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Completed Research

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Abstract
This study investigates if foreign information technology (IT) workers complement or substitute for native IT workers within the production function framework. We first examine the differences between foreign and native IT workers in their skill sets and then test their complementarity/substitution relationship using an US industry-level dataset obtained by matching the productivity data to the Current Population Survey. Our findings suggest that foreign and native IT workers are complements rather than substitutes. The results of this study shed light on this important issue and bear theoretical and practical implications.

Keywords
Immigrants, foreign IT workers, native IT workers, complementarity, substitution, elasticity of substitution

Introduction
The impact of immigrants on the natives has been an important and highly debated issue in many developed countries. Plenty of studies have been devoted to examining the impact in such areas as productivity, employment, innovation, earnings, social welfare, and political landscape (Aobdia et al. 2018; Shachar 2006). The results of these studies not only make intellectual contribution but also bear direct policy implications.

In early times, immigrants to the US tend to be less educated (Friedberg 2001). Quite often they do work natives would not like to do and help keep the price of labor-intensive goods and services down and thereby raising consumer welfare (Cortes 2008; Orrenius and Zavodny 2007). In recent decades, due to the acceleration of the knowledge economy and the fast paces of technological advancement, more skilled immigrants have been coming into the US, and the impact of immigrants on native workers has been evolving. In this study, we examine the impact of one prominent category of highly skilled immigrants: the IT immigrants or foreign IT workers. IT workers or IT professionals are non-executive personnel working in a firm's IT department (Wang and Kaarst-Brown 2014).

In prior literature, the phrase "foreign workers" is used in different ways. Some use it to strictly refer to non-US citizens who enter the US on temporary visas (Mithas and Lucas 2010), while others use it to mean workers not born in the US, such that naturalized citizens are also counted as foreign workers when studying their impact on the natives (Hunt 2011; Matloff 2013). In this study, we define foreign workers as those who were not born in the US. Most foreign workers initially entered the US on temporary visas, such as H-1B visa (Hira 2010; Kerr and Lincoln 2010). Foreign students on F1 visa can also work in the US temporarily through such programs as Optional Practical Training. For more discussions related to the different types of visas and the immigration policies related to them, please refer to (Aobdia et al. 2018; Hira 2010; Hunt 2011; Mithas and Lucas 2010).

Specifically, in this research, we examine the interactions between foreign and native IT workers in the production process. Regarding this topic, two opposing views exist. While some argue foreign and native IT workers compete and substitute for each other, others argue foreign and native IT workers are complementary because they play different roles at workplaces due to the differences in their skill sets, such as global perspectives, work experiences, and language proficiency. Despite the importance of this topic, very limited attention has been paid to it in the information systems (IS) literature. Our study first examines the differences between foreign and native IT workers, and then empirically test their complementarity/substitution relationship through the production function framework. Our results support the view that foreign and native IT workers in the US are complementary rather than substitutive to each other. These findings can potentially deepen our understanding on the interactions between foreign and native IT workers, and contribute to the literature in this field (Lucas and Mithas 2011; Matloff 2003; Mithas and Lucas 2010).

Literature, Theories, and Models

Highly skilled foreign workers are different from other types of immigrants in that they carry significant human capital and play a critical role in today's fast-paced and knowledge-based economy (Kerr 2013). It has been observed that science and technology have been and will continue to be the engine of the US economy, and countries that succeed in the future will be those with citizens who are creative, adaptable, and skillful. Therefore, many countries have implemented policies to compete for highly skilled foreign workers to win the global race for talents (Hunt 2013; Shachar 2006). Among the highly skilled foreign workers, IT workers take a prominent role due to increasing IT investment in the US economy and R&D expenditure by US firms.

