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Impact of modern communication infrastructure on productivity, production structure and factor demands of US industries: Impact revisited

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ABSTRACT

This study investigates the contribution of modern communication infrastructure characterized by high speed broadband access network on the productivity growth, production structure and factor demands for US industries and for the aggregate economy. To evaluate such contribution, we modify the traditional cost function by incorporating communication infrastructure as input in production process in conjunction with other public infrastructures. The network externality and spillover effect of broadband access technology are captured by introducing broadband penetration rate as a shift factor in industry level production function. Empirical results show that the increased use of modern communications infrastructure increases the productivity of all industries with wide variations across industries. Estimated impacts on input demands show that increase in use of communications infrastructure service saves labor and materials and increase the demand for private capital. Finally, aggregate social rate of return on such investment has been estimated for policy implications.

1. Introduction

Existing literature on endogenous growth theory suggests that efficient transfer of knowledge and information, because of its spillover effects, is a key factor to achieve high economic growth. Rapid diffusion of existing knowledge, ideas and information helps acceleration of innovation, economic growth and structural changes in most industries in all countries at all stages of development. Modern communication infrastructure, enriched with its wired and wireless broadband features,[2] is facilitating this process in a very revolutionary way.

Since the introduction of the Internet, the World Wide Web and widespread adoption of wireless communications, accessibility of the Internet via broadband (high speed) is another revolutionary phenomenon of information and communication technology (ICT). With progressive improvement in speed and quality of broadband connections together with ongoing innovation and automation in information technology, the role of modern communication infrastructure in achieving higher rates of economic growth and development is expanding. However, building such infrastructure requires a substantial amount of investment and, therefore, a proper

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[2] According to modern endogenous growth theorists (e.g., Romer, 1990), technology should accelerate economic growth and increase productivity by facilitating a rapid diffusion of ideas and information. It also fosters the development and adoption of new products and processes.

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evaluation of the contribution of such investment is crucial for national strategic policy decisions.

Even though the contribution of communication infrastructure has been extensively evaluated by many researchers in the past, including our studies (e.g., Nadiri and Nandi, 2001; Nadiri, Nandi and Chakraborty, 2009), the nature and characteristics of such technology are changing very rapidly and quite radically. The availability of high speed fixed and mobile broadband (BB) communication technology is significantly improving the efficiency of many activities at both micro and macro economy level. It is generating strong positive impact on productivity and rapidly changing the structure of production in many industries. In the face of such a dynamic role for communication technology, it is a constant challenge for policy makers to adopt the right path to extract the maximum benefits from such technology and to minimize any adverse impacts. Therefore, continuous assessment and understanding of the effects of evolving role of communication infrastructure is critical for ongoing policy decisions, which is the primary motivation for this paper.

To conduct such a study, we first modify the traditional cost function by introducing infrastructure capitals as separate inputs in the production function. This formulation is similar to the cost model used by Nadiri and Nandi (2001) in an earlier research paper with extension of incorporating the role of broadband (BB) technology into the production process. The basic contribution of BB infrastructure capital at the disaggregate level is captured by using communication infrastructure capital as a separate input in the industry level production function. However, due to limitation of BB infrastructure data (issue is addresses in Flamm, Friedlander, Horrigan and Lehr, 2007 and Lehr, Osorio, Gillett and Sirbu, 2005),[3] we could not separate the impacts of BB vs. non-BB part of communications infrastructure [4] on production. Additionally, the current model introduces an exponential growth factor in the production function, which is a function of both 'time' (index of general purpose technological progress) and 'the BB penetration rate' (number of BB subscribers per 100 inhabitants). The rationale behind such a formulation is based on the assumption that the BB technology has the characteristics of general purpose technology (GPT),[5] a concept which is already mentioned by many researchers and is thus likely to affect the exponential growth factor. Together with other technology, this leads to an upward shift in the production function. This formulation facilitates the capture of the network externality and spillover effects of BB networks.

A cost model is estimated using data set for a panel of 41 individual US industries (excluding the communication industry) for the period that spans 1987 to 2008. The study identifies the incremental benefits from BB technology as a general purpose technology (GPT) by the type of industry, which are not already captured through the estimated contribution of communication infrastructure capital as a direct input in industry level production process.[6] A social rate of return on communication infrastructure investment is also estimated. The most important conclusion of our study is that there are sizeable differences in the impacts of communication infrastructure on productivity and production structure of various industries. The new communication technology is generally reducing demand for labor and materials and increasing the demand for capital. These impacts vary in magnitude and direction over time and across industries. *This aspect is very important for understanding the consequence of increasing use of communication infrastructure service on aggregate demand for labor, composition of labor skills and the type of capital formation*.

The present paper is organized in the following manner. Section 2 summarizes the findings of various researches in this area. Section 3 outlines the basic econometric model and Section 4 provides a short description of the data used for estimation. Estimated model parameters are reported in section 5. A summary of the industry-level estimated results is presented in section 6. The implications of these results at the aggregate economy level are discussed in section 7 together with concluding remarks in the last section.

