Information Technology, Skilled Labor, and Factor Substitution: Evidence from the Healthcare Industry

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Abstract

Information technologies (IT) may substitute for routine/manual tasks and complement complex/problem-solving tasks, which can induce bias towards greater demand for skilled labor. This phenomenon of “skill-biased technical change” has important implications for the impact of IT on factor substitution within a firm’s production process. Understanding how the substitution and complementarity relationships depend on the skill levels of labor has not been adequately addressed in the IS and economics literature. Using firm-level panel data from California hospitals from 2002-2006, we specified a translog production function and estimated elasticities of substitution between IT spending and skilled vs. unskilled labor. We found that IT is a substitute for capital and low-skilled labor, but is a complement for high-skilled labor. Additionally, the complementarity effect of IT on high-skilled labor is stronger in magnitude than the substitution effect on low-skilled labor. Our results suggest the impact of IT on labor is non-uniform and skill-biased, favoring high-skilled workers over low-skilled workers.

1. Introduction

Information technology (IT) usage has rapidly expanded across organizations and industries during the last three decades, and IT’s impacts on organizations and their performance are omnipresent and significant. The adoption of IT and the increased intensity of its use have improved production processes and changed the makeup and quality of factors of production being employed (McKenzie 2003). A firm’s capital now includes a growing investment in computer and communication equipment. Other types of machinery increasingly rely on electronic components and software codes for instant monitoring and precise control. While the remarkable automation and information processing power delivered by IT improves labor productivity, it also demands specialized skill sets from workers in many settings. Thus, continued IT investments can have a significant impact and change the skill mix of labor markets in industries. Despite the significant implications of IT on labor, there is paucity of empirical evidence on how IT actually interacts with skilled labor in production processes.

The purpose of this study is to examine how the substitution and complementarity effects of IT on other factors of production (i.e., capital and labor) depend on the skill levels of labor. To address this issue, we specified a translog production function (Christensen et al. 1973) and estimated Allen partial elasticities of substitution (AES) (Allen 1938). The unit of analysis and context of our study is hospitals within the healthcare industry, and we analyzed data gathered by the California Office of Statewide Health Planning and Development (OSHPD) on the operations of 425 acute care hospitals over the period of 2002 to 2006. The empirical focus on healthcare is particularly interesting since investments in healthcare IT have been rising and have been projected to impact the demand for skilled labor (Hillestad et al. 2005). No prior studies have examined how IT substitutes or complements different types of labor input in the hospital setting.
The primary intended contribution of this research is two-fold. First, it evaluates the strategic importance of IT by estimating the complementarity and substitutability between IT and other inputs. Second, it examines how factor substitution relationships depend on different levels of labor skills. The problem stated is important, as the study of the substitutability and complementarity effects enables one to more accurately characterize the business value of IT. Equally important, an examination of the substitutability and complementarity relationships between IT and other inputs in the context of healthcare provides insight into, and empirical justification for, the emphasis placed on IT to control the cost and improve the quality of healthcare systems.

2. Literature Review

In a production process, inputs can be complementary or substitutable. Two inputs used together can enhance, or complement, each other in producing output. Alternatively, they can be substitutes for each other while maintaining the same output level. One essential difference between IT and other inputs is the dual roles that IT plays. Like capital, IT can be used directly as a production technology to improve labor productivity. In this case, IT is considered a substitute for labor because IT allows firms to reduce headcounts. On the other hand, IT is also a potent complementary technology that can reduce the cost of coordinating economic activities, both within and between organizations (Gurbaxani and Whang 1991). As a result, IT represents a unique value proposition in enabling fundamental changes to both the production process and the organizational structure.

While the literature on the business value of IT has been abundant, relatively few have been devoted to the study of complementarity and substitutability effects of IT. Among the few exceptions, Dewan and Min (1997) looked at the substitution of IT and found that IT is a net substitute for both capital and labor. Zhu and Kraemer (2002) and Zhu (2004) reported a resource complementarity between e-commerce capabilities and IT infrastructure. Looking at the levels of firm, industry and sector, Lin and Shao (2006) indicated that IT, capital and labor are not pairwise substitutable, and it is not possible to use IT to replace labor entirely. The traditional view regards technical change as factor-neutral (or Hicks-neutral).

However, researchers recently have argued that the impact of IT on labor force is asymmetric and non-uniform (Autor et al. 2003). This so-called “skill-biased technical change” favors high-skilled labor over low-skilled labor, as IT can complement highly skilled workers by helping them perform non-routine problem-solving and coordination tasks more effectively while at the same time substituting for lower skilled labor by automating their repetitive manual work (Berman et al. 1998). Autor et al. (2003) found that IT is associated with reduced labor input of routine manual tasks and with increased labor input of non-routine cognitive tasks. This skill bias has put IT at the center of the debate on globalization (Krugman 2000). Thus, a key objective of this research is to gain a better understanding of the asymmetric impacts of IT on skilled labor.