Despite all the positives, concerns on hiring foreign IT workers have also been raised. One of the key issues is how foreign IT workers have affected their native counterparts. Some studies argue that foreign IT workers substitute for native IT workers: the US is not short of skilled IT workers; US employers can pay lower wages to foreign IT workers than the natives and thus hiring foreign IT workers help cut costs and increase profits (Hira 2010; Matloff 2004; Matloff 2013). Furthermore, employers can potentially take advantage of foreign workers because it is difficult for them to change jobs, particularly if they are sponsored for permanent residents or green cards. For example, several cases have been reported where US companies hired foreign IT workers to displace older native IT workers with higher salaries, including the well-known case of Disney World (Matloff 2003; Preston 2015).

In contrast to the substitutive narrative between foreign and native workers, some researchers have suggested that immigrants and natives are complementary (Aobdia et al. 2018; Kerr et al. 2015), and hiring foreign workers actually raise the employment of the overall workforce (Kerr et al. 2015; Peri and Sparber 2009). Prior studies suggest that when foreign workers are similar to native employees, they are more likely to be substitutes (Card 2001). However, foreign IT workers and native IT workers are not perfect substitutes, and they may differ from each other in some important ways—their skill sets, experience and perspectives may allow them to enhance each other's productivity (Aobdia et al. 2018; Mithas and Lucas 2010).

Regarding the specific skill sets applied at work, prior studies report that language proficiency plays an important role for job content and wage returns (Hunt 2013; Imai et al. 2019), and foreign workers tend to specialize in occupations requiring quantitative and analytical skills while the natives tend to specialize in those requiring more language and interactive skills (Peri and Sparber 2011). As a result, hiring foreign IT workers may well trigger demand for more native IT workers. For example, Bill Gates has stated in a congressional testimony that Microsoft recruits four additional employees to support each high-skilled foreign IT worker hired on a temporary work visa (Kerr et al. 2015). Therefore, the first objective of this study is to assess how similar or dissimilar foreign and native IT workers are in their skill sets. As immigrants from other countries, most of foreign IT workers are likely to be hampered by their English language proficiency, which is imperative for jobs requiring language and interactive skills. On the other hand, foreign IT workers tend to, on average, have comparative advantages in jobs requiring quantitative and analytical skills.[1] Therefore, in this study, we focus on three skill sets—language skill, interactive skill, and quantitative & analytical skill—to examine the differences between foreign and native IT workers.

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[1] The comparative advantage does not necessarily mean foreign IT workers have higher quantitative & analytical skills than the natives. It is well possible the opposite is true, but only that such an advantage of the natives is not as big as their language and interactive skills.

Our second objective is to assess whether foreign and native IT workers complement or substitute for each other in the production process. In prior literature, researchers have defined factor substitution/complementarity using various approaches (Samuelson 1974). Two approaches have been widely adopted in IS literature. One approach examines whether the marginal contribution of one input factor to the output depends on the level of another input factor in the production process, and this approach is rooted in the organizational complementarity (OC) theory (Brynjolfsson and Milgrom 2013). Another approach is to explore how the input level of one factor influences the input level of another, holding output level constant. The main metric of this approach is the elasticity of substitution, such as Allen elasticity of substitution and Morishima elasticity of substitution (Blackorby and Russell 1989). In this study, we apply both the organizational complementarity (OC) approach and the elasticity of substitution (ES) approach to assess the substitution/complementarity pattern between foreign and native IT workers.

According to the OC theory, the productivity of input factors for the production process can be inter-related, resulting in complementarity or substitution effect (Brynjolfsson and Milgrom 2013). While the substitution effect reflects decreased influence due to the existence of redundant factors, complementary effect arises from the fact that multiple factors are potential enablers to each other.