2. Related literature

Communication infrastructure technology is highly dynamic with the possibility of generating a wide range of economic and social impacts. In the existing literature, several studies (Bebee & Gilling, 1976, Hardy, 1980, Cronin, Parker, Colleran, and Gold (1991 & 1993) and Dholakia and Harlam, 1994; Röller and Waverman, 2001) have already established the contribution of telecommunication infrastructure capital on growth and productivity. However, most of these studies did not address the network externality and spillover effects of such infrastructure. In more recent studies, a group of researchers focused on this aspect. Utilizing an input-output framework, Cronin, Colleran, Herbert, and Lewitzky (1997) reported that, though heterogeneous across industries, investment on Information and Communication Infrastructure capital generates substantial amounts of consumption and production externalities. On the other hand, by incorporating communication infrastructure capital as an input in the industry-level production function,[7] Nadiri and Nandi (2001) captured the externality effects of such networks across US industries and reported *a strong linkage* between access to such infrastructure and productivity gains.

Another branch of researchers studied the contribution of information technology and equipment to the aggregate economy

[3] The difficulties of measuring contribution of broadband infrastructure due to lack of proper data is recognized by many researchers and many of them addressed that issue in their research papers (i.e., Flamm et al., 2007; Lehr et al., 2005).

[4] This infrastructure represents all kinds of traditional and modern communications and broadcasting networks, which include Internet, wired and wireless networks and broadband access networks.

[5] see Czernich et al., 2011, OECD paper, 2008. A caveat of such formulation is that the measured contribution of BB is likely to be biased to the extent that progress/adoption of ICTs co-varies with BB penetration; however, disentangling the effects of two is difficult.

[6] To avoid bias in estimation, infrastructure capital needs to be adjusted for quality improvement. It is not an easy task with the continuous change in communications and information technology.

[7] The incorporation of infrastructure capital in the production process evolved into a standard practice in productivity literature after the pioneer work of Aschauer (1989), and Munnell (1990, 1992), Munnell and Cook, 1990, Nadiri and Mamuneas (1994) in this area.

(Bresnahan, 1986; Jorgenson and Stiroh (1995 & 1999); Morrison and Schwartz, 1996). Morrison, 1997, Stiroh (2001a, 2001b, 2002) adds to such findings by arguing that industries that are intensive in the use of ICT capital experience relatively higher productivity gains from such technology. Nadiri et al. (2009) further extend these studies by examining the benefits to industries from industry-specific ICT capital intensity as well as from the availability of accumulated ICT capitals as national ICT infrastructure. The current paper extends our previous research (Nadiri & Nandi, 2001 and Nadiri et al., 2009) by focusing on the impacts of modern communication infrastructure, enriched by innovation of BB access technology on productivity and production structure.

In the last decade, the introduction and deployment of wired and wireless BB has further enhanced the quality and features of modern communication infrastructure capital. A few early studies provide valuable insights on this topic. Important among these are studies carried out by Crandall and Jackson (2001), Katz, Zenhäuser and Suter (2008) and Lehr et al. (2005). Crandall and Jackson (2001), in a forward-looking study on BB contribution, estimated about $500 billion worth of possible economic gain as a result of ubiquitous deployment of BB, while the other study focused on policy issues. More recent studies were conducted by Crandall, Lehr, and Litan (2007) using US data, by Koutroumpis (2009), Waverman (2009), and Czernich, Falck, Kretschmer, and Woessmann (2011) using OECD data and by Katz and Suter (2009) and Qiang and Rossotto (2009) of the World Bank using data from countries with different income levels. Most of these studies found a positive impact of BB penetration on GDP growth. The estimated incremental growth rates in these studies ranges from 0.9% to 1.5% in response to a 10% increase in BB penetration rate and varies across countries according to their income levels. Regarding the impact on productivity gains, Waverman (2009) found that a 1% increase in BB penetration rate would contribute 0.13% to growth in productivity. They also found that with relatively low ICT penetration, the impact of BB is almost nil. More recent studies also found sizeable impacts of BB access technology on economic growth and some of them also estimated separately the economic impacts of fixed broadband and mobile broadband connections (Thomson and Garbacz (2011), Minges, 2016, ITU (2012), Scott (2012), Katz and Koutroumpis (2012)).

Another important current research issue is whether BB technology itself has the characteristics of general purpose technology (GPT). If so, it has the potential to fundamentally affect the entire economy and it is important to measure such effects on economy for optimum policy decision. By definition, the effect of GPT spreads throughout the economy bringing about generalized productivity gains. In present era, many have already argued that ICT is a GPT (Clarke et al., 2015; Czernich et al., 2011, Basu & Fernald, 2008) and BB as an important component of ICT, will improve the performance of ICT. However, many also argued that BB itself is a GPT as expansion of BB is bringing radical changes in our economy and the way we live. Thus, it is an important question to understand the role of BB as a GPT and how to properly measure it. Many researchers (Wallsten, 2010; Mazumder, Carare, & Chang, 2010; OECD, 2008) are devoting their studies towards it. In our current paper, we also made an attempt to understand the impact of BB technology on the supply side of the economy.

Regarding the impact of broadband in terms of job creation, Crandall, Jackson, and Singer (2003), and Shideler, Badasyan, and Taylor (2007), Crandall et al. (2007), Katz (2009), Atkinson, Castro, and Ezell (2009), and Liebenau, Atkinson, Kärrberg, Castro, and Ezell (2009), studied the total change in employment throughout the economy as a result of deployment of BB[8] and found statistically significant positive impacts. Using US data, Crandall et al. (2007) found that the growth of aggregate employment ranges from 0.2% to 0.3% per year in response to 1% increase in BB penetration rate. However, most of these studies primarily focused on the deployment effect of BB on employment rather than the substitution effect of BB on labor demand. More recently, a few studies, such as Thompson and Garbacz (2008) and MICUS (2008), addressed this issue. MICUS reported job losses across 27 countries of European Union (EU27) due to the substitution effects of increased use of BB infrastructure. According to their report, even though BB deployment created a substantial amount of new jobs in EU27 countries, equally strong negative substitution effects associated with increased use of BB infrastructure resulted in an insignificant net positive impact on jobs creation. In our current study, we analyzed the industry level substitution effect of modern communication infrastructure on factor demands and evaluated the net impacts on factor demands at the industry as well as at the aggregate economy level.

