The Impact of Technology Diffusion on Employment, Compensation, and Productivity: Evidence from the Telecommunications Sector

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Abstract

We study the impact of broadband diffusion on wage, employment, and workforce productivity levels among the communications common carriers in the US. Driven by capital-skill complementarities, broadband diffusion is expected to positively impact wages because of the need for skill and to compensate for the higher levels of output per employee, but can lead to less human capital usage because of a scale effect. Our findings show that fiber optic adoption as broadband diffusion did in fact result in improved compensation for the incrementally skilled and productive workforce, but it adversely affected employment, though not of the same magnitude. With extensive dark fiber availability in the United States, our evidence suggests an intensifying impact on wage levels, employment, and output per employee.

Keywords: broadband technology, dynamic panel data analysis, firm-level capabilities, human capital outcomes, technology diffusion, employee productivity, US telecommunications industry, wage structure.

1. INTRODUCTION

Firms are an amalgam of both technology and human capital. Thus, as progressive firms deploy greater levels of technological capital there will be an effect on their human capital pool. Is there such an effect, and if so is it reflected by variations on the levels of employment and compensation within firms? These questions are fundamental since the nature of the relationship between firms' investment in technological capabilities and their impact on human capital is a central resource allocation concern for scholars and managers.

Simultaneously, these questions are of crucial concern for public policy since the relative variations in levels of employment, workforce productivity, and wage structures among firms deploying different technologies are important for the economic well-being of a nation. A high level of wage dispersion leads to inequality and progressive divergence in living standards between individuals who may not have the skills to occupy positions paying higher compensation. If there is rising wage inequality in an economy, and it is established that higher levels of technology diffusion are associated with higher wages, then institutional processes to enhance technology diffusion are called for so as to narrow the inequality gaps.

The United States telecommunications industry is a unique setting for a natural experiment within which we evaluate the relationship between technology diffusion patterns and the employment, output per capita, and wage structure of firms for information and communications technology (ICT) intensive industries. The literature on ICT states that implementing advancements in ICT diminishes certain jobs that are substituted with the new technology while the high skill levels needed to implement these advanced technologies significantly raises the wages and also results with increased output productivity per employee. Even though these arguments are related to each other, in the literature there is no study aggregating this association.

In this paper, we address this issue by analyzing the relationship between broadband deployment, as an example of new technology, and the levels of average employment, compensation and output per employee within firms at the forefront of technology deployment. The association of new technology implementation and its impacts on wages, employment and productivity is studied in this manuscript using a panel data set of the communications common exchange carriers spanning from 1988 to 2001.

In the following section, we discuss the conceptual issues on the links between technology deployment and wages. In section 3 we discuss the specific relationships between information and communications technologies, including telecommunications technologies and the structure of employment and wages. Section 4 describes the empirical framework. Section 5 describes the statistical procedures and results. In section 6, we conclude with a brief discussion of the implications of our findings.

2. TECHNOLOGY, EMPLOYMENT AND WAGE STRUCTURES

2.1 Primary Theory and Evidence

The linkage between technology and human capital is fundamental in economics and an extensive literature has evaluated the relationship between employment, productivity, wage structures and technology adoption. There are two primary effects, the scale effect and the skill effect that capture the impacts that technology diffusion has on human capital within a firm.

The original insight as to the impact of technology deployment on employment belongs to Adam Smith (1776) who had theorized that, with new technology or modes of doing work, more and more could be done by fewer and fewer persons because the division of labor would lead to productivity. In quantity terms, firms would substitute physical capital for human capital. This is the *scale effect* whereby new technology diffusion could lead to shifts in labor demand and reductions in firm-level employment (Hamermesh, 1993). Productivity literature shows evidence of increased physical capital intensity leading to significant and positive impact on labor productivity (Maliranta, 2004).

The starting point of the resource allocation literature on the *skill effect* is the induced innovation model of Hicks (1932) & Kaldor (1939), in which firms would replace a more expensive factor of production by a cheaper factor. As labor became more expensive, it would be replaced by capital, which would embody the current technology in vogue, as a factor of production. Firms would combine the profit-maximizing quantities of labor and capital, the motivation being to maximize the cost reductions by substituting capital and technology for labor where feasible. Therefore, technology is substituted for skills. Wage rates would fall as technology investments increased. This was an early expression of the skill effect.

This substitution is feasible only when highly skilled employees are present (Nelson and Phelps, 1966). When skilled and educated workforce is not present, the success rate of such adoption would stagger due to increased skills required to implement the new technology. In addition, highly skilled and educated workforce is more open to new innovation. Griliches (1969) further clarified the discussion on substituting labor for physical capital by differentiating between the skilled labor vs. unskilled labor. He found that substituting unskilled labor by physical capital would be a practical move for firms, but the same argument would not be true for skilled labor as the implementation of advanced technologies would require such employees.

High-skill workforce required by such capital-skill complementarity would therefore entail improved workforce productivity and efficiency gains, part of which makes it into higher wage levels. Therefore, higher rates of technology diffusion within firms would result in improved compensation for the incrementally skilled and productive workforce. Additionally, higher compensation rates have direct impact on employee productivity, and subsequent firm-level performance, because the level of compensation affects health, mental alertness, and physical well-being. This reasoning is consistent with the development economics literature (Dasgupta and Ray 1986).

