests that the provision of NAS could create synergy through either decreases in service costs or increases in auditing services because of knowledge spillover arising from NAS. Recently, Brown and Caylor (2006) examine the impact of NAS provided by auditors on audit clients' performance. Their findings suggest that the provision of more NAS by auditors could improve auditee performance. Knechel and Sharma (2010) use audit report lag as a proxy for audit efficiency and find that proxies for audit quality including discretionary accruals and financial restatements do not increase when shorter audit lags occur in conjunction with NAS. Using a bipartite decomposition of total factor productivity, Banker et al. (2005) observe that the provision of more NAS by public accounting firms is associated with higher technical progress and efficiency change, which in turn are associated with higher productivity growth. The objective of the current study, in contrast, is to explore the role of IT capital and human capital in labor productivity growth. Generally, the growing demand for NAS may induce more investment in IT and human capital among public accounting firms. This is because NAS are in general more complex than traditional audits and hence accounting firms need to deploy IT and hire more educated and experienced specialists to handle such services (Abbott et al. 2003). As the demand for NAS increases, accounting firms may find investments in IT and human capital more rewarding (Zeff 2003). Therefore, we posit that public accounting firms that place a greater emphasis on NAS will accumulate more IT and human capital, which leads to higher labor productivity.

OVERVIEW OF THE TAIWANESE AUDIT MARKET

Public companies in Taiwan are required to have their annual and semi-annual financial statements audited by public accounting firms. In addition, quarterly financial statements of public companies are subject to review by public accounting firms. Auditors perform procedures complying with generally accepted auditing standards (GAAS) to assure that the financial statements are prepared in accordance with the generally accepted accounting principles (GAAP) and fairly represent the economic reality of the reporting entity. Both GAAS and GAAP in Taiwan are issued by independent standard-setting bodies (the Auditing Standards Committee and the Financial Accounting Standards Committee, respectively) and are endorsed by the regulator (the Financial Supervisory Commission) before issuance. The Auditing Standards Committee has adopted the auditing standards issued by International Auditing and Assurance Board as its reference framework, while the Financial Accounting Standards Committee employed the accounting standards issued by Financial Accounting Standards Board in the U.S. as its reference framework until 2000 when the Committee decided to align its standards with the then International Accounting Standards (currently International Financial Reporting Standards).

Regarding regulation, in addition to the self-regulation mechanism within the profession, auditor behavior is regulated by the Certified Public Accountants Act, the Business Accounting Act, and the Securities and Exchange Act. With respect to litigation risk, the lawsuits against auditors for civil liability were not common until 2003 when the Investors and Futures Investors Protection Act was enacted and an institution responsible for assisting investors in protecting their own interest was established.

As of 2008, there were 718 companies listed on the Taiwan Stock Exchange and 541 companies listed on the GreTai Securities Market.[5] Among these companies, 83.5 percent had their financial statements audited by Big 4 accounting firms (local firms affiliated with the Big 4 in the U.S.). While the audit market for listed companies is dominated by the Big 4 firms, intense, rather than low, price competition has been a concern among accounting firms in Taiwan (Lai 2000).

In summary, the audit market in Taiwan is similar to the U.S. market in terms of the qualifications and requirements for being an audit partner, the organization of accounting firms, professional standards (Parker and Morris 2001), the regulations governing auditor behavior, and the position of international accounting firms in the market. While there are differences in litigation risk and the size of audit markets, there is also considerable similarity between the Taiwan and U.S. audit markets. For example, Banker et al. (2005, 293) report an 80 percent growth rate of total revenues in their sample of U.S. accounting firms from 1995 to 1999, while our Taiwanese sample shows a similar growth rate (78.9 percent) during the same period. The similarity also extends to the transformation of services. Banker et al. (2005) find that the proportion of revenues from audit services (non-audit services) in their U.S. sample went from 49.51 percent (50.49 percent) in 1995 to 42.33 percent (57.67 percent) in 1999, whereas in our Taiwanese sample they went from 48.71 percent (51.29 percent) to 45.32 percent (54.68 percent) in the same period.

[5] The Taiwan Stock Exchange is the main board and the GreTai Securities Market is the second board in the Taiwan security market.

DECOMPOSITION OF PRODUCTIVITY GROWTH

Given the importance of identifying sources of productivity, numerous studies have investigated the decomposition of productivity change. There are two different types of productivity indexes used in prior studies: the Malmquist productivity index (Färe et al. 1994; Banker et al. 2005) based on the total factor productivity measure and labor productivity indexes based on output per employee (Kumar and Russell 2002; Henderson and Russell 2005). The Malmquist productivity index was developed by Färe et al. (1994) and can be decomposed into an efficiency change index and a technical progress index. In auditing research, Banker et al. (2005) apply the Malmquist productivity index and use three labor inputs (number of partners, number of other professionals, and number of other employees) as well as three outputs (accounting and audit service revenue, tax service revenue, and management advisory service revenue) to estimate productivity growth and its efficiency change and technical progress components.

In contrast, Kumar and Russell (2002) use changes in revenue per employee to measure labor productivity growth and decompose it into efficiency change, technical progress and capital deepening. In a later effort, Henderson and Russell (2005) augment this approach to include human capital as another input and further decompose labor productivity growth into efficiency change, technical progress, physical capital accumulation, and human capital accumulation.

Since IT capital and human capital are important for the operation of public accounting firms, identifying the respective contributions to labor productivity growth from IT capital and human capital accumulation (relative to efficiency change and technical progress) will have implications for the operation of public accounting firms. In this paper, we adapt the quadripartite decomposition method proposed by Henderson and Russell (2005) by replacing physical capital accumulation with IT capital accumulation, but leave the rest of the decomposition intact.[6] That is, we propose that labor productivity growth (Δy) be decomposed into four components: efficiency change (ΔEFF), technical progress ($\Delta TECH$), IT capital accumulation ($\Delta ITCA$), and human capital accumulation (ΔHCA) as follows:

$$\Delta y = \Delta EFF \times \Delta TECH \times \Delta ITCA \times \Delta HCA \tag{1}$$

where Δy is the productivity change between the base period and the subsequent period, ΔEFF is the change in efficiency relative to peers on the efficiency frontier, reflecting movement toward, or away from, the production frontier, and referred to as "catching up to the frontier" (Chang et al. 2009). $\Delta TECH$ represents technical progress capturing the shift in the production frontier, which is defined as the best practice technology of firms in the sample. $\Delta ITCA$ denotes IT capital accumulation, reflecting the impact of continuous IT investment on productivity growth of an accounting firm. ΔHCA denotes human capital accumulation, capturing the productivity growth due to the change in human capital of an accounting firm. Note that Equation (1) indicates that these contributions to productivity growth are multiplicative rather than additive. To make it an additive form, we take natural logarithms on both sides of Equation (1) and obtain:

$$\ln(\Delta y) = \ln(\Delta EFF) + \ln(\Delta TECH) + \ln(\Delta ITCA) + \ln(\Delta HCA). \tag{2}$$

This transformed measure in logarithms has the natural interpretation of a percentage change in productivity (Banker et al. 2005). The left-hand side and the sum of the four terms on the right-hand side of Equation (2) are an identity. Thus, the percentage change in productivity is equal to the sum of the percentage changes in relative efficiency, technology, IT capital, and human capital.

[6] We replace physical capital accumulation with IT capital accumulation because IT capital is the most important investment in the public accounting industry (Banker et al. 2002; Banker et al. 2005; Bröcheler et al. 2004).