3. Analytical model

With the recognition that the national infrastructure capital plays a significant role in enhancing productivity and growth, Nadiri and Nandi (2001) and Nadiri et al. (2009) introduced in their studies an augmented cost function that incorporates both public infrastructure capital and communication infrastructure capital as separate inputs in production. In the current study, we use a similar cost model[9] and consider both types of infrastructure capital as 'unpaid' factors of production.

The sources of funding for public infrastructure capital are taxes and long-term government debt, which will eventually be paid for by future taxes. Governments provide such infrastructure services either free of charge or ask for a small user fee. For communication infrastructure capital, the source of finance is the communication firms themselves and they recoup these expenses by charging their customers for the services rendered. Thus, each industry (as well as each individual) incurs some expense for telecommunication services, which is included as a part of the material cost. However, in addition, each industry in the private sector receives externality benefits in terms of additional efficiency gains from the expansion and modernization of national communication

[8] They estimated the direct impact of BB construction on job creation as well as the multiplier effects of BB deployment though its indirect impact on expansion and employment in various industries. Most of these studies relied on input-output tables to calculate the multiplier effects of BB deployment.

[9] We divided industry-specific capital into ICT and non-ICT capital in our 2009 paper and explained the dual role of ICT capital (as private input and as national infrastructure capital). In this paper, to avoid data complications, we did not follow the same structure as in 2009 but rather followed the one used in the 2001 paper as focus of current paper is to study the impact of ICT as infrastructure. In this formulation, private capital will capture the interaction effect of ICT capital intensity and communication infrastructure but will not be able to explain specifically the contribution of ICT intensity in this process.

infrastructure. For these kinds of efficiency gains, industries do not pay any fee[10] directly, which reflects the public good aspect of communication infrastructure.

The current study extends the previous model (Nadiri and Nandi, 2001, Nadiri et al., 2009) by incorporating the role of broadband (BB) technology into the production process. It introduces an exponential growth factor in the production function, which is a function of both 'time' (index of general purpose technological progress) and 'the BB penetration rate[11] (number of BB subscribers per 100 inhabitants).

The general form of the cost function used in the estimation is as follows:

$$C = C(\mathbf{q}, Y, S_1, S_2, T, BB) \tag{1}$$

where the variables included on the right hand side are interpreted as follow:

q: the vector of input prices including those for labor (L), capital (K) and Material (M).
Y: Output quantity
S_1: The flow of services from telecommunication infrastructure capital
S_2: The flow of services from public infrastructure capital
T: Time index representing disembodied technical change
BB: Broadband penetration rate per 100 populations, which can be interpreted as an index of the availability and use of broadband access technology over time

Though S_1 and S_2 are treated as unpaid factors of production, their shadow price (or willingness to pay) can be determined. These shadow values are measured by the potential savings in costs due to the marginal increase in the use of infrastructure capital. These shadow price or cost savings can be defined to be the negative of the partial derivative of the cost function (1) with respect to S_1 and S_2 as:

$$MBS_{Si} = -\partial C/\partial S_i, \quad i = 1,2 \tag{2}$$

where MBS_1 and MBS_2 can be defined as marginal benefits derived from communication infrastructure capital S_1 and public infrastructure capital S_2 respectively. Following a similar process, we estimate the cost savings derived from a one unit increase in BB penetration, defined as the marginal benefit from BB penetration (MBBB) as:

$$MBBB = -\partial C/\partial BB \tag{3}$$

In addition to the direct productivity effect of infrastructure capital, there are factor demand adjustment effects that arise due to complementarity or substitutability between private inputs L, M and K on the one hand and infrastructure capital services S_1 and S_2 on the other. These effects are calculated as:

$$\partial X_i/\partial S_j \quad \text{for } i = L, M, K \text{ and } j = 1, 2 \tag{4}$$

where X_i is the quantity of input i and S_j is the size of infrastructure j where j = 1,2.

Based on whether the outcomes for the left-hand-side variables in equation (4) are less than, equal to or greater than zero, the infrastructure impact on input demand can be defined as factor saving, factor neutral or factor using.

Using model parameters, we also estimate few other critical cost elasticities, which are required to measure the impacts of two types of infrastructure capital on cost structure, output growth and input demands. These elasticities are as follows:

i. Cost elasticity with respect to S_i:

$$\eta_{CSi} = -\left(\frac{\delta C}{\delta Si}\right)\left(\frac{Si}{C}\right) \text{ for } i = 1,2$$

ii. Cost elasticity with respect to output Y holding the use of S_1 and S_2 constant:

$$\eta = -\left(\frac{\delta C}{\delta Y}\right)\left(\frac{Y}{C}\right)$$

iii. Cost elasticity of output when use of input S_1 is allowed to change:

$$\eta_{s1} = \eta/(1 - \eta_{CS1})$$

iv. Cost elasticity when both inputs S_1 and S_2 are allowed to change:

$$\eta* = \eta/(1 - \eta_{CS1} - \eta_{CS2})$$

[10] ICT innovation could take place in the government sector but most of the application and deployment is done by the private sector and, once the infrastructure is there, one can enjoy the externality benefits without any direct payment.