To implement the OC approach, we estimate a Cobb-Douglas (CD) production function:

$$V_{it} = \alpha\delta_i\theta_t C_{it}^{\beta_C} K_{it}^{\beta_K} L_{it}^{\beta_L}$$

where V is value added, C is IT capital, K is non-IT capital, L is labor, α is the multi-factor productivity, δ_i is the dummy variable for industry i, θ_t is the dummy variable for year t, and βs are the output elasticities for the corresponding input factors. Taking log on both sides, and using lower case for logarithm, we obtain the following log linear form:

$$v_{it} = \alpha + \beta_c c_{it} + \beta_k k_{it} + \beta_l l_{it} + \delta_i + \theta_t + \varepsilon_{it} \tag{1}$$

All βs are expected to be positive since conceptually all of them should contribute positively to value added.[2] The Labor input (*l*) can be further divided into non-IT labor (*lo*) and IT-labor (*lt*), and thus we have the following:

$$v_{it} = \alpha + \beta_c c_{it} + \beta_k k_{it} + \beta_{lo} lo_{it} + \beta_{lt} lt_{it} + \delta_i + \theta_t + \varepsilon_{it} \tag{2}$$

Further splitting IT labor (*lt)* into native IT labor (*ln*) and foreign IT labor (*lf*) leads to the following:

$$v_{it} = \alpha + \beta_c c_{it} + \beta_k k_{it} + \beta_{lo} lo_{it} + \beta_{ln} ln_{it} + \beta_{lf} lf_{it} + \delta_i + \theta_t + \varepsilon_{it} \tag{3}$$

Based on Equation (3) and consistent with the OC theory, an interaction term is added to test the substitution/complementarity effect between native IT labor (*ln*) and foreign IT labor (*lf*). Therefore, we estimate the following equation:

$$v_{it} = \alpha + \beta_c c_{it} + \beta_k k_{it} + \beta_{lo} lo_{it} + \beta_{ln} ln_{it} + \beta_{lf} lf_{it} + + \beta_{lnlf} ln_{it} lf_{it} + \delta_i + \theta_t + \varepsilon_{it} \tag{4}$$

If $\beta_{lnlf} > 0$, then *ln* and *lf* are complements, in the sense that a higher level of foreign IT labor increases the marginal contribution of the native IT labor; on the other hand, if $\beta_{lnlf} < 0$, then *ln* and *lf* are substitutes, since a higher level of foreign IT labor decreases the marginal contribution of the native IT labor.

As a second test, we apply the ES approach. In this framework, two factors are considered complements/substitutes if an increase in the input quantity of one factor increases/decreases the input quantity of another factor (Allen 1938). This tradeoff between input factors is captured through the metric of ES, which has been adopted by prior IS studies (Dewan and Min 1997; Zhang et al. 2015). For a n-input

[2] In the logarithm CD function, the coefficient measures the output elasticity of the input factor, i.e., the percentage change of output given a one percent change of the input factor.

production function $y = f(\mathbf{X})$, where y is the output and $\mathbf{X}$ is the vector of inputs, for constant output, the Allen elasticity of substitution (AES) (Uzawa 1962) between two inputs i and j is given as $\sigma_{ij}^{A} = \frac{\sum_i x_i f_i}{x_i x_j} \frac{\mathbf{H}_{ij}}{\mathbf{H}}$, where $\mathbf{H}$ is the bordered Hessian determinant of $f(\mathbf{X})$, and $\mathbf{H}_{ij}$ is the cofactor associated with f_{ij}. Inputs i and j are substitutes if $\sigma_{ij}^{A} > 0$, meaning an increase in the price of j decreases the input quantity of j but increases the input quantity of i; inputs i and j are complements if $\sigma_{ij}^{A} < 0$. Therefore, AES measures the change in one input factor due to the price change of another input factor, holding output and all other input factor prices constant.

However, one major drawback of AES is that it is symmetric so that $\sigma_{ij}^{A} = \sigma_{ji}^{A}$, and thus does not consider which input's price is changing. Moreover, AES is not informative beyond the fact that it has the same sign as the cross-price elasticity of demand (Blackorby and Russell 1989). Overcoming these drawbacks, the Morishima elasticity of substitution (MES) is constructed as $\sigma_{ij}^{M} = \frac{f_j}{x_i}\frac{\mathbf{H}_{ij}}{\mathbf{H}} - \frac{f_j}{x_j}\frac{\mathbf{H}_{jj}}{\mathbf{H}}$, where σ_{ij}^{M} measures the change in input i relative to input j as a result of a price change in input j. When $\sigma_{ij}^{M} > 0$, inputs i and j are substitutes, meaning that an increase in the price of j *increases* the ratio of input i over input j. When $\sigma_{ij}^{M} < 0$, inputs i and j are complements, meaning that an increase in the price of j *decreases* the ratio of input i over input j. In addition, MES is asymmetric, so that $\sigma_{ij}^{M} \neq \sigma_{ji}^{M}$. Therefore, MES measures the change in the ratio between two input quantities when price of one input factor is changing.