Goldin and Katz (1998) note that physical capital and skilled labor have not always been viewed as relative complements. In particular, they suggest that transitions between production processes change the relative demand for skill. In their analysis they argue for the proposition that shifts in technology, rather than changes in relative factor prices, have been more important across history in altering capital-output and capital-labor ratios.

In their analysis, they find that technology-skill and capital-skill complementarily emerged across the manufacturing sector as particular technologies, known as batch and continuous-process methods of production, spread within progressive firms. This trend was reinforced by another technological change, the switch to purchased electricity from steam and hydraulic energy sources. Similarly, Chandler (1977) also noted that the managerial revolution was brought about by many of the technologies that increased the demand for educated labor on the shop-floor. For example, the demand for more educated workers on the farm increased as farm machinery became more complex.

Reinforcing the shift in manufacturing was an increased demand for educated labor to sell, install and service technologically-advanced products. Ample and cheap electricity made the production of various materials, such as aluminum and other electrochemicals that used skilled labor, feasible. Cheap electricity encouraged a more intensive use of machines, thereby increasing demand for skilled personnel to maintain them.

2.2 General Purpose Technology

Are technologies that engender the capital-skill complementarity phenomenon general purpose technologies? As described by Goldin and Katz (1998), the technologies that lead to a shift from capital-skill substitution to capital-skill complementarities fall within the rubric of general purpose technologies. General purpose technologies are technologies, first described by Bresnahan and Trajtenberg (1995), which reshape production so that the returns to human capital increase (Helpman and Trajtenberg, 1998).

These technologies open up new opportunities, are pervasive in use, create innovation complementarities and necessitate reorganization of production and different factor mixes. Consequently, in industries deploying general purpose technologies, there is a shift in demand for higher skilled and more expensive human capital (Katz, 2000).

For example, electricity permitted reorganization of the workshop floor (Goldin and Katz, 1998). Similarly, the telegraph enabled rapid conveyance of inventory stock and employee tasks and railroads transformed retailing by allowing nationwide catalog sales (Chandler, 1977), while assembly line operations transformed manufacturing (Hounshell, 1984). More rapid communications between firms prevented inventory mismatches and resource misallocations, and employees were able to work from more convenient locations.

The replacement, that occurred, of unskilled human capital and obsolete fixed capital by skilled human capital and new technology catalyzed productive efficiency growth, with a portion of the gains accruing to the human capital who were responsible for implementation of these technologies. General purpose technologies have tended to widen the dispersion in the wage distribution by increasing the returns to skilled human capital and depressing those of unskilled human capital (Aghion, Howitt and Violante, 2002; Jacobs and Nahuis, 2002).

In the contemporary literature, the diffusion of information and communications technologies have been similarly associated with rising wage dispersions because of the capital-skills complementarity. As information and communications technologies have diffused, returns to users and those who are relatively greater adopters have been apparent in higher wage levels, and a substantial number of empirical studies have associated greater returns to skills, and higher wage levels with such patterns of information and communications technology diffusion.

3. INFORMATION AND COMMUNICATIONS TECHNOLOGY DIFFUSION, EMPLOYMENT AND WAGES

3.1 Information and Communications Technologies as General Purpose Technologies

Recent literature highlights the fact that information and communications technologies are contemporary general purpose technologies. On this issue, the theoretical insights of Bresnahan (1999) are important. The impact of information and communications technologies at the level of the firm is profound. This impact occurs not because of the usage of equipment, per-se, but because of changes in the organization of production and work within the firm, the industry and across industries. Bresnahan (1999) terms this as a theory of organizational complementarity between the diffusion of information and communications technologies and the use of higher skilled and higher paid employees.

It is a theory of complementarity between information and communications technologies and the human capital of users of these technologies. The diffusion of general purpose information and communications technologies makes the work of individuals more analytical and raises the return to cognitive skills and education. The skill bias arises from the shift out of the demand curve for highly cognitively skilled human capital with better mental skills (Hirshhorn, 1984) as the price of information and communications hardware falls. The economic complementarity effects of the diffusion of information and communications technologies suggests that as the prices of information and communications technologies fall, leading to their greater diffusion, this causes a rise in the demand for highly skilled and compensated human capital.

The firm level impact is to increase the demand for additional new skill, such as the non-cognitive skills and higher-order mental skills necessary for dealing with a general purpose technology. These skills include interpersonal and management skills, skills to operate autonomously and to exercise judgment. There are monetary premiums for possessing these skills. In addition, information and communications technologies directly substitute machine decision making for human decision making in low-skilled and medium-skilled white collar work and augment individual productivity by changing the organization of work (Liker, et. al., 1999). This attribute leads to the scale effect being observed.