[11] According to our data, BB infrastructure capital is a part of modern communication infrastructure capital stock. BB penetration rate is used as a *shift factor* in the industry-level production function to capture the incremental benefits from BB technology that are not captured by the estimates of contribution of communication infrastructure capital.

The inverse forms of the above three cost elasticities (ii to iv) with respect to output (1/η, 1/ηs$_1$, 1/η*) can be interpreted as returns to scale under the respective conditions.

The specific form of the cost model referred in (1) used for empirical estimation is the following normalized translog cost function:

$$\begin{aligned}\ln\left(\frac{C}{P_M}\right) &= \alpha_0 + \sum_i \alpha_i \ln \widetilde{p}_i + \alpha_Y \ln Y + \alpha_G \ln(S_1^{\theta}\cdot S_2^{1-\theta}) + \alpha_N (T + \lambda BB)\\ &+ \frac{1}{2}\{\sum_i \alpha_{ii} \ln \widetilde{p}_i^2 + \alpha_{YY} \ln Y^2 + \alpha_{GG} \ln(S_1^{\theta}\cdot S_2^{1-\theta})^2 + \alpha_{NN}(T + \lambda BB)^2\}\\ &+ \sum_i \alpha_{Yi} \ln \widetilde{p}_i \ln Y + \alpha_{YG} \ln Y \ln(S_1^{\theta}\cdot S_2^{1-\theta}) + \alpha_{YN} \ln Y\cdot(T + \lambda BB)\\ &+ \sum_{i\neq j} \alpha_{ij} \ln \widetilde{p}_i \ln \widetilde{p}_j + \sum_i \alpha_{iG} \ln \widetilde{p}_i \ln(S_1^{\theta}\cdot S_2^{1-\theta}) + \sum_i \alpha_{iN} \ln \widetilde{p}_i\cdot(T + \lambda BB)\\ &+ \alpha_{GN} \ln(S_1^{\theta}\cdot S_2^{1-\theta})\cdot(T + \lambda BB)\end{aligned} \tag{5}$$

for$i, j = L, K$.

T+ λBB is the shift factor in the production function, where the first term T is the index of all general technological progress and the second term captures the impact of broadband penetration. C refers to total production cost while (C/P_M) is the normalized total cost in terms of material input. $\widetilde{P}_L = (P_L/P_M)$and $\widetilde{P}_K = (P_K/P_M)$are the relative prices of the factors factor labor and capital respectively. The total production cost (C) is computed using the following equation: $C = P_L L + P_M M + P_K K$, where P_K is the rental price of (K). The variable Y in the cost function (5) is the industry level output. S_1 and S_2 are the levels of total communication infrastructure and public infrastructure capital services respectively. We assume that the two types of infrastructure capital, S_1 and S_2, are complementary to each other. Therefore, we add a binding relation, $G = S_1^{\theta} S_2^{1-\theta}$. In the estimation of the model, we used an industry-specific utilization rate as an index for adjusting the stocks of the two types of infrastructure capital.[12] T in the equation refers to an index of technical change and BB represents the broadband penetration rate per 100 populations, which varies over time.

Using Shepherd's Lemma, the cost-share (share in variable cost) equations for labor, material and capital (Diewart, 1974) are obtained by taking logarithmic derivatives of the cost function with respect to the corresponding input price:

$$\text{Si} = \text{qi Xi}/\text{ C}= \frac{\partial \ln\left(\frac{C}{P_m}\right)}{\partial ln P_i} \quad \text{for } i = L, M, K \tag{6}$$

These factor-share equations characterize the equilibrium conditions for the variable factors of production. The two specific factor-share equations of interest are:

$$S_L = \alpha_L + \alpha_{LL} \ln \widetilde{P}_L + \alpha_{LK} \ln \widetilde{P}_K + \alpha_{LG} \ln(S_1^{\theta} S_2^{1-\theta}) + \alpha_{YL} \ln Y + \alpha_{LN}.\ (T + \lambda BB) \tag{7}$$

$$S_K = \alpha_K + \alpha_{LK} \ln \widetilde{P}_L + \alpha_{KK} \ln \widetilde{P}_K + \alpha_{K1G} \ln(S_1^{\theta} S_2^{1-\theta}) + \alpha_{YK} \ln Y + \alpha_{KN}\cdot(T + \lambda BB) \tag{8}$$

where S_L, S_K are the cost shares of labor and capitals respectively. The share of the material input is determined by:

$$S_M = 1 - \sum_{i\neq M} S_i \quad i = L, K$$

As reflected by equations (7) and (8), the input shares in each industry are not only dependent on the relative prices of inputs and technical change, but also on publicly- and privately-financed infrastructure capital and BB penetration.

On the other hand, by applying the profit maximization condition, we derive the revenue share equation (Fuss and Waverman, 1978). The revenue-share equation representing the output market equilibrium condition is given by:

$$S_Y = \alpha_Y + \alpha_{YY} \ln Y + \alpha_{YL} \ln \widetilde{P}_L + \alpha_{YK} \ln \widehat{P_K} + \alpha_{YG} \ln(S_1^{\theta} S_2^{1-\theta}) + \alpha_{YN}.\ (T + +\lambda BB) \tag{9}$$

4. Data

The model described in the previous section is estimated using data for 41 US industries covering the period 1987–2008.[13] The industry grouping is derived from detailed classifications of industries under the new classification codes of North American Industry Classification System (NAICS) (introduced in 2000) and is described in the appendix (see Table-A1 in appendix).