It has been noted that the signs of AES and MES do not always agree. We reconcile the difference as follows. Let AES_{ij} / MES_{ij} be the AES/MES between input i and input j when the price of j changes. When both AES and MES are positive, input i and input j are substitutes. When both AES and MES are negative, input i and input j are "strong complements". When AES is negative but MES is positive, the percentage change in input i is always smaller than the percentage change in input j when the price of input j increases, but indeed the quantity of input i decreases; in this case, we define input j as a "weak complements" with input i.[3] Table 1 summarize these interpretations.

AES_{ij}	MES_{ij}	
+	+	Substitutes
–	+	Weak Complements
–	–	Strong Complements

Table 1. Interpretations of AES and MES

To estimate AES and MES, we extend the CD production function and adopt a more flexible functional form, the Translog function (Chwelos et al. 2010; Dewan and Min 1997; Hitt and Snir 1999; Zhang et al. 2015) as follows:

$$\begin{aligned} v_{it} &= \alpha + \beta_c c_{it} + \beta_k k_{it} + \beta_l l_{it} + \beta_{cc} c_{it}^2 + \beta_{ck} c_{it} k_{it} + \beta_{cl} c_{it} l_{it} \\ &\quad + \beta_{kk} k_{it}^2 + \beta_{kl} k_{it} l_{it} + \beta_{ll} l_{it}^2 + \delta_i + \theta_t + \varepsilon_{it} \end{aligned} \tag{5}$$

[3] Mathematically, the case of "+" and "–" does not exit.

We then split labor input (*l*) into non-IT labor (*lo*), native IT labor (*ln*), and foreign IT labor (*lf*), and estimate a five-input Translog production function:

$$\begin{aligned} v_{it} &= \alpha + \beta_c c_{it} + \beta_k k_{it} + \beta_{lo} lo_{it} + \beta_{ln} ln_{it} + \beta_{lf} lf_{it} + \beta_{cc} c_{it}^2 + \beta_{ck} c_{it} k_{it} + \beta_{clo} c_{it} lo_{it} \\ &+ \beta_{cln} c_{it} ln_{it} + \beta_{clf} c_{it} lf_{it} + \beta_{kk} k_{it}^2 + \beta_{klo} k_{it} lo_{it} + \beta_{kln} k_{it} ln_{it} + \beta_{klf} k_{lf} lf_{it} + \beta_{lolo} lo_{it}^2 \\ &+ \beta_{loln} lo_{it} ln_{it} + \beta_{lolf} lo_{it} lf_{it} + \beta_{lnln} ln_{it}^2 + \beta_{lnlf} ln_{it} lf_{it} + \beta_{lflf} lf_{it}^2 + \delta_i + \theta_t + \varepsilon \end{aligned} \quad (6)$$

We use the coefficients from Equation (6) to further estimate the AES and MES between foreign and native IT workers. Details of the estimation are available from (Dewan and Min 1997; Zhang et al. 2015).

Data

First, to examine the skill differences between foreign and native IT workers, we make use of the US Current Population Survey (CPS) and the O*NET database.

CPS is a monthly survey of more than 60,000 households conducted by the US Bureau of Labor Statistics. The CPS survey includes basic monthly surveys as well as supplementary surveys on various topics. The annual social and economic supplement (ASEC) survey is conducted in March each year. It includes more households as well as more questions related to social and economic aspect of the US population. We make use of the 2016 ASEC data in this study to assess the skill differences. We extract job code and country of birth for each employee from the data. We then use them to identify all the IT workers, as well as if they are native or foreign. The job codes of IT workers from ASEC 2016 include computer and information systems managers, computer and information research scientists, computer systems analysts, information security analysts, computer programmers, software developers, web developers, computer support specialists, database administrators, network and computer systems administrators, and computer network architects.