Information and communications technology equipment are general purpose assets that through their adoption companies can develop a new set of service delivery processes. Technical progress, enhancing the quality of the equipment, also brings new opportunities to firms to offer new services. Invention of new services those processes will deliver, and of the human side of the delivery mechanism, are difficult tasks calling for qualified employees. Following this line of thought, the human capital demand shifts towards more innovative managers and technical specialists. The demand for innovative managers increases as the firms need managers that can think of ways to take advantage of the new processes offered by information and communications technologies and subsequently increase firm productivity (Maliranta, 2004). New, and scarce, cognitive and managerial skills, which require high compensation, are needed (Piore and Sabel, 1984). The demand for technical specialists in user and supplier companies also increases as these companies need personnel to operate according to routines and control the various facets of the new activities. According to human capital theory, wages will be higher for employees with higher levels of skills who have the characteristics to be productive when given access to new technologies (Mincer, 1974). Firms complementing information and communications technologies by highly skilled workforce tend to be more productive and innovative; i.e. invest more in new ICT than other firms (Hempell, 2005).

3.2 Broadband Technology as a General Purpose Technology and Its Impact on Wage Structures

We expect that the diffusion of broadband technology in the local exchange firms we evaluate will have a positive impact on the wage structure within the adopting firms. Broadband technology arrival can transform the composition of the local loop network operated by telecommunications companies (Hatfield, Mitchell and Srinagesh, 2005) and the consumer benefits from broadband deployment are large (Bauer, Kim and Wildman, 2003).

Lipsey, Carlaw and Bekar (2006) define general purpose technology as those technologies that share characteristics such as wide scope for changes and elaboration, applicability across a broad range of uses, potential for use in a variety of products and processes and complementarities with other new technologies. Such change in common carriers necessitate higher-skilled, highly paid employees, which can be coined as the skill effect.

Broadband access, like several other information and communications technologies, is a general purpose technology that enables not only communications but also the connectivity for the carrying out of transactions or activities more efficiently and is as an instrument to develop new transactions and activities (Bertschek and Kaiser, 2004). Its first impact is to raise the capacity of the telecommunications network by an order of magnitude (Preissl, 1995). This renders the employment of many employees superfluous, contributing to the scale effect associated with technology diffusion, a finding consistent with intra-firm field work in the industry (Brown, et. al. 1997). The scale effect also suggests excessive returns of ICT investments on output growth (O'Mahony, 2005).

By offering higher bandwidth and non-stop availability, broadband technologies offer superior features compared to legacy networks. Broadband technologies, deployed by the firms we study, include xDSL, which are digital subscriber lines of various types, fiber optic networks and broadband wireless access. The diffusion of broadband technology within telecommunications firms notably changes their economics. Fiber optics technology is considerably different from the legacy twisted-pair copper networks on which broadband features are barely satisfied. In addition, the broadband services include variety of xDSL technologies. The retro-fitting of such variety of new technological functionalities, which substantially alter the core technological variety of a telecommunications network, creates complexity in organizing and maintaining the network. Network architecture is now more complex. This process changes the employee mix required in building and operating the network since highly-skilled individuals are needed to deal with the changing economics and technological heterogeneities.

The broadband diffusion introduces new tasks such as product and services innovation and customer relationship management to the existing tasks of the telecom workforce skills. The new tasks either call for hiring higher-skilled employees or training existing employees to gain the new skills required. Both cases would lead substantial wage increases. This principle is illustrated with an example from tele-medicine, which requires transmission of large files that can help with key areas of tele-medicine; such as tele-diagnosis, tele-ultrasound or telesonography, tele-monitoring, and teleradiology (Bauer et al., 2003). The transmission of large files is feasible when broadband connection is used. The medical applications of telemedicine have their own specialized equipment that is connected to the broadband network. The telecommunications employees need to understand medical applications so that they are able to design the systems for doctors and hospitals in addition to network management tasks they need to fulfill. Additionally, they require marketing skill to effectively market these systems to the health care and medical professions. Clearly, several new skills, such as product development and marketing, are required within the telecommunications firms so as to develop very category-specific broadband applications and market these to the targeted customer groups. Broadband diffusion will raise average compensation levels within the deploying firms due to the new workforce skills required. All of the foregoing reasoning leads us to hypothesize that:

H1: The diffusion of broadband technology is, as measured by the deployment of fiber optics, will have a negative impact on employment patterns and a positive impact on output per employee because of the scale effect, while the level of wages among the firms that have deployed higher levels of broadband will be higher, on average, because of the skill effect.

4. EMPIRICAL ANALYSIS

We assess the impact of broadband adoption by a panel of the population of telecommunications carriers, and its subsequent diffusion among the carriers over time on the structure of employment and wages among the firms. Within a panel data framework, we assess average compensation levels among the firms, measuring variations in employment and wage structures, as a function of a measure of diffusion of technology and against variables controlling for other factors affecting the level of average employment and wages.

Typically, studies of employment, wages and productivity are carried out at the individual, plant or industry level, but rarely at the firm level (Brown and Campbell, 2002). We cannot evaluate individual level compensation or on individual level skills. We do not have the data. We cannot also say what types of employees are being added or released.

We evaluate the impact of technology diffusion on the average employment, wages and employee output by testing the impact of the period-to-period broadband adoptions for each firm and construct a panel data set, with data being available for each firm for the full fourteen year period during which broadband will have diffused through the firm.

This approach provides cumulative information on firm-level broadband diffusion patterns over time. In addition, for each period the availability of data on cross-sectional adoption decisions, available for each firm, permit control via instrumental variables of factors that explain variations in endogenous firm-level technology adoption.