The nominal values of chain-type price indices, gross output and intermediate inputs for different industries are obtained from the data section for Gross Domestic Product by Industry Account published by the Bureau of Economic Analysis. The number of full-time-equivalent employees is used as the quantity of labor. The wage index is constructed by dividing compensation of employees by the number of full-time-equivalent employees.

Capital input data, which is the service flows for equipment, structure and other kinds of capital assets and the corresponding rental price for each industry, are obtained from capital data published by Division of Major Sector Productivity, Bureau of Labor

[12] In principle, each input, including the communications capital stock, should be adjusted by input-specific utilization rates. However, data limitations preclude such an option.

[13] Final time series data preparation involved very complicated data processing and data integration to accommodate changes in the classification codes and the structure of other data. This precluded us from extending the time series easily in the later part of our research.

Statistics (BLS, U.S. Department of labor). These capital input data, productive capital stock and the rental price information[14] are obtained at the NAICS 3-digit industry level and the necessary aggregation is performed using appropriate weights to match the data with our industry classifications.

To capture the effect of communication infrastructure and public infrastructure capitals on production cost, we use the annual data for net capital stock of the communications industry as well as the net capital stock of nonresidential government physical capital from the Bureau of Economic Analysis (BEA, U.S. Department of Commerce) database. For public infrastructure capital, annual data series for total non-residential net government physical capital stock were created by summing federal, state and local net capital stock of structure and equipment, excluding defense-related capital stocks. Federal structures include industrial, educational, hospital and other buildings, highways constructions and other structures. State and local structures include educational, hospital and other buildings, highways and streets, constructions and development and other structures. Broadband penetration data for US economy for the period 1998–2008 were obtained from International Telecommunication Union Database (ITU-World Telecommunication/ICT Indicator, 2009). Broadband Penetration rate is estimated using both fixed broadband subscribers count and mobile broadband subscribers count per 100 inhabitants. The data on capacity utilization by year were obtained from Federal Reserve Statistical Release published by Federal Reserve Board in March, 2011.

5. Results of the estimation

The model is non-linear in parameters and variables and is therefore estimated by the non-linear Least Square method. We estimate the translog cost function (5) jointly with the factor-share equations shown in (7 & 8) and the revenue-share equation shown in (9). An important assumption underlying the system of equations is that both public infrastructure services and private communications infrastructure services are exogenous to the production process across industries.[15] Exogeneity of the latter infrastructure makes it necessary for us to exclude the communications industry from our panel data. Accordingly, we exclude cost and share equations for the communications industry and estimate the parameters of interest for the remaining 41 industries. Since the focus of this study is to analyze the impact of communications and broadband infrastructure on private sectors of the US economy, we do not report in detail the impact of public infrastructure capital on the productivity and structure of production of industries.

The primary parameter estimates are reported in Table 1. As is reflected in Table 1, the estimated model satisfies all the regularity conditions. Cost functions are non-decreasing in output, linearly homogeneous in input prices, and concave with respect to changes in prices. The estimates of the parameters together with many of the industry dummy variables are statistically significant. This is indicative of differences in the cost structure across industries. It is interesting to note the standard errors for all the equations are small.

6. Impacts at the industry level

6.1. Benefits from communication infrastructure

To estimate the direct productivity effect of the communication infrastructure capital at the industry level, we estimate the cost elasticity $\eta_{CS1} = (\partial C/\partial S_1)\ (S_1/C)$ with respect to communication infrastructure capital services, S_1, for each industry using the estimates of model parameters.[16] These elasticities are negative for all industries, which imply that an increase in use of communication infrastructure capital services reduces the cost in all 41 industries, including industries in manufacturing and non-manufacturing sectors.[17] The magnitude of the cost elasticity (η_{CS1}) with respect to the communication infrastructure capital for the period 1987–2008 varies across industries from (−0.0158) to (−0.0217**).** If we compare these results with those obtained by Nadiri and Nandi (2001) in their earlier paper, we observe a sizeable difference in magnitude of productivity gains from use of communication infrastructure in recent years. The previous study reported a range of estimated average cost elasticities across industries of −0.0084 to −0.0104 for the sample period of 1950–1991. Thus, the range of current negative cost elasticities or the cost saving effects of communication infrastructure capital of this study is significantly larger than the estimated savings effects obtained in the previous study. These extra productivity gains at the industry level can be attributed to the improved quality and expansion of modern communication infrastructure networks.

Using the estimates of industry level marginal cost elasticities, we compute the marginal benefits derived from communication infrastructure services, S_1, for each industry. The respective formula ($MBS_1 = -\partial C/\partial S_1$) is given by equation (2), which is the negative of the partial derivative of cost function (5) with respect to infrastructure capital S_1. We measure this for each industry i by using the following expression:

[14] Complete information on the methods and data underlying these measures of all capital-related variables can be found from the Division of Multifactor Productivity of the Bureau of Labor Statistics.

[15] While this assumption is legitimate for publicly funded infrastructure service, it is not appropriate for privately-funded communication infrastructure services. However, for ease of estimation, we limit the scope of this study by considering communications services as exogenous to the system of equations.