We use data envelopment analysis (DEA) to measure the efficiency of public accounting firms in our sample with total revenue as the output, and total number of employees, IT capital, and human capital as the inputs. We use total revenue as the only output because, like Henderson and Russell (2005), we are interested in estimating labor productivity.[7] Aside from using total number of employees as an input, we include IT capital and human capital as two additional inputs for the purpose of decomposing labor productivity growth into IT capital accumulation and human capital accumulation in addition to efficiency change and technical progress. This is different from Banker et al. (2005) who use three labor inputs as measured by the number of employees for each of three different kinds of workforce. Their input measures implicitly lump the number of employees and human capital together because the experience and educational requirements for a partner are different from those for other types of staff.[8] Appendix A presents a brief introduction to DEA as used in our study. We employ DEA to estimate the production frontier of public accounting firms for 1993 and 2003 separately. For each year, the efficiency score for each accounting firm obtained from the estimated frontier is then used for the quadripartite decomposition.

Appendix B provides step-by-step details of how we apply the quadripartite decomposition of labor productivity growth proposed by Henderson and Russell (2005) to an accounting firm in our sample. It shows that labor productivity growth for an accounting firm is defined as labor productivity in 2003 divided by labor productivity in 1993, where labor productivity is total revenue per employee.[9] The efficiency score in 2003 divided by the efficiency score in 1993 denotes efficiency change from 1993 to 2003. Further, we use efficient accounting firms to construct production frontiers. The extent to which the frontier shifts at each firm's observed input mix is termed as technical progress. Finally, the movement along the production frontier brought about by the change in IT capital intensity and human capital between 1993 and 2003 are defined as IT capital accumulation and human capital accumulation.

EMPIRICAL ESTIMATION AND RESULTS

Data and Sample Selection

The data used for this study were obtained from *Annual Survey of Accounting Firms in Taiwan*, which is published by the Department of Statistics of Taiwan's Ministry of Finance. The database was constructed from responses to surveys of all public accounting firms in Taiwan. We choose the Taiwanese audit market as our particular setting because this data set has a number of advantages relative to *Accounting Today*'s annual surveys of public accounting firms in the U.S. First, the census data on accounting firms include comprehensive information about investment in IT, such as computer equipment, software and databases, as well as human capital variables such as the number of employees, average employee age, and employee education level, which are not available in *Accounting Today*'s annual surveys. The data set includes other data items such as the number of partners, the number of professionals, the number of administrative staff and other employees, as well as average salary per employee. Second, the annual survey of accounting firms in Taiwan published by the Ministry of Finance is arguably more authoritative compared to surveys conducted by a non-governmental institution in the U.S. Third, the data set provides longitudinal data on IT investment and human capital which enables us to evaluate the different contributions of IT capital and human capital accumulation to the productivity growth of public

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7 The single-output structure has been used in prior studies to estimate productivity at the firm level (e.g., Brynjolfsson and Hitt 1996).

8 Human capital is a function of education and experience. For details on the measurement of human capital, see the sub-section "Measurement of Variables."

9 For simplicity, we use "productivity" for "labor productivity" unless otherwise specified.

accounting firms over time. Such features allow for the decomposition of productivity growth into four components, which, to our knowledge, other data sets do not. Further, with the increasing globalization of audit firms, our findings based on Taiwanese audit firms may also have implications for international audit firms in terms of improving their productivity worldwide.

We started with the year 1993 because it was the first year that the data were available, and ended with 2003 because the Ministry of Finance subsequently discontinued conducting annual surveys.[10] Our initial sample contained 68 public accounting firms in Taiwan. Fifty-one public accounting firms remained after excluding 17 firms for incomplete data. Our final sample consisted of the 51 public accounting firms, including four Big 4 firms and 47 non-Big 4 firms, that appear consistently over the period 1993–2003.

Measurement of Variables

As mentioned earlier, we use total revenue as the output, and total number of employees, IT capital, and human capital as the inputs in performing DEA to measure the efficiency of public accounting firms in the sample.[11] Total revenue is measured in the local currency, New Taiwan (NT) dollars.[12] IT capital is measured by the total IT-related assets reported in the survey, including computer equipment, computer software, and database which are also valued in NT dollars. Human capital is represented by a human capital index that is estimated on the basis of returns to education and experience.[13] Following prior literature (i.e., Hall and Jones 1999; Psacharopoulos 1994; Klenow and Rodriguez-Clare 1997), we estimate a human capital index (H) for each accounting firm j at time t. The index assumes that human capital is a function of education level and work experience. Specifically, it takes an exponential function form as follows:[14]

$$H_j^t = h(ed_j^t, ex_j^t) = \exp(\phi_p P + \phi_i I + \phi_s S + \lambda_1 ex + \lambda_2 ex^2) \tag{3}$$

where ed_j^t denotes the average number of years of education of workers in public accounting firm j at time t; ex_j^t represents the average experience of the worker in public accounting firm j at time t, and the average experience is defined as the average age less average years of schooling and the seven years before attending school (Mitchell 1998); ϕ_p, ϕ_i, and ϕ_s are marginal returns for the first four years of education, the next four years of education, and education beyond the eighth year; and λ_1 and λ_2 are marginal returns on years of work experience and work experience squared. Following Hall and Jones (1999), Psacharopoulos (1994), and Klenow and Rodriguez-Clare (1997), we use $\phi_p = 0.134$, $\phi_i = 0.101$, $\phi_s = 0.068$, $\lambda_1 = 0.0495$, and $\lambda_2 = -0.0007$ in our computation of the human capital index (H) in Equation (3). Note that the human capital index is estimated for different levels of education and experience with differential returns to each, and a higher index value estimated from Equation (3) for a public accounting firm indicates that it has a better workforce.

[10] In the analysis reported later, we also split the whole period into two sub-periods using 1998 as the cut-off year to address the potential structural change in the sample period. The relative contributions of the four components (IT capital accumulation, human capital accumulation, efficiency change, and technical progress) based on the first sub-period are qualitatively the same as those based on the second sub-period and those based on the whole period.

[11] Note that in performing DEA, total revenue is the output, whereas revenue per employee (total revenue divided by the number of employees) is used to measure labor productivity in quadripartite decomposition (Kumar and Russell 2002).

[12] The currency exchange rates between U.S. dollars and NT dollars ranged from NT\$27.17 to NT\$32.58 per U.S. dollar during our sample period.

[13] Prior auditing studies measure human capital in terms of education and experience (e.g., Bedard et al. 2007; Bröcheler et al. 2004).

[14] Hall and Jones (1999), Psacharopoulos (1994), and Klenow and Rodriguez-Clare (1997) evaluate the returns to education and experience for a sample of 56 countries, including Taiwan.

Descriptive Statistics

Panel A of Table 1 provides descriptive statistics for total revenues, total number of employees, IT capital, human capital, and mix of service revenues for 1993 and 2003.[15] Median values for revenues and total number of employees are much smaller than the means, indicating a large difference between the largest firms and the more numerous smaller firms in the sample. The mean (median) total revenue grew by 138 percent (165 percent) during the period 1993–2003, while the mean (median) total number of employees grew by 64 percent (30 percent). The mean (median) IT capital grew by 280 percent (530 percent) and the mean (median) human capital increased by 24 percent (34 percent). Since the human capital index is based on education and experience and the return to education and experience, the increase in mean human capital indicates that the accounting firms hired/retained more educated and experienced workers and hence accumulated human capital over the sample period. Finally, the mix of service revenues reveals a decline in the share of revenue generated by traditional audit services (AS), with a corresponding increase in the share of revenues generated by non-audit services (NAS). The growth of non-audit services in the revenue mix is consistent with the trend in global auditing markets.