We use regressions of the following autoregressive form for panel data, where variables are indexed over acquired firms *(i)* and over time *(t)*.

$$EMPLOYMENT_{it} = \lambda_0 + \sum_{s=1}^{2} \lambda_{1s} f(EMPLOYMENT_{it-s}) + \lambda_2 BROADBAND + \lambda_i^c\ CONTROLS + \varepsilon \quad (1)$$

$$COMPENSATION_{it} = \gamma_0 + \sum_{s=1}^{2} \gamma_{1s} f(COMPENSATION_{it-s}) + \gamma_2 BROADBAND + \gamma_i^c\ CONTROLS + \varepsilon \quad (2)$$

$$PRODUCTIVITY_{it} = \delta_0 + \sum_{s=1}^{2} \delta_{1s} f(PRODUCTIVITY_{it-s}) + \delta_2 BROADBAND + \delta_i^c\ CONTROLS + \varepsilon \quad (3)$$

In the equations above, *EMPLOYMENT, COMPENSATION* and PRODUCTIVITY refer to the variables measuring average employment, average compensation and average output per employee. The *BROADBAND* variable represents the variable capturing the diffusion of broadband technology over time. The terms *CONTROLS* refer to the several control variable used for each of the equations in the analysis. These are subsequently discussed in detail.

4.1 Data

We use a balanced panel of annual data for US local exchange companies from the *Statistics of Communications Common Carriers* (SCCC) for the fourteen year period 1988 to 2001. We compile firm level operational and financial data for all of the principal local operating companies between the years 1988 to 2001. These companies account for ninety nine percent of telephone lines in the

United States. These data have been much used before.

Data are obtained from several sources. These are: the FCC *Statistics of Common Communications Carriers* (SCCC), the *Federal-State Joint Board Monitoring Reports*, FCC reports on *Competition in the Telecommunications Industry*, National Regulatory Research Institute (NRRI) reports, and reports of the US Census Bureau. Several rounds of data checks ensure reliability and consistency of the firm-specific data used in our variables. All key dependent and independent variables and most controls variables are computed using the financial and operational items in the SCCC data. The information on the states in which each of the local exchange companies operate are also extracted from the FCC's CCC Statistics.

4.2 Variables

Dependent Variables: The employment variable *(Employment)* is the level of employment at any period, which includes total number of employees (full time and part-time) that are employed by the firm during a particular year. The compensation variable *(Compensation)* helps capture differences in the firm level quality of human capital. There are two possible ways to measure the quality of firm level human capital in the literature. One is by type of educational qualifications, which is not publicly released for the firms studied, in equations that measure individual level wage variations (Mincer, 1974). The other is the publicly released data on compensation, which is used as the proxy for human capital quality. In this analysis, compensation is measured as the average dollar value of compensation cost per employee. While our data provides both full-time and part-time numbers of employees for telecommunications carries, there is no direct and objective method to delineate the contributions of part-time versus full-time employees. Therefore, we follow Uri (2001) and we only use total number of employees as our labor input measure, and in deriving compensation and productivity per employee. The fact that part-time employees accounted for less that 1.6% of the telecommunications carriers' workforce during our sample period helps in alleviating potential bias concerns (see Table 1). Still, our results are robust to other versions of compensation where full-time employees are compensated on average twice as much as their part-time counterparts. In any case, we are interested in variations in firm-level employee compensation. The employee output *(Productivity)* variable is the total operating revenue per employee.

Primary Independent Variable: The measurement of technology in this genre of work is a difficult issue to deal with (Brown and Campbell, 2002). We are fortunate to have a precise measure. Based on recent literature in the subject (Hatfield, Mitchell and Srinagesh, 2005; Koski and Majumdar, 2002; Sharkey, 2002), we use the percentage of total fiber kilometers to total cable kilometers as the proxy measure to capture the levels of broadband technology investments that have diffused among the firms studied. The measure *(Broadband)* captures the level of investments in broadband assets. This is the important technology in the sector.

Controls: The scaling effect associated with technology diffusion will imply that larger firms may actually lose more staff than smaller firms. Also bigger employers may pay more. The employer size and wage effect is important in the literature and well-studied. Brown and Medoff (1989) reach a general conclusion that larger firms pay higher wages. To be consistent with previous studies, we use log of total operating revenues as a measure of size *(Size)*. Output growth also affects employment, and we include a measure of past sales performance, growth in sales *(Growth),* as a control variable in the employment equation.

Average levels of employment and compensation are affected by a variety of industry-related factors. We control for the nature of interconnection regimes, since these are of importance in the sector (Armstrong, 2002). A higher level of access costs can exercise a downward pressure on employment and wages, since the total amount of cash available for expenditures are limited if access charges are high. In the absence of a fine measure over the full time period, the relative access cost, computed as the ratio of access costs to total operating revenues *(Access Cost)*, proxies for interconnection regimes.