[16] In terms of parameters of equation (5), cost elasticity for industry i with respect to communication infrastructure S_1 is given by: $\eta_{CiS1} = (\partial C^i/\partial S_1)(S_1/C^i) = \theta\{\alpha_G + \alpha_{GG}\ln(S_1^{\vartheta} S_2^{1-\vartheta}) + \alpha_{YG}\ln Y_i + \alpha_{LG}\ln\widetilde{P}_L + \alpha_{KG}\ln\widetilde{P}_K + \alpha_{GN}.\ (T + +\lambda BB)\}$.

[17] The small magnitudes of these benefits are partly due to the relatively small ratio of industry cost to the size of telecommunication infrastructure capital stock (see Nadiri & Mamuneas, 1994 for further explanations).

Table 1
Estimation of cost function (time period: 1987–2008).

Parameters	Estimate	Standard Errors	T-Statistics
α_G	−0.18125	0.03838	−4.72139
α_Y	0.61835	0.05118	12.08280
α_0	3.06821	0.36766	8.34535
α_T	−0.02382	0.00731	−3.18498
α_L	0.79375	0.14178	5.59863
α_{BB}	0.00901	0.00486	1.85397
α_{LL}	0.08187	0.00485	16.88780
α_{KK}	−0.00156	0.00159	−0.97766
α_{YY}	0.04727	0.00723	6.53610
α_{YL}	−0.07244	0.00606	−11.96170
α_{YK}	−0.03169	0.00332	−9.53786
α_{YT}	0.00425	0.00097	4.36558
α_{LK}	0.00025	0.00178	0.14292
α_{LT}	−0.00084	0.00053	−1.59464
α_{LG}	0.01317	0.01484	0.88714
α_{KG}	0.03170	0.00312	10.15810
λ	0.00901	0.00486	1.85397
Equation	Standard Error	R^2	D-W
Total Cost	.0.05537	0.99674	1.33718
Labor-Share	0.01267	0.99326	1.77976
Capital-Share	0.00872	0.99014	1.43546
Output Share	0.04959	0.98598	1.34535

$$MBS_1{}^i = -\partial C^i/\partial S_1 = (\eta_{CiS1} * (C^i/ S_1)\ i = 1 \text{ to } 41. \tag{10}$$

This expression suggests that the marginal benefit of communication infrastructure capital, S_1, is expressed in terms of cost reduction. The magnitude of the marginal benefit depends on the ratio of the industry's cost to the size of its infrastructure capital stock (C^i/S_1). Other factors that determine the magnitude of the marginal benefit for each industry are the level of output Y_i, the value of θ and the relative input prices of labor, capital and materials. The stocks of communication infrastructure capital S_1 and public infrastructure capital S_2 and the level of general technology.

In column 3 of Table 2 we report the industry-level average marginal benefits (MBS_1) with respond to the communication infrastructure services S_1 in real terms (i.e. in terms of material price) over the sample period. These marginal benefits indicate how much each industry is willing to pay for an additional unit of communication infrastructure capital services. Marginal benefit estimates are positive for all industries. However, the magnitude of the benefit varies considerably across industries depending on the nature of the industry.

A low rate of MBS_1 is observed in Motion Picture and Sound Recording (27), Apparel, Leather and Allied Products (17), Furniture (13), Information and Data Processing (29) and Textile Mill Products (16). The magnitude of MBS_1 is mainly high for the industries in service sector. The top five industries with high MBS_1 are: Other Services (42, a group of service industries), Health and Social Associates (39), Construction (4), Bank, Fund, Security (30) and Retail Trade (24).

When we compare these results with those obtained in Nadiri and Nandi (2001), we find that the difference between the two studies is related to the changing pattern of the magnitude of marginal benefits across industries. For most of the industries in the manufacturing sector, the magnitude of the marginal benefit remained the same over the two study periods. However, for a small set of industries in the manufacturing sector, magnitudes of the marginal benefit doubled or more than doubled over the years. Important among these industries are Mining, Construction, Petroleum and chemical industries. In the service sector, for Banking and Insurance (Industry codes 30–32) and trade (industry codes 23–24); the magnitudes of the marginal benefit remained pretty much the same. However, interestingly, we find that, in addition to Health and Social Assistance service, a new group of service industries has been experiencing a higher level of marginal benefit from communication infrastructure capital in recent years. These industries are Accommodation and food service (41) and Technical Service (35). The growth of such a group of service industries in recent years could be the result of availability of an improved quality of ICT service.

6.2. Benefits from broadband penetration

The incremental benefit received from BB penetration rate is estimated by introducing a shift factor in the cost function of each industry, which varies with BB penetration. We then estimate the cost-saving benefits due to increase in BB penetration rate by using proper model parameters. The marginal benefits derived from BB penetration (MBBB) at the industry level are reported in column 4 of Table 2. The results show that the magnitudes of the marginal benefits again appeared to be high for service industries. The estimated benefits show that all industries exhibit some scope for saving cost by increasing their use of BB services. However, the

Table 2
Marginal benefit from communications infrastructure (MB_{S1}) & broadband penetration (MB_{BB}): Mean values: 1987–2008.