Due to the importance of IT and human capital for the operations of accounting firms, we are interested in the roles that IT capital and human capital play in labor productivity growth. We include IT capital and human capital in our estimation of public accounting firm efficiency, and then exclude them from the estimation to compare the efficiency measures. Panel B of Table 1 indicates that when IT capital and human capital are considered in efficiency measurement, the mean (median) efficiency in 1993 and 2003 is 0.87 (0.86) and 0.88 (0.87), respectively; whereas the mean (median) efficiency decreases to 0.72 (0.73) and 0.74 (0.78) in 1993 and 2003, respectively, when IT capital and human capital are excluded from efficiency estimation. The mean (median) differences between efficiency with and without IT capital and human capital are statistically significant ($p < 0.01$). In addition, the proportion of efficient firms increases from 7.8 percent to 13.7 percent, when we consider IT capital and human capital in efficiency measurement in 1993. Similarly, the proportion of efficient firms increases from 5.8 percent to 11.7 percent after including IT capital and human capital in efficiency estimation in 2003. Finally, Panel C of Table 1 reports the number of firms that stay efficient, become more efficient, and become less efficient after the inclusion of IT capital and human capital in efficiency estimation.[16] In both years, a majority of our sample firms (37 for 1993 and 33 for 2003, both out of 51 firms) become more efficient with the incorporation of IT capital and human capital. Overall, the statistics in Table 1 suggest that IT capital and human capital combined have a significant effect on the efficiency of public accounting firms in our sample.

Empirical Results

Panel A of Table 2 reports labor productivity growth and its four components in accordance with Equation (2) for Taiwanese accounting firms.[17] The mean labor productivity growth was 51.1 percent, suggesting that, on average, revenues per employee increased about 51 percent from 1993 to 2003. The four components contribute differently to this labor productivity growth. Specifically, the mean efficiency change was 0.2 percent, the mean technical progress was about 6.3 percent, the mean IT capital accumulation was about 30.2 percent, and the mean human capital accumu-

[15] Total revenues and IT capital expenditures are inflation-adjusted using 1993 as the base year.

[16] A firm is classified as "Stay efficient" if it remains on the production frontier after the inclusion of IT capital and human capital in efficiency estimation. Firms are classified as "More efficient" ("Less efficient") if their efficiency score increases (decreases) after the inclusion of IT capital and human capital.

[17] Appendix C provides descriptive statistics of $\ln(\Delta y)$, $\ln(\Delta EFF)$, $\ln(\Delta TECH)$, $\ln(\Delta ITCA)$, and $\ln(\Delta HCA)$ for each accounting firm in our sample.

TABLE 1

Summary Statistics

Panel A: Descriptive Statistics (n = 51)

Variables	Years	Mean	Std. Dev.	Min	Median	Max
Revenues	1993	15.73	51.94	0.39	2.81	77.22
	2003	37.47	102.95	1.43	7.47	229.07
Employees	1993	101.61	204.17	15	55	604
	2003	167.14	323.77	30	72	2001
IT Capital	1993	1.31	13.27	0.00	0.26	45.64
	2003	4.98	12.48	0.08	1.64	201.32
Human Capital	1993	1.86	0.51	1.22	1.72	2.94
	2003	2.31	0.59	1.52	2.30	3.31
AS%	1993	49.62	11.43	38.56	50.11	75.44
	2003	44.06	11.86	34.73	45.72	72.27
NAS%	1993	50.38	12.06	24.56	51.36	61.44
	2003	55.77	12.75	28.73	56.32	65.27

Panel B: Efficiency Indexes with versus without IT Capital (IT) and Human Capital (HC)

Statistics	Years	Without IT and HC	With IT and HC	Test Statistics for Differences[a]
Mean	1993	0.72	0.87	2.55***
	2003	0.74	0.88	2.41***
Median	1993	0.73	0.86	2.43***
	2003	0.78	0.87	2.39***
Number (%) of Efficient Firms	1993	4 (7.8%)	7 (13.7%)	—
	2003	3 (5.8%)	6 (11.7%)	—

(continued on next page)

Panel C: Number of Firms that Remain Efficient, Become More Efficient and Become Less Efficient after the Inclusion of IT and HC

Years	Stay Efficient[b]	More Efficient[b]	Less Efficient[b]
1993	3	37	11
2003	2	33	16

*, **, *** Indicate significance at the 0.10, 0.05, and 0.01 level, respectively.

[a] The t-test is for differences in means, while Wilcoxon test for differences in medians.

[b] Firms are classified as "Stay efficient" if they remain on the production frontier after the inclusion of IT capital and human capital. Firms are classified as "More efficient" ("Less efficient") if their efficiency score increases (decreases) after the inclusion of IT capital and human capital.

Efficiencies are estimated from the DEA model in (5) of Appendix A.

Variable Definitions:

Revenues = total revenue expressed in units of 10 million NT dollars deflated to 1993;
Employees = number of employees;
IT Capital = total IT capital expressed in units of 10 million NT dollars deflated to 1993;
Human Capital = an augmentation factor equal to exp(0.134 $*$ first four years of education + 0.101 $*$ the next four years of education + 0.068 $*$ education beyond the eighth year + 0.0495 $*$ work experience −0.0007 $*$ work experience squared) (see Hall and Jones 1999);
AS% = proportion of audit services revenues; and
NAS% = proportion of non-audit services revenue.

TABLE 2
Quadripartite Productivity Decomposition Indexes

Panel A: Full Sample

	Productivity Growth	Percentage Contribution to Productivity Growth			
	Productivity Growth ln(Δ*y*)	**Efficiency Change ln(Δ*EFF*)**	**Technical Progress ln(Δ*TECH*)**	**IT Accumulation ln(Δ*ITCA*)**	**HC Accumulation ln(Δ*HCA*)**
1993–2003	0.511	0.002	0.063	0.302	0.143
1993–1998	0.238	0.004	0.029	0.136	0.067
1998–2003	0.273	−0.002	0.034	0.166	0.076

Panel B: Big 4 versus Non-Big 4 Accounting Firms

			Percentage Contribution to Productivity Growth			
		ln(Δ*y*)	**ln(Δ*EFF*)**	**ln(Δ*TECH*)**	**ln(Δ*ITCA*)**	**ln(Δ*HCA*)**
Big 4	1993–2003	0.909	0.062	0.154	0.508	0.182
	1993–1998	0.416	0.030	0.073	0.230	0.081
	1998–2003	0.493	0.032	0.081	0.278	0.101
Non-Big 4	1993–2003	0.477	−0.003	0.055	0.284	0.140
	1993–1998	0.230	−0.002	0.026	0.135	0.068
	1998–2003	0.247	−0.001	0.029	0.149	0.072
Difference (t-test)	1993–2003	0.432***	0.065	0.099***	0.224**	0.042
	1993–1998	0.186**	0.032	0.047**	0.095*	0.013
	1998–2003	0.246***	0.033	0.052**	0.129**	0.029

*, **, *** Indicate significance at the 0.10, 0.05, and 0.01 levels, respectively.

lation was about 14.3 percent. In addition, we split the sample period into two sub-periods using 1998 as the cut-off year to address the potential structural changes during our sample period. We re-run our decomposition analysis for the two sub-periods: 1993 to 1998, and 1998 to 2003. The results in Panel A of Table 2 indicate the robustness of our findings pertaining to the relative contribution of the four components of productivity growth in the two sub-periods.

We accordingly conclude that the labor productivity growth of accounting firms in Taiwan over the period 1993–2003 is attributable primarily to IT capital accumulation and human capital accumulation. As for the small improvement in efficiency, one possible explanation is that if a majority of accounting firms failed to catch up with the relatively few accounting firms that push out the production frontier, then technical progress would still take place, but efficiency change in the industry would be low relative to the advancing best practice (Banker et al. 2005). That is, firms' positions relative to the production frontier on average have changed very little such that productivity growth has come mainly from changes in other factors such as changes in the frontier, IT capital and human capital.[18] Based on this finding, it seems appropriate to incorporate IT capital and human capital in measuring productivity growth in order to identify the major contributors to productivity growth for public accounting firms.