We use market share constructs as a proxy for market power of the local exchange carriers. Even though in regulated industries a high market share does not necessarily imply monopoly behavior (Spulber, 2002), inclusion of all the products and geographic markets a firm is involved with in market share calculations provides a reasonable sense of the market power of that firm in its industry segment. A firm with relatively greater market power can exercise such power vis-à-vis unions as well, and can enjoy attempt to shed staff or enjoy a lower average wage relative to other firms. The market share variable *(Market Share)* is constructed by taking the ratio of a firm's total number of lines across the states it operates to the total number of lines in all of the states in which it operates.

The key environmental factors are the business lines and urban population ratios (Sharkey, 2002). These affect the structure of wages and put pressure on wages to rise upwards. The business lines construct *(Business Lines)* is measured by the ratio of total business lines to total access lines for each company. A larger share promises a profitable customer base, encouraging volume growth and efficiency. This requires the employment of higher-quality human capital paid, on average, higher wages. The urban population ratio *(Urban)* is the weighted average ratio of urban population to total population in each firm's territory. This ratio is weighted by the fraction of lines that the firm has the operating rights to in the specific state or states.

Progressive firms possess unobservable and heterogeneous characteristics reflecting higher management quality. Such firms may use more staff and are also likely to be oriented towards using higher quality human capital. We use three variables to control for firm-specific effects. These are the ratios of advertising, customer costs, and corporate costs to the total operating revenues. The advertising *(Advertising)* and customer cost *(Customer Cost)* variables, computed as the ratio of advertising and customer operations expenses to total operating revenues, measures how marketing oriented each carrier is. The corporate costs variable *(Corporate Cost)* is a proxy measuring the importance given by the firms to advance long term business capabilities through planning and human resource development type of activities. It is the ratio of corporate operations expenses to total operating revenues.

Other than the standard instruments, we include additional instrument in the employment equation. The impact of negative or positive financial performance is first manifested in employee numbers. We include measures of past financial performance as instruments for the endogenous lagged dependent variable. Two-period lagged values of two instrumental variables, the ratio of cash flow over assets, measured as the ratio of total operating revenues to total assets ($Cash\ Flow_{t-1}$ and $Cash\ Flow_{t-2}$), and the ratio of plant specific operations expenses to communications plant in service ($Efficiency_{t-1}$ and $Efficiency_{t-1}$) are used to control for endogeneity.

In addition, to control for industry effects on lagged values of employment, we use an intensity of competition variable as an instrument. The intensity of competition variable is the number of possible competitors who have been given a license to operate in the various states. This control represents the possible intensity of market competition in each state. This variable is relevant to control for the impact of the Telecommunications Act of 1996.

The competition data are collected from the FCC Competition in Telecommunications Industry reports. For each incumbent local exchange carrier, the competition variable *(Competition)* is computed as the sum of the number of competitive local exchange carriers operating in the same state or states as the incumbent.

Table 1 (in the appendix) provides the list of independent and control variables used in this study along with the descriptive statistics. The table also includes details of what each variables aims to measure in the analysis.

On average, telecommunications carriers had around 12,000 employees during our study period with the compensation per employee averaging around $46,500/year. These companies were growing at a steady rate of 3% and operating predominantly in urban areas.

5. ESTIMATION AND RESULTS

Estimation: Unobserved heterogeneity and omitted variables biases cause concern. We use the Arellano and Bond (1991) dynamic panel data approach to control for these as much as possible in testing for the impact of broadband diffusion over time. The employment and compensation variable are regressed over the broadband variable, prior employment and compensation variables and control variables. The use of dynamic panel data analysis in evaluating the impact of technology diffusion allows for the control of heterogeneity in adjustment dynamics between different firms.

Longitudinal estimation is necessary given the inherently lagged nature of the phenomena. This approach also addresses the unobservable heterogeneity and omitted variables biases. Dynamic panel data estimation is one of the most stringent panel-data estimation techniques available at present for this purpose. The use of a dynamic panel data approach teases out the effects of technology diffusion, controlling for not only exogenous factors but also firms' past behaviour and history, and the results for the broadband variable reflect the impact of just the broadband adoption decision, of course at various points in time but aggregated within a panel estimation framework to reflect composite diffusion both between and within firms, on average compensation levels (Greene, 2003).

To control for endogeneity between broadband technology diffusion and compensation, we use the Arellano and Bond (1991) instrumental variable estimation method for panel data using generalized method of moments (GMM) estimators. The Arellano and Bond (1991) dynamic panel data analysis technique derives GMM estimates using prior employment and compensation levels.

The lagged dependent variables in the model account for the dynamic and heterogeneity effects, subject to the inclusion of other controls. The correlation of the lagged endogenous variables may affect the analysis even if no auto-correlation is assumed. The use of instruments bypasses the error correlation issues when GMM with instruments, lagged dependent variables in this case, are used. The use of GMM estimators increases the computational efficiency without impairing effectiveness through the use of lagged values as instruments (Yaffee, 2003). Additional variables included as instruments are the past period performance variables, $Cash\ Flow_{t-1}$ and $Cash\ Flow_{t-2}$ and $Efficiency_{t-1}$ and $Efficiency_{t-1}$.

The Arellano and Bond (1991) specification acknowledges the dynamic relationships and interdependencies among technology diffusion, employment and compensation. The estimation employs error adjustment techniques to model the influence of past levels of adoption, thus absorbing the impact of any structural distortions to have occurred and could affect the companies in the period. The technology variable would, therefore, capture the unexplained remaining variation in the employment and compensation values.