The O*NET database is administered by the US Department of Labor, and it documents detailed job-level information for all jobs categories. Moreover, for every job, it provides scores in the form of O*NET measurement items/dimensions. We make use of nine O*NET dimensions—three for language skill (English language, speaking, and writing), three for interactive skill (independence, persuasion, and providing consultation), and three for quantitative & analytical skill (mathematics, physics, and science). O*NET uses different job codes from CPS, and we match CPS job codes to O*NET job codes using the crosswalk provided by BLS. This way, for all the IT workers identified in 2016 ASEC, we know their job codes as well as their scores on the nine skill dimensions; thereby, we can calculate the skill scores for native and foreign IT workers respectively and further compare their differences.

Second, to assess the complementarity/substitution effect between foreign and native IT workers, we make use of the productivity data from the Bureau of Labor Statistics (BLS) website. The productivity dataset is based on the North American Industry Classification System (NAICS). Specifically, we collect data on value added (*V*), total capital stock, IT capital stock (*C*), and labor input (*L*) for 59 three-digit NAICS industries from 1993 to 2015. IT capital (*C*) is the aggregate stock of software and information processing equipment—which includes computer and peripheral equipment, communications, instruments, photocopy and related equipment, medical equipment and related equipment, electromedical instruments, and office and accounting equipment. We obtain non-IT capital (*K*) by subtracting IT capital from the total capital stock. Labor *(L)* is measured as the total cost of labor. All variables are measured in billions of constant 2009 dollars.

In order to obtain IT labor as well as native and foreign IT labor as required in Equation (5) and (6), we make use of the ASEC surveys from 1993-2015. In addition to job code and country of birth, ASEC also identifies industry code for every employee. Therefore, for each industry in each year, based on the job code, we are able to identify whether an employee belongs to IT labor, and then based on country of birth, we further identity if the employee is a native IT labor or a foreign IT labor. We then calculate the percentages of IT labor, native and foreign IT labor for every CPS industry and match the CPS industries to the NAICS-based industries through a crosswalk for each corresponding year. This is appropriate because ASEC is a national survey and its sample is representative of US population and labor force. Finally, given the labor input of each NAICS industry and the percentages of IT labor, native IT labor, and foreign IT labor, we can calculate the input cost of non-IT labor (*Lo*), IT labor (*Lt*), native IT labor (*Ln*), and foreign IT labor (*Lf*), respectively. Our final dataset is an unbalanced panel from 1993 to 2015 covering 55 industries. The detailed variable definitions are provided in Table 2.

Variables	Definitions
V	Value added; in billions of 2009 dollars.
C	IT capital, the aggregate stock of software and information processing equipment; in billions of 2009 dollars.
K	Non-IT capital, measured as the difference between total capital stock and IT capital; in billions of 2009 dollars.
L	Total labor cost, in billions of 2009 dollars.
Lo	Total cost for non-IT labor, measured as $L\times$ percentage of non-IT labor; in billions of 2009 dollars.
Lt	Total cost for IT labor, measured as $L\times$ percentage of IT labor; in billions of 2009 dollars.
Ln	Total cost for native IT labor, measured as $L\times$ percentage of native IT labor; in billions of 2009 dollars.
Lf	Total cost for foreign IT labor, measured as $L\times$ percentage of foreign IT labor; in billions of 2009 dollars.
Year	Dummy variables for calendar year from 1993–2015
Industry	Dummy variables for 55 industries

Table 2. Definition of Variables

Results

From 2016 ASEC, we identify 2,345 IT workers in total. Among them, 1,694 are native and 651 are foreign IT workers. The three skill sets and nine skill dimensions from O*NET database are listed in Table 3, together with the average scores for native and foreign IT workers respectively. It can be seen that, for *language skill* and *interactive skill*, natives are consistently higher than foreign IT workers in all dimensions.[4] On the other hand, for *quantitative & analytical skill*, foreign IT workers are consistently higher than the natives in all dimensions. We further conduct t-test and the results show the differences between foreign and native IT workers are significant ($p<0.001$) across all dimensions. These results indicate foreign and native IT workers indeed stand out with different skill sets, supporting the view that they are more likely to be complements not substitutes.