Panel B of Table 2 reports statistical test results for differences between Big 4 and non-Big 4 firms in terms of percentage changes in productivity, efficiency, technology, IT capital accumulation, and human capital accumulation.[19] It indicates that Big 4 accounting firms experienced greater productivity growth than non-Big 4 firms in the period 1993–2003, primarily due to the contributions of technical progress and, in particular, IT capital accumulation. The lower growth rate of non-Big 4 firms is attributable to their relative lack of efficiency gain, technical progress, and IT capital accumulation. There appears to be no difference in the contribution of human capital accumulation between Big-4 and non-Big 4 firms. Further, productivity growth, technical progress, and IT capital accumulation are all significantly different between these two groups of firms, suggesting that the difference in productivity growth between Big 4 and non-Big 4 accounting firms is explained primarily by IT capital accumulation, in addition to technical progress. Finally, we re-run our difference analysis between Big 4 and non-Big 4 for each of the two sub-periods: 1993 to 1998 and 1998 to 2003. The results in Panel B of Table 2 indicate the robustness of our findings pertaining to the differences between Big 4 and non-Big 4 firms in productivity growth and its four components.

The above results suggest that while the advance of technology affords all accounting firms opportunities to improve productivity, not all firms exploit these opportunities equally. Since the Big 4 accounting firms have invested more resources to revamp their IT systems and infrastructure (Bierstaker et al. 2001), they are rewarded with greater technical progress and IT capital accumulation, which in turn leads to higher productivity growth.

As explained earlier, we posit that accounting firms that place a greater emphasis on NAS will have higher IT and human capital accumulation, which eventually will lead to higher productivity growth. To evaluate this possibility, we investigate the association between NAS and productivity growth, as well as between NAS and each of the four contributors to productivity growth. Specifically, we follow Banker et al. (2005) and regress each of the five percentage change measures on percentage revenues derived from NAS (*NAS%*) in 1993, and change in percentage revenues from NAS (Δ*NAS%*) between 1993 and 2003. We also control for the effect of Big 4 as indicated in the following estimation model:

[18] We gratefully acknowledge an anonymous reviewer for suggesting this explanation.

[19] The t-test was performed to test for the differences between Big 4 and non-Big 4 firms in these percentage changes during the sample period. Therefore, four Big 4 firms and 47 non-Big 4 firms were used in our tests. The Wilcoxon test was also performed and yielded consistent results.

$$\ln(change\ measure) = \beta_0 + \beta_1 \times NAS\% + \beta_2 \times \Delta NAS\% + \beta_3 \times BIG4 + \varepsilon \quad (4)$$

where ln(*change measure*) = ln(*productivity growth*), ln(*efficiency change*), ln(*technical progress*), ln(*IT capital accumulation*), and ln(*human capital accumulation*). We do not include *AS%* and Δ*AS%* in Equation (4) because *AS%* and *NAS%* add up to 100 and the two change variables add up to zero. Therefore, the coefficient estimates are interpreted as relative to *AS%*.

We follow Banker et al. (2005) to use *NAS%* and Δ*NAS%* as proxies for firms that were first-movers to NAS and that had high NAS growth during the eleven-year period, respectively. The coefficients β_1 and β_2 are expected to be positive because firms with high *NAS%* and firms with high growth in *NAS%* from 1993 to 2003 should experience higher productivity change, technical progress, efficiency change, IT capital accumulation, and human capital accumulation.

We report the regression results in Table 3. Panel A shows that there is no significant association between efficiency change and *NAS%*, and between efficiency change and Δ*NAS%*. A similar pattern is found for technical progress. In contrast, *NAS%* is significantly positively associated with IT capital accumulation whereas Δ*NAS%* is significantly positively associated with both IT and human capital accumulation. These results suggest that while public accounting firms that were early movers into NAS tend to be ones that had higher changes in IT capital accumulation, accounting firms which emphasized growth in NAS tend to be ones that had higher changes in both IT and human capital accumulation. In addition, we observe that productivity growth is significantly positively associated with both early movement into NAS and high growth in NAS, indicating that, *ceteris paribus*, a first-mover firm and a firm with higher growth in NAS have higher productivity growth than a firm that focused on traditional AS services during 1993–2003. Finally, we re-run our regression models for the two sub-periods: 1993 to 1998, and 1998 to 2003. Panels B and C of Table 3 show the regression coefficients, and the Chow test statistic does not reject the null hypothesis of parameter stability, suggesting that the regression coefficients are stable across sub-periods.

Robustness Checks

As reported earlier, we find that productivity growth and its contributing components for Big 4 firms are different from those for non-Big 4 firms. Therefore, we check whether our results on NAS effects are robust to firm type by adding interaction terms for NAS variables and a dummy variable (*BIG4* = 1; *non-BIG4* = 0) and repeating the regressions. We find that the coefficients for *NAS%* and Δ*NAS%* are still significantly and positively associated with productivity growth and IT capital accumulation.[20] However, the coefficients for interaction terms *NAS%* × *BIG4* and Δ*NAS%* × *BIG4* are all insignificant, indicating that the effects of NAS and changes in NAS on productivity growth and its four components do not differ between Big 4 and non-Big 4 firms.[21] Taken together, these findings suggest that public accounting firms, whether they are Big 4 or non-Big 4 firms, can gain productivity growth through IT capital accumulation as they increase NAS in the revenue mix.[22]

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[20] In the regression with productivity growth as the dependent variable, coefficient estimates for *NAS%* and Δ*NAS%* are 0.843 and 0.782, respectively ($p < 0.05$), and coefficient estimates are 0.638 and 0.482 ($p < 0.05$) when IT capital accumulation is the dependent variable.

[21] When the dependent variables are productivity growth, efficiency change, technical progress, IT capital accumulation, and human capital accumulation, regression coefficients for *NAS%* × *BIG4* are 0.241, 0.076, 0.036, 0.124, and 0.005, respectively. Regression coefficients for Δ*NAS%* × *BIG4* with productivity growth and the four components as the dependent variables are 0.194, 0.038, 0.025, 0.122, and 0.009, respectively.

[22] The insignificant results for the interaction terms could be due to the small sample size for the Big 4 firms. The analysis focusing on the non-Big 4 firms shows that the effects of *NAS%* and Δ*NAS%* on productivity growth and IT capital accumulation are significant, consistent with results using the full sample.

TABLE 3

OLS Regression Results for the Determinants of Productivity Growth in Accounting Firms (p-values in parentheses)

$$\ln(\textit{change measure}) = \beta_0 + \beta_1 \times NAS\% + \beta_2 \times \Delta NAS\% + \beta_3 BIG4 + \varepsilon$$

Panel A: 1993–2003

Dependent Variables	β_0	β_1	β_2	β_3	Adj.R^2
Efficiency Change	−0.231	0.322	0.058	0.007	0.07
	(0.18)	(0.15)	(0.36)	(0.22)	
Technical Progress	0.088	−0.072	0.098	0.016**	0.11
	(0.21)	(0.25)	(0.13)	(0.03)	
IT Accumulation	−0.201	0.543*	0.395**	0.018*	0.45
	(0.13)	(0.07)	(0.03)	(0.08)	
HC Accumulation	0.125*	−0.026	0.153**	0.006	0.27
	(0.05)	(0.39)	(0.04)	(0.26)	
Productivity Growth	−0.219	0.766*	0.704**	0.047**	0.51
	(0.21)	(0.06)	(0.01)	(0.02)	

Panel B: 1993–1998

Dependent Variables	β_0	β_1	β_2	β_3	Adj.R^2
Efficiency Change	−0.129	0.301	0.066	0.012	0.06
	(0.29)	(0.18)	(0.31)	(0.16)	
Technical Progress	0.048	−0.045	0.123	0.020*	0.08
	(0.32)	(0.38)	(0.12)	(0.05)	
IT Accumulation	−0.171	0.398	0.411**	0.015	0.38
	(0.18)	(0.12)	(0.04)	(0.13)	
HC Accumulation	0.155**	−0.019	0.163**	0.007	0.21
	(0.02)	(0.37)	(0.03)	(0.28)	
Productivity Growth	−0.098	0.635	0.764**	0.054**	0.45
	(0.34)	(0.13)	(0.02)	(0.01)	

(continued on next page)

Panel C: 1998–2003

Dependent Variables	β_0	β_1	β_2	β_3	**Adj.R^2**
Efficiency Change	−0.202	0.298	0.049	0.010	0.05
	(0.23)	(0.21)	(0.38)	(0.19)	
Technical Progress	0.078	−0.077	0.086	0.018**	0.13
	(0.26)	(0.23)	(0.19)	(0.02)	
IT Accumulation	−0.232	0.552*	0.388*	0.023**	0.40
	(0.11)	(0.06)	(0.06)	(0.04)	
HC Accumulation	0.089	−0.029	0.158**	0.008	0.19
	(0.15)	(0.37)	(0.04)	(0.22)	
Productivity Growth	−0.267	0.744*	0.681**	0.059***	0.49
	(0.18)	(0.05)	(0.03)	(0.00)	

*, **, *** Indicate significance at the 0.10, 0.05, and 0.01 levels, respectively.