The estimator offers substantial efficiency gains in saving degrees of freedom and lowers the impact of bias in the estimators due to small sample size (Blundell and Bond, 1998). Omitted variable bias is controlled for and multi-collinearity reduced, improving the accuracy of parameter estimates (Hsiao, 2003). We report two-step estimates corrected for heteroskedasticity-consistent asymptotic standard errors.

Estimation Results for the Employment Equations: Tables 2 and 3 report the results for the Arellano and Bond (1991) dynamic panel estimates. Model (A) and (B) of table 2 relate to the employment equations. Two lags of the dependent variable are included in the model to control for prior firm history and endogeneity. This practice is consistent with dynamic panel data estimation. The coefficient of the broadband variable is negative and significant ($p < 0.05$), denoting that a greater rate of broadband diffusion within firms has a negative impact on the structure of employment in the firms studied. The scale effect, with physical and human capital substitution, albeit of less highly-skilled individuals, can be at play.

The size *(Size)* variable is important in the wages and employment literature, and we exclude the size variable in model (B). We find that the broadband variable has not changed in magnitude, sign and significance as a result. In fact, after excluding the size variable, the magnitude of the broadband variable is somewhat larger. Both of these results provide evidence that the scale effect associated with technology diffusion, that changes occur in the ratio of human capital to physical capital, leading to displacement of human capital, when the quality of physical capital improves, is not disproved.

Estimation Results for the Compensation Equations: Models (C) and (D) of Table 2 are the wages or compensation equations. In model (D) we exclude the *Size* variable. In both models, the broadband variable is positive and significant ($p < 0.01$), denoting that a higher level of diffusion of broadband technology is associated with higher levels of compensation among the firms. In fact, after exclusion of the size variable, the magnitude of the wages variables is somewhat larger.

Results for the Productivity Equations: Models (E) and (F) of Table 3 are the employee output or productivity equations, with and without the size variable respectively. The significance of size coefficient and the higher loading on broadband variable in Model (E) both indicate that output per employee is substantially higher in larger firms and reflect strong positive correlation between size and broadband diffusion in their impact on employee productivity. This constitutes another evidence of the importance of scale economies in the telecommunication sector. As per the impact of new technology, both models suggest that broadband variable is positive and economically and statistically significant suggesting that broadband diffusion is associated with higher levels of output per employee. We conclude that broadband diffusion is associated with fewer numbers of skilled employees, who are compensated with higher wages as they are able to generate more output per capita. These estimates provide *prima facie* evidence that the capital-skills complementarity hypothesis is valid within the telecommunications sector.

6. CONCLUSION

We have evaluated the impact of broadband diffusion among all the local exchange companies in the US telecommunications industry between 1988 and 2001. Broadband is a general purpose technology, within the broad rubric of information and communications technologies, and its diffusion is expected positively impact wages in the adopting firms because of a skill effect, though it may lower average employment while increasing the employee output because of a scale effect.

Firms or industries that implement skill based technical change will hire more high skilled workers than low skilled workers and average wages will go up as a result of the skill effect even though total average employment may go down because of the displacement of the less-skilled employees because of the scale effect. The scale effect will also drive the average output per employee up. As the quality of physical capital improves, more output is likely to be generated with the capital invested and, ceterus paribus, the levels of human capital within a firm will decline. Yet, the decline in the quantity of human capital will occur among those now relatively unskilled and untrained, and demand for those with training will rise.

What are the specific implications of our results? An evaluation of the results, based on the dynamic panel data estimates as reported in table 2, shows that a one percentage point increase in the diffusion of fiber optics broadband technology in the telecommunications companies' networks is associated with approximately a one percent decrease in average employment levels among the firms. The average diffusion of fiber optic has been low in the period studied, averaging just 2.85 percent of total lines. Therefore, there is a substantial amount of investment still to be made in upgrading the network. If fiber optic levels were to double from the levels we observed, there would be a 2.8 percent decline in employment, because of the scale effect associated with new technology diffusion.

On the other hand, a one percentage point increase in the diffusion of fiber optics technology is associated with a 2.55 percent increase in average levels of compensation. Using the same logic as above, if the levels of fiber optics technology were to double, we would observe a 7.25 percentage increase in average wages among the employees of the companies concerned. This, by any means, is a substantial increase in average wages or compensation occurring because of the operation of the skill effect. Its effect is to overshadow the negative scale effect associated with the diffusion of new technology.

The diffusion of broadband technology, measured as the extent of fiber optic cabling, has had the impact of raising wage levels among the firms where the level of adoption is relatively higher. This finding has several managerial and policy implications. From the point of view of theory, these results strongly support the technology-skill or capital-skill complementarity hypothesis within the telecommunications industry, since the adoption of broadband technology by firms does alter the composition of skill in the firms concerned. This result also augments evidence from the individual level studies which have examined the impact of information and communications technology diffusion on variations in the wage structure.