Industry Code	Industry Title	MB_{S1}	MB_{BB}
1	Agriculture, forestry, fishing	0.00658	0.05426
2	Mining	0.00917	0.07387
3	Utilities	0.00851	0.08701
4	Construction	0.02349	0.21662
5	Lumber and Wood Products	0.00249	0.02208
6	Stone, Clay, glass	0.00264	0.02193
7	Primary Metals	0.00584	0.04198
8	Fabricated Metal	0.00689	0.06001
9	Industrial machinery, equipment	0.00672	0.06060
10	Computer and electronic equipment	0.00864	0.08945
11	Electrical equipment	0.00264	0.02361
12	Transportation equipment	0.01574	0.14035
13	Furnitures	0.00184	0.01593
14	Misc. manufacturing	0.00307	0.02701
15	Food and beverage and tobacco products	0.01546	0.12760
16	Textile Mill Products	0.00248	0.01608
17	Apparel and leather and allied products	0.00179	0.00969
18	Paper and allied	0.00446	0.03406
19	Printing, Publishing and allied	0.00242	0.02190
20	Petroleum and Coal Products	0.01252	0.09270
21	Chemicals	0.01254	0.11429
22	Rubber and misc plastics	0.00445	0.04052
23	Wholesale trade	0.01608	0.17209
24	Retail trade	0.02050	0.19645
25	Transportation and warehousing Services	0.01541	0.14286
26	Publishing	0.00614	0.05994
27	Motion picture and sound recording industries	0.00196	0.01682
28	Communications	NA	NA
29	Information and data processing services	0.00173	0.02206
30	Bank, funds, Security	0.01925	0.23643
31	Insurance	0.01117	0.09842
32	Real estate	0.01671	0.17190
33	Rental and leasing services	0.00296	0.04266
34	Legal Services	0.00391	0.03540
35	Technical Services	0.01588	0.18650
36	Management	0.00599	0.06472
37	Administrative and waste management services	0.00914	0.10685
38	Educational Services	0.00407	0.03632
39	Health and Social Assistance	0.02478	0.26018
40	Arts, entertainment, and recreation	0.00294	0.03178
41	Accommodation and food services	0.01303	0.11677
42	Other Services	0.04858	0.41785

FN: MB_{S1}: Impact of 1% change in usage of communications infrastructure service & MB_{BB}: Impact of 1% increase in broadband penetration at the national level. Industry 42 represents summary benefit for a group of service industries.

scope for increasing the productivity in Health service industry and Bank and related financial service industries is significantly higher than in other industries.[18] The top five industries with high MBBB are: Other Service (42), Health and Social Assistance (39), Bank, Fund and Security (30), Construction (4) and Retail Trade (24). This suggests that industries that need more information to communicate as a part of their production process will benefit more from an increase in BB penetration.

6.3. Trend in marginal benefits

Table 3 and Table 4 show the industry-level mean values of marginal benefits derived from communication infrastructure for the period 1987–2008 and that for BB deployment for the period 1999–2008. Similar estimates are also shown for sub-periods in each table. If we compare the mean value of marginal benefits in pre- and post-2005 period for both communication infrastructure services and BB access service, we see that, for communication infrastructure services, even though cost savings are positive for most of the industries, the magnitude of the savings has declined significantly in post-2005 period, which is reflected in the magnitude of 'Ratio' being less than 1 in Table 3. However, the marginal benefits from BB penetration have increased for many industries in post-2005 period with the magnitude of 'Ratio' being greater than 1 in Table 4. Thus, the observed phenomenon indicates that the scope for

[18] It is expected that Health industry will be able to realize more productivity gains with the increasing innovation of various wireless devices capable of monitoring various health conditions and transmitting the information to doctors or health professionals in real time for better treatments.

Table 3
Trend in marginal benefits derived from communications infrastructure (MBS_1).

Industry Number	Industry title	1987–1998 Mean Values	1999–2004 Mean Values	2005–2008 Mean Values	1999–2004 to 2005–2008	
					Ratio*	Change
1	Agriculture, forestry, fishing	0.00770	0.00543	0.00495	0.91288	−0.00047
2	Mining	0.01099	0.00703	0.00692	0.98555	−0.00010
3	Utilities	0.00921	0.00847	0.00644	0.76006	−0.00203
4	Construction	0.02572	0.02116	0.02028	0.95826	−0.00088
5	Lumber and Wood Products	0.00276	0.00221	0.00210	0.95351	−0.00010
6	Stone, Clay, glass	0.00308	0.00212	0.00207	0.97437	−0.00005
7	Primary Metals	0.00723	0.00445	0.00376	0.84425	−0.00069
8	Fabricated Metal	0.00786	0.00591	0.00543	0.91788	−0.00049
9	Industrial machinery, equipment	0.00746	0.00596	0.00565	0.94792	−0.00031
10	Computer and electronic equipment	0.00761	0.01128	0.00777	0.68865	−0.00351
11	Electrical equipment	0.00301	0.00239	0.00192	0.80623	−0.00046
12	Transportation equipment	0.01759	0.01399	0.01282	0.91612	−0.00117
13	Furniture	0.00207	0.00165	0.00144	0.87498	−0.00021
14	Misc. manufacturing	0.00346	0.00267	0.00249	0.93479	−0.00017
15	Food, beverage and tobacco products	0.01839	0.01208	0.01175	0.97218	−0.00034
16	Textile Mill Products	0.00319	0.00188	0.00124	0.66017	−0.00064
17	Apparel and leather and allied products	0.00248	0.00121	0.00060	0.49688	−0.00061
18	Paper and allied	0.00547	0.00351	0.00285	0.81290	−0.00066
19	Printing, Publishing and allied	0.00269	0.00222	0.00188	0.84609	−0.00034
20	Petroleum and Coal Products	0.01557	0.00916	0.00841	0.91780	−0.00075
21	Chemicals	0.01416	0.01092	0.01009	0.92391	−0.00083
22	Rubber and misc. plastics	0.00498	0.00401	0.00354	0.88326	−0.00047
23	Wholesale trade	0.01590	0.01578	0.01709	1.08348	0.00132
24	Retail trade	0.02195	0.01880	0.01872	0.99581	−0.00008
25	Transportation and warehousing Services	0.01697	0.01400	0.01287	0.91951	−0.00113
26	Publishing	0.00611	0.00637	0.00586	0.92027	−0.00051
27	Motion picture and sound recording industries	0.00136	0.00222	0.00211	0.95457	−0.00010
28	Communications	NA	NA	NA	NA	NA
29	Information and data processing services	0.00219	0.00175	0.00157	0.89462	−0.00018
30	Bank, Funds, Security	0.01622	0.02161	0.02480	1.14766	0.00319
31	Insurance	0.01255	0.00925	0.00989	1.06880	0.00064
32	Real estate	0.01670	0.01522	0.01897	1.24678	0.00376
33	Rental and leasing services	0.00218	0.00331	0.00478	1.44194	0.00146
34	Legal Services	0.00431	0.00352	0.00328	0.93279	−0.00024
35	Technical Services	0.01425	0.01714	0.01889	1.10212	0.00175
36	Management	0.00602	0.00570	0.00633	1.11167	0.00064
37	Administrative and waste management services	0.00825	0.00999	0.01054	1.05542	0.00055
38	Educational Services	0.00455	0.00356	0.00339	0.95214	−0.00017
39	Health and Social Assistance	0.02479	0.02390	0.02608	1.09143	0.00218
40	Arts, entertainment, and recreation	0.00289	0.00294	0.00309	1.04894	0.00014
41	Accommodation and food services	0.01452	0.01126	0.01118	0.99263	−0.00008
42	Other Services	0.05607	0.03985	0.03922	0.98422	−0.00063