We also investigate the sensitivity of our results to the measurement of human capital accumulation. In doing so, we use the average salary of all employees to substitute for the human capital index because salary variation can be explained by experience and education combined (Juhn et al. 1993). Under this alternative measure, the mean productivity growth of accounting firms was 54.8 percent, of which 1.8 percent came from efficiency gains, 6.9 percent from technical progress, 29.0 percent from IT capital accumulation, and 16.8 percent from human capital accumulation. Consistent with results reported in Panel A of Table 2, IT capital and human capital accumulation are the two main contributors to productivity growth. Similarly, our regression results for the effect of firm type and NAS also hold using the average salary measurement.

Finally, it is possible that productivity changed after the consolidation from Big 5 to Big 4 in 2002. Therefore, we check the robustness of our results by restricting our attention to the pre-merger period (1993–2002) and repeat our analysis.[23] The results are consistent with those based on the full sample. The mean productivity growth is slightly higher at 52.3 percent, compared to 51.1 percent for the period 1993–2003. Similarly, we find that IT capital accumulation is the primary contributor to productivity growth. The multivariate tests based on OLS regression confirm that *NAS%* and Δ*NAS%* are significantly and positively associated with productivity growth and IT capital accumulation.

Additional Analysis

Since we use revenues per employee as the measure of productivity rather than the total factor approach of Banker et al. (2005), we cannot directly compare our findings with those of Banker et al. (2005) to see how the inclusion of IT capital and human capital as inputs would affect their results. As an alternative, we follow Banker et al. (2005) and decompose productivity growth into efficiency change and technical progress. Based on Taiwanese data, we compare the results excluding IT capital and human capital with the results including IT capital as an additional input. Specifically, we first use the three inputs (partners, professionals, and others) and the three outputs (accounting and audit service revenue, tax service revenue, and MAS revenue) defined in Banker et al. (2005) in the application of DEA to estimate efficiency, and then decompose productivity growth into efficiency change and technical progress. As reported in Panel A of Table 4 (without IT capital), productivity growth, efficiency change, and technical progress of our sample firms are 0.073, 0.021, and 0.052, respectively. These results reveal a pattern similar to the one reported in Banker et al. (2005), though with different magnitude, in that technical progress rather than efficiency change is the major driver of productivity growth. The same table (Panel B with IT capital) shows that when IT capital is included as an input, productivity growth increases from 0.073 to 0.082. The percentage contribution of efficiency change decreases from 0.021 to 0.020 while the percentage contribution of technical progress increases from 0.052 to 0.062. This suggests that inclusion of IT capital as an input changes the relative contributions to productivity growth because technical progress becomes even more important. While it is desirable to consider human capital as another input to perform the same analysis, lack of complete data on age and education for each type of employees prevents us from doing so.

In addition, we follow Banker et al. (2005) and examine the association between NAS and productivity growth and between NAS and the two components (i.e., efficiency change and technical progress), and compare the results (not tabulated here) from including IT capital and excluding IT capital as an input. When IT capital is not included as an input, we find that both *NAS%* and

[23] In 2001, the Enron scandal in the U.S. resulted in the global collapse of Arthur Andersen. As a result, the Taiwan member firm of Arthur Andersen merged with Deloitte Touche Tohmatsu's Taiwan member firm and its operations continued under the Deloitte Touche Tohmatsu name beginning June 1, 2003.

TABLE 4
Productivity Decomposition

Panel A: Bipartite Productivity Decomposition Indexes (per Banker et al. 2005)

	Percentage Contribution to Productivity Growth	
Productivity Growth	**Efficiency Change**	**Technical Progress**
0.073	0.021	0.052

Panel B: Bipartite Productivity Decomposition Indexes (Extending Banker et al. 2005 by Including IT Capital as an Additional Input)

	Percentage Contribution to Productivity Growth	
Productivity Growth	**Efficiency Change**	**Technical Progress**
0.082	0.020	0.062

In Panel A, production correspondence is estimated between three outputs (accounting and auditing service revenue, tax service revenue, and management advisory services revenue) and three types of labor inputs (the number of partners, the number of professionals, and the number of administrative staff and other employees).

In Panel B, IT capital is added as another input, resulting in four inputs. Both decompositions follow the total factor approach of Banker et al. (2005).

$\Delta NAS\%$ are significantly and positively associated with productivity growth (with coefficients 0.068 and 0.133, $p < 0.05$). Their associations with efficiency change are not significant, but they have significantly positive associations with technical progress (coefficients 0.059 and 0.146, $p < 0.10$). These findings are consistent with Banker et al. (2005). Further, we include IT capital to repeat the analysis and find that *NAS%* and $\Delta NAS\%$ are positively and more significantly associated with technical progress (coefficients are 0.079 and 0.159, $p < 0.01$). This indicates that inclusion of IT capital as an input enhances the association between NAS and technical progress. Taken together, the inclusion of IT capital as an input in the approach of Banker et al. (2005) increases the contribution of technical progress to productivity growth and strengthens the association between NAS and technical progress.

CONCLUSION

Prior research has investigated how efficiency change and technical progress affect productivity growth among public accounting firms (Banker et al. 2005). In this paper, we extend prior research by identifying and evaluating the relative contributions of two additional underlying drivers of productivity growth, namely the accumulation of IT capital and human capital. Specifically, we estimated productivity growth and four contributing components in the public accounting industry using balanced panel data from 51 public accounting firms in Taiwan from 1993 to 2003. We found that, for the full sample, the mean productivity growth during the eleven-year period was 51.1 percent, of which 0.2 percent came from efficiency change, 6.3 percent from technical progress, 30.2 percent from IT capital accumulation, and 14.3 percent from human capital accumulation. This implies that it is primarily IT and human capital deepening, as opposed to efficiency change or technical progress, that have contributed the most to productivity growth of public accounting firms. We also found significantly greater productivity growth among Big 4 accounting firms compared to non-Big 4 firms, and that difference resulted from technical progress and IT capital accumulation. This indicates that the advance of IT has benefited the Big 4 more than non-Big 4 firms. Finally, public accounting firms that were early movers into NAS and those that had higher growth in NAS business enjoyed greater productivity growth than their peers and also had significantly more IT and human capital accumulation.