Second, based on the coefficient estimates reported for models (C) and (D) in table 2, the results show that a doubling of fiber-optics broadband cabling in the companies' networks is associated with over a 7 percent rise in average compensation levels. For the telecommunications sector of the United States as a whole, and for the concerned companies, this is an important finding. The United States is not at all at the forefront of broadband diffusion among the OECD countries, in spite of broadband being a general purpose technology. Neither are the local exchange carriers that we study at the forefront of broadband technology diffusion within the United States (Frieden, 2005). Our data also show this to be the case.

In the United States, while most households are passed by broadband cabling, for the period studied less than a fifth did have broadband connectivity and had to rely on narrow-band dial-up facilities for Internet connectivity. Only very recently has this picture changed. Also, the local exchange carriers have represented less than a fifth of broadband penetration in the United States, with the rest of national broadband diffusion being accounted for by the cable companies. Nevertheless, the local exchange companies possess the last mile connectivity monopoly, with access to over one hundred and fifty million homes in the nation, and fiber in their network backbone has very substantial connotations.

If the quantity of broadband adopted by the local exchange companies increases, then not only does productivity increase, because broadband is a general purpose technology, but there is the spread of new Internet-based business models built on the broadband platform. The evidence on the business and economic impact of broadband (Bauer, Kim and Wildman, 2003; Firth and Mellor, 2005, Frieden, 2005) is now categorical about the large magnitude of the expected impacts from its deployment.

Also, in accordance with our results, while the impact on the quantity of employment will be negative, the impact on the quality of employment within the United States as a whole is substantial because of the substantially rising wage levels associated with enhanced broadband diffusion patterns. If the average levels of fiber optics cabling among the firms studied were to increase to, say, 15 percent, we would expect to see average compensation levels rise by over 35 percent among the firms, as the skill effect kicked in and the demand for higher-skilled employees increased substantially. Albeit, employment levels would decline by about 15 percent, but these declines would be more than compensated by the increases in average compensation levels that resulted.

The level of broadband diffusion in the United States is much lower than other OECD countries. By that yardstick, if our results are generalized across other OECD countries, the United States has also fallen behind in comparative wage levels relative to these countries, given the impact that a general purpose technology has on raising wage levels (Ferguson, 2004). Greater diffusion of broadband will narrow the wages gap that the United States faces relative to the other OECD countries. Second, the wage level in firms that adopt greater amounts of broadband will be much higher than that in firms which do not. This has important implications for labor market dynamics in the information and communications technology sector in the United States.

Of course, as the speed of broadband diffusion increases, and there is every possibility of this taking place since the present level of diffusion in the United States is so low, especially among the local exchange companies, it is quite likely that variations in the wage levels between firms in the same segment of the industry will widen considerably as some firms pull ahead from the pack in broadband adoption.

Nevertheless, at an aggregate level the enhanced speed of diffusion from the low base will considerably raise living standards of employees in the telecommunications sector because of rising wages. In fact, the wage levels can rise substantially given the current very low levels of broadband diffusion. Therefore, diffusion of broadband technology is to be extremely strongly encouraged by all means possible. From the perspective of the managers of telecommunications firms, the diffusion of broadband technology, as with other information and communications technologies, enhances the quality of the skill set in the firm as a whole. This will have a substantial effect on other parameters of performance such as customer satisfaction, market share and profitability.

Simultaneously, because broadband diffusion brings with it several new functionalities, it requires the human capital pool in the telecommunications companies to possess new skills. Thus, the skill-sets in the sector will also be enhanced. Again, the same diffusion dynamic will come to play. As some firms pull ahead in the broadband diffusion race, because of the speed of their individual adoption, the level of skills in firms that adopt greater amounts of broadband will be higher than that in firms falling behind in adoption.

As broadband diffusion increases among the firms studied, with substantial scope available to do so because diffusion levels observed were low, the impact of such continuing diffusion of broadband technology on enhancing compensation and wage levels in the sector can be profound for firms' performance and overall competitiveness. Nevertheless, greater variations in broadband diffusion patterns between firms will also be associated with significantly notable divergences in human capital capabilities. Of course, what the impact of such human capital capability divergences is on eventual industry evolution patterns remains an entirely speculative issue at the present. It is quite likely that the unobservable firm-specific characteristics that drive the speed of diffusion within some firms, and simultaneously impact the quality of the human capital pool, will also lead these firms to be those that acquire other firms in the sector and drive sector evolution forward via consolidation. These are issues calling for further substantial research.

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Table 1: List of Variables and Descriptive Statistics

Variable	Description	Valid Observations	Mean	Median	Standard Deviation
Employment	Total employment of each firm	561	12,016	6,005	16,325
Workforce Composition	Ratio of Part-Time employees out of total number of employees	561	1.6%	1.0%	2.0%
Compensation	The average dollar value of compensation cost per employee	561	46.50	43.73	11.84
Productivity	The average dollar output, using total operating revenues, per employee	561	216.91	200.72	81.46
Fiber cable ratio	Percentage of total fiber km to total cable km	572	2.78	1.78	2.96
Size	Log of total operating revenues	562	13.90	13.98	1.29
Access cost	Ratio of access costs to total operating revenues	562	2.6%	2.0%	2.6%
Line share	Ratio of firm's lines relative to the total number of lines in various states	574	49.0%	62.4%	39.0%
Business lines ratio	Ratio of total business lines to total access lines for each company	573	25.5%	24.8%	6.9%
Urban ratio	Weighted average ratio of urban population to total population	574	78.5%	77.4%	11.1%
Advertisement	Ratio of advertising expenses to total operating revenues	562	3.5%	3.3%	1.1%
Customer costs	Ratio of customer operations expenses to total operating revenues	562	12.6%	12.4%	2.4%
Corporate costs	Ratio of corporate operations expenses to total operating revenues	562	10.8%	10.7%	3.2%
Competition	Number of competitors given a license to operate in the various states	574	8.6	3.0	14.6
Growth	Revenue growth relative to past years revenues	521	3.3%	3.3%	10.4%