We next test the complementarity/substitution between foreign and native IT workers within the production framework. The summary statistics for variables used are presented in Table 4. Recall that we apply two different approaches for doing this: the OC approach and the ES approach. We proceed with the OC approach first.

In order to address the common issues with panel data such as heteroscedasticity and auto-correlation, we adopt the feasible least squares regression (FGLS) to estimate Equation (1)–(4), adjusting for heteroscedasticity and panel-specific AR1 structure. The main results are presented in Table 5.

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[4] The independence score for native IT workers is lower than that for foreign IT workers; this suggests native IT workers are less independent and thus more interactive than foreign IT workers as required by their work.

Skill Sets	**Skill Dimensions**	**Average Scores for Native**	**Average Scores for Foreign**	**Significance Level for t-test**
Language Skill	English Language	3.695	3.642	***
	Speaking	3.536	3.478	***
	Writing	3.417	3.375	***
Interactive Skill	Independence	3.938	3.954	***
	Persuasion	2.821	2.796	***
	Providing consultation	3.239	3.169	***
Quantitative & Analytical Skill	Mathematics	2.879	3.027	***
	Physics	1.660	1.764	***
	Science	2.437	2.567	***

Note: ***p<0.001 for t-test of skill score equality between foreign vs native IT workers.

Table 3. The Skill Differences between Foreign and Native IT Workers

Variable	**Mean**	**Std. dev.**	**Min.**	**Max.**
Value Added (*V*)	155.984	172.634	−95.499	789.373
IT Capital (*C*)	28.409	53.018	237	484.252
Non-IT Capital (*K*)	477.016	842.425	19.455	5,931.621
Non-IT Labor (*Lo*)	10.269	129.022	0	624.795
Native IT labor (*Ln*)	3.541	9.603	0	123.139
Foreign IT Labor (*Lf*)	1.001	3.777	0	63.165

Table 4. Summary Statistics (N=1,247)

	Eqn. (1)	**Eqn. (2)**	**Eqn. (3)**	**Eqn. (4)**
IT Capital (*c*)	0.049*** (0.018)	0.037** (0.017)	0.029* (0.016)	0.035** (0.016)
Non-IT Capital (*k*)	0.267*** (0.051)	0.356*** (0.049)	0.573*** (.04853)	0.559*** (0.049)
Labor (*l*)	0.436*** (0.038)			
Non-IT Labor (*lo*)		0.376*** (0.034)	0.361*** (0.034)	0.369*** (0.033)
IT Labor (*lt*)		0.007* (0.004)		
Native IT Labor (*ln*)			.01975*** (0.005)	0.026*** (0.006)
Foreign IT Labor (*lf*)			0.013*** .00404	0.010** (0.004)
Native IT Labor × Foreign IT Labor (*ln* × *lf*)				0.005** (0.002)
Industry Dummies	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes
N	1,218	1,110	718	718

Table 5. Results on the Interaction between Native and Foreign IT Labor

Our baseline results from Equation (1) with three production inputs show that IT capital, non-IT capital, and labor all have positive and significant output elasticities. In particular, a one percent increase in IT capital is associated with a 0.049% increase in value added, which is higher than that from prior IT productivity studies (e.g., (Brynjolfsson and Hitt 1996) report 0.017%), although consistent with more recent studies such as (Cheng and Nault 2012), whose estimate is about 0.055%. We interpret this comparison as IT gaining more importance during the production process in the modern business world. As a result, output has become more elastic with changes in the IT capital input over time.