3. Model and Data

Following Hitt and Snir (1999), we specified a translog production function to facilitate the estimation of elasticities of substitution for IT in the healthcare context. In contrast to the Cobb-Douglas and constant elasticity of substitution (CES) production functions, the translog function does not impose inherent constraints on the elasticities of substitution between factors of production. The translog functional form used for our analysis is specified as:
\[ \ln Y = \alpha_0 + \sum_{i=1}^{4} \alpha_i \ln X_i + \sum_{j=1}^{4} \beta_{ij} \ln X_i \ln X_j + \varepsilon \]  
\[ \text{where } Y \text{ is the output (i.e., adjusted patient days) of hospitals, and } X_i \text{ represents the four inputs being used (i.e., } K: \text{capital, } H: \text{high-skilled labor, } O: \text{low-skilled labor, and } I: \text{IT).} \]

In the second stage, the Allen partial elasticities of substitution (AES) between IT and other inputs are defined as (Chambers 1988):

\[ \sigma_{ij} = \frac{\sum_{i=1}^{4} X_i f_i F_{ij}}{X_i X_j} \]

where \( f = Y, f_i \) is the first derivative with respect to input \( X_i \), \( F \) is the bordered Hessian determinant

\[ F = \begin{vmatrix} 0 & f_1 & f_2 & f_3 & f_4 \\ f_1 & f_{11} & f_{12} & f_{13} & f_{14} \\ f_2 & f_{21} & f_{22} & f_{23} & f_{24} \\ f_3 & f_{31} & f_{32} & f_{33} & f_{34} \\ f_4 & f_{41} & f_{42} & f_{43} & f_{44} \end{vmatrix} \]

and \( F_{ij} \) is the cofactor associated with \( f_{ij} \).

We collected panel data from the 2002-2006 Annual Financial Disclosure Reports and Patient Discharge Databases of OSHPD. OSHPD required acute care hospitals in the state to annually submit a financial disclosure report, which contains firm-level information on outputs (adjusted patient days), capital, IT spending (including IT labor, purchased services, leases and depreciation), and labor expenses classified by type and function of workers (ie, clinical vs. non-clinical, management vs. clerical). The analytical dataset is an unbalanced panel, consisting of 1,183 observations involving 425 hospitals over a 5-year period.

Output \( Y \) is the adjusted patient days of a hospital in a given year. Capital \( K \) is the total capital expense. We grouped labor expenses into two categories. High-skilled labor \( H \) consists of labor expenses for clinical workers like physicians and registered nurses as well as non-clinical workers in management positions. Low-skilled labor \( O \) includes labor expenses for such clinical workers as technicians, licensed vocational nurses, and aides as well as non-clinical clerical and other workers. Finally, IT spending \( I \) is defined as IT expenses (purchased services, leases and depreciation) plus three times IT labor expense. Table 1 presents the descriptive statistics of the variables used.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>STD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y ) (adjusted patient days)</td>
<td>108144</td>
<td>100925</td>
<td>538</td>
<td>779592</td>
</tr>
<tr>
<td>( K ) (capital)</td>
<td>38.40</td>
<td>52.23</td>
<td>0.27</td>
<td>581.54</td>
</tr>
<tr>
<td>( H ) (labor expense for high skilled workers)</td>
<td>31.35</td>
<td>37.96</td>
<td>0.29</td>
<td>301.53</td>
</tr>
<tr>
<td>( O ) (labor expense for low skilled workers)</td>
<td>30.33</td>
<td>43.28</td>
<td>0.38</td>
<td>430.09</td>
</tr>
<tr>
<td>( I ) (IT spending + 3 \times IT labor expense)</td>
<td>4.39</td>
<td>9.17</td>
<td>0.004</td>
<td>89.92</td>
</tr>
</tbody>
</table>

4. Results

We used the panel models to estimate the translog production function (1). Also, a Hausman test was performed for the correlation between the error and the regressors, and the result suggested the fixed effect model is more appropriate to fit the data than the random effect model (Chi-square statistic = 152.54 with \( p \)-value < 0.00001). Therefore, we reported the results from
the fixed effect model in Table 2 and used their coefficient estimates for the subsequent AES computations.

We derived the AES according to (2) for the elasticities of substitution of IT for capital, high skilled labor, and low skilled labor. It is noted that the AES is symmetric (i.e., $\sigma_{KI} = \sigma_{IK}$), and a positive sign suggests substitutability and a negative sign implies complementarity between two factors of production. We evaluated the AES at the median values of the input and output variables and obtained $\sigma_{KI} = 0.711$, $\sigma_{HI} = -0.414$, and $\sigma_{OI} = 0.115$. We found that IT is a net substitute for capital, a finding consistent with those of previous studies (Dewan and Min 1997). More importantly, IT was found to be a substitute for low skilled labor but a complement for high skilled workers. The magnitude of the complementarity effect is stronger than that of substitutability effect. These results suggest IT-induced skill bias exists.