Our findings have the following implications. First, in view of the significant contribution of IT and human capital accumulation to labor productivity growth, public accounting firms may consider investing more in IT and human capital in order to improve their revenues per employee. However, it is worth noting that accounting firms need to take into account the possibility that after some optimal level of investment in IT and human capital, there may be diminishing marginal returns to such investments. In addition, the potential effect of IT and human capital investments on audit quality would also be relevant in deciding the level of investments. Second, public accounting firms that emphasize NAS services tend to have higher rates of IT and human capital accumulation, which leads to greater growth in their productivity. This has further implications for the policy debate over the Sarbanes-Oxley Act, which has prohibited public accounting firms from providing certain types of non-audit services to their audit clients. While Sarbanes-Oxley applies to public accounting firms in the U.S., the increasing globalization of capital and audit markets may make affiliated firms overseas subject to similar restrictions. Some countries (e.g., Taiwan) are contemplating similar policies. These policies stem from a concern for maintaining auditor independence but tend to overlook other aspects associated with non-audit services. While Brown and Caylor (2006) document that companies with more non-audit services are associated with higher performance, our study adds to this discussion from another angle by presenting evidence of a positive association between non-audit services and the productivity growth of public accounting firms. Our finding that NAS is positively associated with productivity growth of public accounting firms, and the literature suggesting that public accounting firms with more quasi-rents will be more concerned with their audit quality (e.g., DeAngelo 1981), suggest that public accounting firms will not compromise their independence when they also provide NAS to their audit clients.

Our study has four major limitations. First, while our use of revenue per employee provides useful insights into labor productivity growth of accounting firms, the approach of Banker et al. (2005) should instead be employed if the objective is to estimate total factor productivity. Also, when examining the effect of NAS provision on productivity growth, we do not simultaneously consider the effect on audit quality. Knechel and Sharma (2010) suggest an approach to investigating the effects of NAS provision on audit efficiency and effectiveness. Second, we note that the U.S. audit market changed dramatically after the Sarbanes-Oxley Act of 2002, and some other countries have adopted similar policies on auditor behavior. Since our sample period ends in 2003, these policy changes may affect the generalizability of our findings to subsequent years. This also suggests that future research may need to investigate productivity growth and its contributing components among accounting firms in the post-Sarbanes-Oxley environment, and examine possible before-and-after differences. Third, while our findings may have implications for audit markets similar to Taiwan's, the research setting may limit the generalizability to public accounting industries in other countries. Finally, service quality is an important contextual factor that can significantly affect productivity growth and its components. Our study does not incorporate this factor into the analysis due to lack of data.

APPENDIX A
DATA ENVELOPMENT ANALYSIS

We use nonparametric data envelopment analysis (DEA) to construct the production frontier for public accounting firms in Taiwan. Let $\langle Y_j^t, L_j^t, H_j^t, K_j^t \rangle$, $j = 1, \ldots, N$, and $t = 0, 1$ be the observed aggregate output (i.e., total revenues), aggregated labor input (i.e., total number of employees), human capital (represented by a human capital index that is estimated on the basis of returns to education and experience) and IT capital (measured by the total IT related assets, including computer equipment, computer software, and databases) for each of accounting firm j at time t. In our study, 1993 is denoted by $t = 0$, 2003 by $t = 1$. We follow a convention in the macroeconomics literature (Henderson and Russell 2005) and assume that human capital enters the technology (production frontier) as multiplicative augmentation of labor input so that the amount of labor input measured in augmented units (referred to in Henderson and Russell [2005] as efficiency units), $\hat{L}$, is defined as $\hat{L} = \mathrm{L} \times \mathrm{H}$, where L represents physical labor input and H denotes human capital input. Then, the efficiency score of an accounting firm j at time t, e_j^t ($e_j^t \leq 1$), can be obtained using the following DEA model (Charnes et al. 1978):

$$
\begin{aligned}
& e_j^t = \text{Max } e \\
& \text{s.t.} \sum_{j=1}^{N} \lambda_j Y_j^t \geq \theta Y_j^t / e \\
& \sum_{j=1}^{N} \lambda_j \hat{L}_j^t \leq \hat{L}_j^t \qquad (5) \\
& \sum_{j=1}^{N} \lambda_j K_j^t \leq K_j^t \\
& e, \lambda_j \geq 0
\end{aligned}
$$

where e is a scalar and λ_j are the best possible weights placed on each of $j = 1,\ldots,N$. Firm j in period t is located on the frontier and rated as an efficient one if $e_j^t = 1$. Otherwise, firm j is located below the frontier and rated as an inefficient firm.

APPENDIX B
STEP-BY-STEP DETAILS ON THE CALCULATION OF PRODUCTIVITY GROWTH INDEXES

To see what is involved in Equation (1) and how we apply Henderson and Russell (2005), we present step-by-step details on calculating productivity growth indexes in Equation (1) using an accounting firm (Firm #1) from our sample firms as an example. Table 5 summarizes relevant data values on that sample firm.

Step One: Calculation of Productivity Growth (Δy)

Denote revenues and total number of employees in period t by Y^t and L^t, respectively. Labor productivity (revenue per employee) at period t can be calculated as $y^t = Y^t / L^t$. Then, we can estimate labor productivity growth (Δy) in the current period ($t = 1$; i.e., year 2003) from the base period ($t = 0$; i.e., year 1993) by dividing revenue per employee in the current period (y^1) by revenue per employee in the base period (y^0) as follows:

$$\Delta y = y^1 / y^0. \qquad (6)$$

From Table 5, we observe that revenue (Y^0) and employees (L^0) in the base period for Firm #1 are 26.22 and 34, respectively. We can calculate Firm #1's labor productivity in the base period as $y^0 = Y^0 / L^0 = 26.22 / 34 = 0.77$. Similarly, we can calculate its labor productivity in the current

TABLE 5
Data on One Sample Accounting Firm (Firm #1)

Variables	Base Period ($t = 0$)	Current Period ($t = 1$)
Revenue (Y^t)	26.22	68.51
Employee (L^t)	34	39
IT Capital (K^t)	22.31	90.78
Human Capital (H^t)	1.88	2.47
$\hat{L}^t = H^t \times L^t$	63.92	96.33
Efficiency score (e^t)	0.55	0.61

We use 1993 as base period and 2003 as current period.

period as $y^1 = Y^1 / L^1 = 68.51 / 39 = 1.76$. Thus, Firm #1's labor productivity growth between the base period and the current period is determined as:

$$\Delta y = y^1/y^0 = 1.76/0.77 = 2.29. \tag{6A}$$

Let $\hat{y}^t = Y^t / L^tH^t$ be the revenue per efficiency unit of labor in period t. Given $y^t = Y^t / L^t$ and $\hat{y}^t = y^t / H^t$, we can rewrite (6) as:

$$\Delta y = \hat{y}^1 H^1/\hat{y}^0 H^0 = \frac{\hat{y}^1}{\hat{y}^0} \times \frac{H^1}{H^0} \tag{7}$$

where $\frac{\hat{y}^1}{\hat{y}^0}$ and $\frac{H^1}{H^0}$ represent the change of output per efficiency unit of labor and human capital, respectively, between the base period and the current period.

Step Two: Decomposition of the Growth of Output $\frac{\hat{y}^1}{\hat{y}^0}$

Denote IT capital intensity at period t by $\hat{k}^t = K^t / L^tH^t$. The potential maximum output per efficiency unit of labor, given the IT capital intensity in period t and using the technology of period t, can be estimated as $\bar{y}^t(\hat{k}^t) = \hat{y}^t / e^t$, where e is the efficiency score estimated from the DEA model in (5). Then, we can express the growth of output between the base period and the current period as:

$$\frac{\hat{y}^1}{\hat{y}^0} = \frac{e^1}{e^0} \times \frac{\bar{y}^1(\hat{k}^1)}{\bar{y}^0(\hat{k}^0)}. \tag{8}$$