Equation (2) splits the labor input into non-IT labor and IT labor. The results show that both types of labor have positive and significant contribution to value added, and that non-IT labor has a much greater output elasticity than IT labor, which could be explained by the fact that non-IT labor in general takes a much greater proportion than IT labor in terms of total labor cost.

Equation (3) further splits IT labor into native IT labor and foreign IT labor. The coefficients for both native and foreign IT labor are positive and significant, indicating their significant contribution to value added. Most importantly, in Equation (4), the interaction term between native and foreign IT labor is also positive and significant. This result indicates that native IT workers and foreign IT workers are complementary rather than substitutive. In other words, we find evidence that foreign IT workers make native IT workers' marginal contribution greater thus improving their productivity. In sum, results from Table 5 support the view that foreign and native IT labor are complements to each other.

Next, we assess the complementarity/substitution between foreign and native IT workers using the ES approach. We first estimate Equation (6) (the results are not shown due to page limitation). Using the coefficient estimates, we then estimate AES and MES, and present them in Table 6 across the three labor inputs: native IT labor (*Ln*), foreign IT labor (*Lf*), and non-IT labor (*Lo*).

Elasticity	***i=Ln*** ***j=Lf***	***i=Ln*** ***j=Lo***	***i=Lf*** ***j=Lo***
AES_{ij}	−10.393*** (2.07)	2.026*** (0.32)	3.470*** (0.53)
MES_{ij}	0.879*** (0.01)	2.061*** (0.31)	2.971*** (0.36)
MES_{ji}	0.685*** (0.04)	1.272*** (0.07)	1.261*** (0.08)

Note: Bootstrapped standard errors are in parentheses.

Table 6. Estimated AES and MES

Recall that AES_{ij} is the AES between input *i* and input *j*. Due to the symmetrical nature of AES, AES_{ij} is equal to AES_{ji}, and thus does not consider which input's price changes. MES_{ij} is the MES between input *i* and input *j* when the price of input *j* changes; MES_{ji} is the MES between the two inputs when the price of input *i* changes. Table 6 shows that AES_{ln_lf} is negative, and all the rest of the elasticity measures are positive.

To intuitively interpret the above AES and MES results, we apply Table 1 and provide the qualitative interpretations in Table 7 below, with a focus on the relationship between native and foreign IT labor input. Table 7 indicates that when the wage of native IT workers (*Ln*) changes, *Ln* is a weak complement to foreign IT workers (*Lf*): *an increase in the wage of native IT workers not only deceases the input quantity for native IT workers, but also decreases the input quantity for foreign IT workers, only at a slower rate.* When the wage of foreign IT workers (*Lf*) increases, we find largely similar result, i.e., they are also weak complements. Therefore, results from the ES approach are consistent with those from the OC approach—foreign IT workers and native IT workers are complements rather than substitutes.

Relative to / Price Change of	*Ln*	*Lf*	*Lo*
Ln		**Weak Complements**	Substitutes
Lf	**Weak Complements**		Substitutes
Lo	Substitutes	Substitutes	

Table 7. Interpretation of the AES & MES Results

Discussion and Conclusion

In this research, we explore the interaction between native and foreign IT workers—whether they are complements or substitutes. Prior literature has proposed both complementarity and substitution effect, but with little empirical evidence. We identify the differences between foreign and native IT workers in their skill sets, and further show that foreign and native IT workers are complements to each other. Our findings indicate that firms hire foreign IT workers mainly due to their skill sets, not for their lower wages. Indeed, prior literature actually show that foreign IT workers are paid higher than the natives (Lucas and Mithas 2011; Mithas and Lucas 2010). Our results show that foreign IT workers can increase the productivity of native IT workers and hiring foreign IT workers may create more job opportunities for native IT workers. We do realize limitations may exist for our study. For example, our study is conducted at industry level, and we do not observe how the skill sets from foreign and native IT workers are applied in workplace. Future studies may address these issues by collecting more granular data at firm or individual levels and possibly apply case analysis to reveal the mechanisms of complementarity between foreign and native IT workers.

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