Sources: FCC Common Carrier Statistics; FCC Reports on Competition in the Telecommunications Industry; Federal-State Joint Board Monitoring Reports. For more information and details on various variables and data sources, see Yaylacicegi (2005).

Table 2: Arellano-Bond dynamic panel data regression results with *employment* and *compensation* as the dependent variables.

	Employment Equation				Compensation Equation			
	Model (A)		*Model (B)*		*Model (C)*		*Model (D)*	
	Coeff. (SE)	t-stat	Coeff. (SE)	t-stat	Coeff. (SE)	t-stat	Coeff. (SE)	t-stat
Constant	-32.849 (23.001)	1.43*	-7.654 (17.698)	0.43	1.884 (0.281)	6.70***	1.734 (0.302)	5.75***
Broadband	-108.544 (45.064)	2.41**	-128.831 (41.440)	3.11***	1.196 (0.353)	3.39***	1.142 (0.359)	3.18***
Employment $_{t-1}$	1.002 (0.013)	77.71***	1.005 (0.013)	78.22***				
Employment$_{t-2}$	-0.210 (0.013)	16.50***	-0.211 (0.013)	16.61***				
Compensation $_{t-1}$					0.255 (0.119)	2.13**	0.201 (0.116)	1.73*
Compensation$_{t-2}$					-0.093 (0.078)	1.19	-0.109 (0.078)	1.39
Size	527.200 (272.056)	1.94**			-7.551 (2.97)	2.54**		
Access Cost	-3269.914 (1866.772)	1.75**	-3549.475 (1967.024)	1.80**	-28.040 (29.034)	0.97	-12.185 (28.663)	0.43
Market Share	623.985 (234.342)	2.66**	550.207 (233.468)	2.36**	-24.597 (9.315)	2.64**	-22.215 (9.349)	2.52**
Business Lines	-1763.919 (1002.04)	1.76**	-1853.748 (1013.252)	1.83**	42.435 (25.018)	1.70*	42.225 (24.858)	1.70*
Urban	242.204 (2314.59)	0.10	433.057 (2568.58)	0.17	21.781 (12.172)	1.79*	27.016 (11.721)	2.30**
Advertising	10027.72 (3818.571)	2.63**	11723.29 (3581.909)	3.27***	-46.555 (88.043)	0.53	-44.815 (88.265)	0.51
Customer Costs	-5826.763 (1764.249)	3.30***	-5826.55 (1834.53)	3.18***	82.892 (43.362)	1.91**	71.439 (43.041)	1.66*
Corporate Costs	-5210.081 (1140.239)	4.57***	-5687.909 (1068.241)	5.32***	20.842 (9.679)	2.15**	23.893 (9.493)	2.52**
Growth	-616.763 (138.351)	4.46***	-461.132 (94.83)	4.86***				
Competition					-0.337 (0.045)	0.75	-0.320 (0.446)	0.72
Wald χ^2	53818.88		52206.18		47.16		45.41	
N	435		435		435		435	

***, **, and * represent significance at the 1%, 5%, and 10% levels respectively.

Table 3: Arellano-Bond dynamic panel data regression results with *Productivity* as the dependent variable.

	Productivity Equation			
	Model (E)		*Model (F)*	
	Coeff. (SE)	t-stat	Coeff. (SE)	t-stat
Constant	4.36 (0.355)	12.28***	13.423 (0.478)	28.1***
Broadband	2.504 (0.719)	3.48***	1.301 (0.563)	2.31**
Productivity $_{t-1}$	0.142 (0.021)	6.78***	0.190 (0.017)	11.01***
Productivity $_{t-2}$	0.071 (0.009)	7.21***	0.108 (0.011)	9.45***
Size	245.03 (16.83)	14.55***		
Access Cost	13.74 (89.20)	0.15	-120.28 (109.64)	-1.1
Market Share	-10.19 (27.45)	-0.37	22.37 (27.67)	0.81
Business Lines	231.21 (55.96)	4.13***	286.09 (54.21)	5.28***
Urban	138.18 (141.65)	0.98	-275.21 (128.358)	-2.14**
Advertising	-562.82 (192.01)	-2.93***	-57.77 (214.30)	-0.27
Customer Costs	145.01 (61.7)	2.35**	21.49 (78.38)	0.27
Corporate Costs	162.41 (25.68)	6.32***	67.87 (25.48)	2.66***
Competition	-0.149 (0.097)	-1.54	-0.219 (0.096)	-2.29**
Wald χ^2	9258		881.12	
N	435		435	

***, **, and * represent significance at the 1%, 5%, and 10% levels respectively.