Next, let $\hat{k}^{10} = K^1 / (L^1H^0)$ be the counterfactual IT capital intensity in the current period if human capital remained unchanged from the base period, and let $\hat{k}^{01} = K^0 / (L^0H^1)$ be the counterfactual IT capital intensity in the base period if human capital was assumed to be equal to the current period level (Henderson and Russell 2005). Then, denote potential maximum revenue per efficiency unit of labor at $\hat{k}^{10}$ and $\hat{k}^{01}$ using technologies attainable in periods 0 and 1 by $\bar{y}^0(\hat{k}^{10})$ and $\bar{y}^1(\hat{k}^{01})$, respectively. We can multiply the numerator and denominator of (8) by $\bar{y}^0(\hat{k}^1)\bar{y}^0(\hat{k}^{10})$ and re-arrange terms to obtain:

$$\frac{\hat{y}^1}{\hat{y}^0} = \frac{e^1}{e^0} \times \frac{\bar{y}^1(\hat{k}^1)}{\bar{y}^0(\hat{k}^1)} \times \frac{\bar{y}^0(\hat{k}^{10})}{\bar{y}^0(\hat{k}^0)} \times \frac{\bar{y}^0(\hat{k}^1)}{\bar{y}^0(\hat{k}^{10})}. \tag{9}$$

Alternatively, we can multiply the numerator and denominator of (8) by $\bar{y}^1(\hat{k}^0)\bar{y}^1(\hat{k}^{01})$ and rearrange terms to yield:

$$\frac{\hat{y}^1}{\hat{y}^0} = \frac{e^1}{e^0} \times \frac{\bar{y}^1(\hat{k}^0)}{\bar{y}^0(\hat{k}^0)} \times \frac{\bar{y}^1(\hat{k}^1)}{\bar{y}^1(\hat{k}^{01})} \times \frac{\bar{y}^1(\hat{k}^{01})}{\bar{y}^1(\hat{k}^0)}. \tag{10}$$

Substituting (9) into (7), we have:

$$\frac{y^1}{y^0} = \frac{e^1}{e^0} \times \frac{\bar{y}^1(\hat{k}^1)}{\bar{y}^0(\hat{k}^1)} \times \frac{\bar{y}^0(\hat{k}^{10})}{\bar{y}^0(\hat{k}^0)} \times \left[\frac{\bar{y}^0(\hat{k}^1)}{\bar{y}^0(\hat{k}^{10})} \times \frac{H^1}{H^0}\right]. \tag{11}$$

Similarly, substituting (10) into (7), we obtain:

$$\frac{y^1}{y^0} = \frac{e^1}{e^0} \times \frac{\bar{y}^1(\hat{k}^0)}{\bar{y}^0(\hat{k}^0)} \times \frac{\bar{y}^1(\hat{k}^1)}{\bar{y}^1(\hat{k}^{01})} \times \left[\frac{\bar{y}^1(\hat{k}^{01})}{\bar{y}^1(\hat{k}^0)} \times \frac{H^1}{H^0}\right] \tag{12}$$

where the first term in both (11) and (12) represents efficiency change (ΔEFF), the second term is technical progress ($\Delta TECH$), the third term denotes IT capital accumulation ($\Delta ITCA$), and the fourth term captures human capital accumulation (ΔHCA) between the base period and the current period.

Since the second terms in the right-hand side of (11) and (12) are not identical and the choice between them is arbitrary, we take the geometric mean of the two as a measure of technical progress. Similarly, for the third term and the fourth term, we perform the same procedure as a measure of IT capital accumulation and human capital accumulation, respectively, as indicated below:

$$\begin{aligned}\frac{y^1}{y^0} &= \Delta EFF \times (\Delta TECH^0 \times \Delta TECH^1)^{1/2} \times (\Delta ITCA^0 \cdot \Delta ITCA^1)^{1/2} \times (\Delta HCA^0 \cdot \Delta HCA^1)^{1/2} \\ &= \Delta EFF \times \Delta TECH \times \Delta ITCA \times \Delta HCA. \end{aligned} \tag{13}$$

Step Three: Estimation of Efficiency Change (ΔEFF)

Table 5 indicates that the efficiency scores estimated from the DEA model for Firm #1 at the base period and at the current period are $e^0 = 0.55$ and $e^1 = 0.61$, respectively. We can calculate its efficiency change (ΔEFF) from the base period to the current period as the ratio of its current period efficiency score (e^1) to its base period efficiency score (e^0) as:

$$\Delta EFF = e^1/e^0 = 0.61/0.55 = 1.11. \tag{13A}$$

Step Four: Computation of Technical Progress ($\Delta TECH$)

Let T^0 and T^1 be piecewise-linear best practice production frontiers estimated from the DEA model in (5) for the full sample of public accounting firms in Taiwan in the base period and in the current period, respectively. From the piecewise-linear best practice production frontiers, we can calculate the slope and intercept for each piecewise segment. However, note that the intercept term and slope term of T^t vary with IT capital intensity $\hat{k}^t$. Thus, we define the potential maximum revenue per efficiency unit of labor for Firm #1 at the current period IT capital intensity and using the current period technology ($\bar{y}^1(\hat{k}^1)$), at the current period IT capital intensity using the base period technology ($\bar{y}^0(\hat{k}^1)$), at the base period IT capital intensity using the base period technology ($\bar{y}^0(\hat{k}^0)$), and at the base period IT capital intensity using the current period technology ($\bar{y}^1(\hat{k}^0)$) respectively as follows:

$$\bar{y}^1(\hat{k}^1) = \text{intercept of } T^1 + \text{slope of } T^1 \times \hat{k}^1;$$

$$\bar{y}^0(\hat{k}^1) = \text{intercept of } T^0 + \text{slope of } T^0 \times \hat{k}^1;$$

$$\bar{y}^0(\hat{k}^0) = \text{intercept of } T^0 + \text{slope of } T^0 \times \hat{k}^0; \text{ and}$$

$$\bar{y}^1(\hat{k}^0) = \text{intercept } T^1 + \text{slope of } T^1 \times \hat{k}^0.$$

Inserting values $\hat{k}^t$ from Table 5 into the corresponding frontiers above, we can obtain:

$$\bar{y}^1(\hat{k}^1) = 0.68 + 0.51 \times (90.78/(39 \times 2.47)) = 1.17;$$

$$\bar{y}^0(\hat{k}^1) = 0.35 + 1.28 \times (22.31/(34 \times 1.88)) = 0.80;$$

$$\bar{y}^1(\hat{k}^0) = 1.03 + 0 \times (90.78/(39 \times 2.47)) = 1.03;$$

$$\bar{y}^0(\hat{k}^0) = 0.42 + 0.93 \times (22.31/(34 \times 1.88)) = 0.74.$$

The differences between $\bar{y}^0(\hat{k}^1)$ and $\bar{y}^1(\hat{k}^1)$ and between $\bar{y}^0(\hat{k}^0)$ and $\bar{y}^1(\hat{k}^0)$ are both caused by the shift in the production frontier (i.e., from T^0 and T^1). We can compute the technical progress ($\Delta TECH$) as the geometric mean of the two, being a measure of the effect of the frontier change, and represented by:

$$\Delta TECH = \left[\frac{\bar{y}^1(\hat{k}^1)}{\bar{y}^0(\hat{k}^1)} \times \frac{\bar{y}^1(\hat{k}^0)}{\bar{y}^0(\hat{k}^0)}\right]^{0.5} = \left[\frac{1.17}{1.03} \times \frac{0.80}{0.74}\right]^{0.5} = 1.10. \tag{13B}$$

Step Five: Calculation of IT Capital Accumulation ($\Delta ITCA$)

The change from $\hat{k}^0 = K^0 / \hat{L}^0$ to $\hat{k}^1 = K^1 / \hat{L}^1$ represents the accumulation of IT capital and human capital. Thus, both the difference between $\bar{y}^0(\hat{k}^1)$ and $\bar{y}^0(\hat{k}^0)$ and the difference between $\bar{y}^1(\hat{k}^1)$ and $\bar{y}^1(\hat{k}^0)$ reflect the change in potential maximum revenue per efficiency unit of labor brought about by the change in IT capital intensity and human capital. In contrast, the changes from $\hat{k}^0 = K^0 / L^0H^0$ to $\hat{k}^{10} = K^1 / L^1H^0$ and from $\hat{k}^{01} = K^0 / L^0H^1$ to $\hat{k}^1 = K^1 / L^1H^1$ only represent the change in IT capital intensity because these changes are under the same human capital level. Therefore, we can determine the potential maximum revenue per efficiency unit of labor for Firm #1 at $\hat{k}^{10}$ using the base period technology ($\bar{y}^0(\hat{k}^{10})$), and at $\hat{k}^{01}$ using the current period technology ($\bar{y}^1(\hat{k}^{01})$), respectively, as follows:

$$\bar{y}^0(\hat{k}^{10}) = \text{intercept of } T^0 + \text{slope of } T^0 \times \hat{k}^{10};$$