Table 2. Results of Translog Production Function

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_K$</td>
<td>1.123***</td>
<td>0.231</td>
</tr>
<tr>
<td>$\alpha_H$</td>
<td>0.080</td>
<td>0.199</td>
</tr>
<tr>
<td>$\alpha_O$</td>
<td>0.679***</td>
<td>0.202</td>
</tr>
<tr>
<td>$\alpha_I$</td>
<td>0.053**</td>
<td>0.025</td>
</tr>
<tr>
<td>$\beta_{KK}$</td>
<td>0.013</td>
<td>0.020</td>
</tr>
<tr>
<td>$\beta_{HH}$</td>
<td>0.042**</td>
<td>0.021</td>
</tr>
<tr>
<td>$\beta_{OO}$</td>
<td>0.059***</td>
<td>0.019</td>
</tr>
<tr>
<td>$\beta_{HI}$</td>
<td>-0.001**</td>
<td>0.001</td>
</tr>
<tr>
<td>$\beta_{KH}$</td>
<td>-0.012</td>
<td>0.034</td>
</tr>
<tr>
<td>$\beta_{KO}$</td>
<td>-0.076**</td>
<td>0.031</td>
</tr>
<tr>
<td>$\beta_{KI}$</td>
<td>0.005</td>
<td>0.004</td>
</tr>
<tr>
<td>$\beta_{HO}$</td>
<td>-0.059**</td>
<td>0.025</td>
</tr>
<tr>
<td>$\beta_{HI}$</td>
<td>-0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>$\beta_{OI}$</td>
<td>-0.006*</td>
<td>0.003</td>
</tr>
<tr>
<td>Constant</td>
<td>-10.957***</td>
<td>1.651</td>
</tr>
</tbody>
</table>

$N = 1,183$, $R^2 = 0.94$, Adjusted $R^2 = 0.92$, $F$-statistic = 583.41

5. Discussion and Implications

Although the contribution of IT to labor productivity growth has been well recognized (Brynjolfsson and Hitt 1996), the impact of IT on skilled labor has received much less attention. Recent research suggests that the impact of IT on labor is not uniform and may vary depending on the skill levels of workers (Autor et al. 2003). This skill-biased technical change raises a legitimate question of whether and to what extent IT substitutes for (or complements) labor as a factor of production in the production process. On this topic, Gries and Jungblut (1999) developed an analytic model and examined the effects of IT on innovation dynamics and labor demand. Their analysis revealed the demand for skilled labor would increase compared with unskilled labor if human capital development lags the pace of innovation. Our study provides empirical evidence to support their arguments. More specifically, IT is found to complement skilled workers by helping them become more productive but at the same time substitute for unskilled labor by reducing the amount of their work or performing their jobs directly instead.
Since the greatest impact of IT consists in its capabilities to innovate business processes, the adoption of IT would require a new skill set of workers and hence would increase the demand for higher skilled labor. On the other hand, IT can automate inefficient manual tasks or make obsolete the repetitive activities that used to be performed by low skilled workers, leading to the de-skilling of these routine manual tasks. As a consequence, the demand for unskilled labor would decrease. Considering the unlimited potential of IT in improving workflows and the increased skill intensity of jobs, it is only reasonable to expect that the adverse effect on unskilled labor force will become even more significant in the future.

There are several important implications that can be drawn from our findings. First, the diffusion of IT innovations must be accompanied by education and training aimed at enhancing the qualification of the workforce. We need to increase both the share of skilled workers and their human capital endowment. Only in this case will the potential increase in labor productivity enabled by IT be realized. Second, while IT raises the demand for highly skilled and educated workers, wage disparities are likely to widen. To address this inequality issue, it is insufficient to just focus on aggregate unemployment rates. Instead, individual attributes such as educational level, age, gender and propensity need also be taken into account. Third, in the healthcare domain, the unbalanced demand for skilled over unskilled workers is perhaps even more critical (Furukawa et al. 2010a, 2010b). Some areas in the U.S. already have registered nurse shortages, and that problem could be exacerbated with the implementation of health IT systems like electronic medical records.

6. Conclusions

Using firm-level panel data of 425 hospitals in California over the 2002-2006 period, this paper estimated the translog production function and examined how factor substitution of IT with capital and labor in the production process depends on the skill level of workers. In line with previous studies, our results suggest that IT is a net substitute for capital. More importantly, we found that IT exerts different impacts on labor depending on the skill levels of the workforce. IT has a substitutability effect on low skilled labor and an even stronger complementarity effect on higher skilled workers, thus rendering empirical evidence for the skill biased technical change associated with IT. Several practical implications are then drawn from the findings. Future research will consider how factor substitution relationships vary by process type (clinical vs. non-clinical).

References