$\bar{y}^1(\hat{k}^{01}) = \text{intercept of } T^1 + \text{slope of } T^1 \times \hat{k}^{01}.$

Inserting values of $\hat{k}^{10}$ and $\hat{k}^{01}$ into the corresponding frontiers above, we can obtain:

$$\bar{y}^1(\hat{k}^{01}) = 0.35 + 1.28 \times (22.31/(34 \times 2.47)) = 0.69;$$

$$\bar{y}^0(\hat{k}^{10}) = 1.03 + 0 \times (90.8/(39 \times 1.88)) = 1.03.$$

Taking the geometric mean of the two as a measure of the effect of IT capital accumulation, we can obtain the IT capital accumulation ($\Delta ITCA$) as shown below:

$$\Delta ITCA = \left[\frac{\bar{y}^0(\hat{k}^{10})}{\bar{y}^0(\hat{k}^0)} \times \frac{\bar{y}^1(\hat{k}^1)}{\bar{y}^1(\hat{k}^{01})}\right]^{0.5} = \left[\frac{1.03}{0.74} \times \frac{1.17}{0.69}\right]^{0.5} = 1.54. \quad (13C)$$

Step Six: Calculation of Human Capital Accumulation (ΔHCA)

Similarly, the changes from $\hat{k}^{10} = K^1 / L^1H^0$ to $\hat{k}^1 = K^1 / L^1H^1$ and from $\hat{k}^0 = K^0 / L^0H^0$ to $\hat{k}^{01} = K^0 / L^0H^1$ only represent the accumulation of human capital because these changes are under the same IT capital intensity level. Therefore, the difference between $\bar{y}^0(\hat{k}^{10})$ and $\bar{y}^0(\hat{k}^1)$ and the difference between $\bar{y}^1(\hat{k}^0)$ and $\bar{y}^1(\hat{k}^{01})$ reflect the effect of the change in human capital while holding the IT capital intensity fixed at the base-period level and current-period level, separately. We can again take the geometric mean of the two as a measure of human capital accumulation (ΔHCA) as:[24]

$$\Delta HCA = \left[\frac{\bar{y}^0(\hat{k}^1)}{\bar{y}^0(\hat{k}^{10})} \times \frac{\bar{y}^1(\hat{k}^{01})}{\bar{y}^1(\hat{k}^0)}\right]^{0.5} \times \frac{H^1}{H^0} = \left[\frac{1.03}{1.03} \times \frac{0.69}{0.80}\right]^{0.5} \times \frac{2.47}{1.88} = 1.22. \quad (13D)$$

Taken together (6A) and (13A)–(13D), the change in labor productivity (Δy) of Firm #1 is the product of its efficiency change (ΔEFF), technical progress ($\Delta TECH$), IT capital accumulation ($\Delta ITCA$), and human capital accumulation (ΔHCA) as represented by:

$$\Delta y = \Delta EFF \times \Delta TECH \times \Delta ITCA \times \Delta HCA = 1.11 \times 1.10 \times 1.54 \times 1.22 = 2.29. \quad (14)$$

Taking logarithms on both sides of (14), we obtain:

$$\text{Ln}(\Delta y) = 0.103 + 0.094 + 0.432 + 0.198 = 0.828. \quad (15)$$

Equation (15) indicates that Firm #1 experienced 82.8 percent productivity growth between the base period and the current period, of which 10.3 percent was contributed by efficiency change, 9.4 percent was contributed by technical progress, 43.2 percent was contributed by IT capital accumulation, and 19.8 percent was contributed by human capital accumulation.

[24] The term H^1 / H^0 was added to translate the change in potential maximum revenue per efficiency unit of labor into the change in labor productivity (Henderson and Russell 2005).

APPENDIX C
QUADRIPARTITE PRODUCTIVITY DECOMPOSITION INDEXES FOR EACH INDIVIDUAL ACCOUNTING FIRM

Firm #	ln(Δ*y*)	ln(Δ*EFF*)	ln(Δ*TECH*)	ln(Δ*ITCA*)	ln(Δ*HCA*)
1	0.828	0.103	0.094	0.432	0.198
2	0.283	−0.184	0	0.421	0.043
3	0.580	0.181	0.151	0.200	0.043
4	0.359	0.034	0.145	0.131	0.046
5	0.064	−0.131	0.004	0.138	0.050
6	0.331	−0.082	0.099	0.248	0.062
7	0.253	−0.122	0.002	0.299	0.071
8	0.545	0.048	0	0.414	0.080
9	0.670	−0.059	0.140	0.497	0.087
10	0.112	−0.193	0.085	0.128	0.087
11	0.478	−0.004	0.025	0.359	0.096
12	0.310	−0.154	0.151	0.207	0.101
13	0.752	0.255	0.172	0.218	0.103
14	0.285	−0.179	0.011	0.345	0.105
15	0.366	0.103	0.006	0.145	0.108
16	0.025	−0.082	0	0	0.110
17	0.241	−0.253	0.002	0.379	0.110
18	0.207	−0.151	0	0.239	0.117
19	0.497	0.034	0.075	0.262	0.122
20	0.831	0.075	0	0.630	0.124
21	0.522	−0.011	0.011	0.396	0.124
22	0.437	−0.046	0.168	0.179	0.133
23	0.453	−0.009	0.004	0.322	0.133
24	0.297	−0.066	0.080	0.147	0.133
25	0.930	0.133	0.002	0.651	0.140
26	0.621	0.267	0.025	0.184	0.142
27	1.082	0.232	0.009	0.695	0.142
28	0.543	−0.278	0.002	0.670	0.147
29	0.527	0.126	0.011	0.239	0.147
30	0.147	−0.179	0.013	0.161	0.149
31	0.511	−0.075	0.043	0.391	0.149
32	0.170	−0.211	0.142	0.082	0.151
33	**0.886**	**0.085**	**0.131**	**0.515**	**0.151**
34	0.375	0.027	0.004	0.184	0.156
35	1.250	0.752	0.011	0.322	0.161
36	0.303	0.179	0.016	−0.055	0.163
37	−0.184	−0.158	0.009	−0.221	0.177
38	**0.771**	**−0.071**	**0.138**	**0.524**	**0.179**
39	**1.075**	**0.202**	**0.158**	**0.527**	**0.184**
40	0.591	0.071	0.013	0.315	0.188
41	0.343	−0.179	0.020	0.308	0.191
42	0.527	0.064	0.170	0.250	0.039
43	1.356	0.168	0.089	0.888	0.207
44	0.425	−0.179	0.002	0.391	0.209
45	**0.907**	**0.034**	**0.191**	**0.467**	**0.214**
46	0.419	−0.105	0.133	0.165	0.223

(continued on next page)

Firm #	ln(Δy)	ln(ΔEFF)	ln(ΔTECH)	ln(ΔITCA)	ln(ΔHCA)
47	0.499	0.029	0.013	0.225	0.227
48	0.656	0.260	0.073	0.089	0.230
49	0.594	−0.048	0.023	0.377	0.239
50	0.497	0.009	0.029	0.193	0.262
51	0.529	−0.188	0.340	0.050	0.324
Mean	0.511	0.002	0.063	0.302	0.143
Standard Deviation	0.307	0.180	0.074	0.204	0.059

Numbers in bold are designations for Big 4 firms.

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