Note: Ratio > 1 implies increasing trend in Marginal Benefits in post 2005 period.

increasing productivity by increased use of BB technology is still quite high and is rising over time. The most likely reason for this is that the potential benefits from the application of wireless broadband are increasing people's ability to perform a variety of work from any location and from any state: mobile or static. The post-2005 period is the time when BB penetration started to increase faster than before and industries received more benefits from BB due to expanded connectivity, which enhanced the network externality effect and spillover effect of BB across various industries. In the future, by using richer data for BB infrastructure capital, such results can be verified further.

6.4. Impacts on factor demand and production structure

The use of communication infrastructure capital can influence the industry demand for primary inputs in two ways. The first effect is the 'substitution or complementary effect' of infrastructure capital on the demand for their inputs. The direction and magnitude of this effect depend on the substitution or complementarity embedded in the production structure of the industry. The

Table 4
Trend in marginal benefits derived from broadband networks.

Industry no.	Industry title	1999–2004	2005–2008	1999–2004 to 2005–2008 (Ratio* & Change)	
1	Agriculture, forestry, fishing	0.05463	0.05369	0.98284	−0.00094
2	Mining	0.07156	0.07734	1.08078	0.00578
3	Utilities	0.09593	0.07363	0.76761	−0.02229
4	Construction	0.21484	0.21928	1.02065	0.00444
5	Lumber and Wood Products	0.02185	0.02242	1.02642	0.00058
6	Stone, Clay, glass	0.02180	0.02214	1.01582	0.00034
7	Primary Metals	0.04279	0.04077	0.95266	−0.00203
8	Fabricated Metal	0.06019	0.05973	0.99238	−0.00046
9	Industrial machinery, equipment	0.05922	0.06267	1.05826	0.00345
10	Computer and electronic equipment	0.08969	0.08910	0.99335	−0.00060
11	Electrical equipment	0.02475	0.02191	0.88546	−0.00283
12	Transportation equipment	0.14013	0.14069	1.00399	0.00056
13	Furniture	0.01621	0.01551	0.95650	−0.00071
14	Misc. manufacturing	0.02641	0.02790	1.05649	0.00149
15	Food, beverage and tobacco products	0.12642	0.12937	1.02332	0.00295
16	Textile Mill Products	0.01798	0.01323	0.73561	−0.00475
17	Apparel and leather and allied products	0.01175	0.00660	0.56189	−0.00515
18	Paper and allied	0.03543	0.03202	0.90379	−0.00341
19	Printing, Publishing and allied	0.02271	0.02070	0.91147	−0.00201
20	Petroleum and Coal Products	0.09721	0.08592	0.88389	−0.01129
21	Chemicals	0.11576	0.11207	0.96806	−0.00370
22	Rubber and misc. plastics	0.04156	0.03895	0.93718	−0.00261
23	Wholesale trade	0.16000	0.19022	1.18889	0.03022
24	Retail trade	0.18962	0.20669	1.09000	0.01707
25	Transportation and warehousing Services	0.14408	0.14102	0.97871	−0.00307
26	Publishing industries	0.05816	0.06261	1.07639	0.00444
27	Motion picture and sound recording industries	0.02116	0.02339	1.10537	0.00223
28	Communications	0.00000	0.00000	0.00000	0.00000
29	Information and data processing services	0.01650	0.01729	1.04816	0.00079
30	Bank, funds, Security	0.21122	0.27424	1.29834	0.06302
31	Insurance	0.09086	0.10976	1.20797	0.01890
32	Real estate	0.15319	0.19997	1.30536	0.04678
33	Rental and leasing services	0.03550	0.05340	1.50413	0.01790
34	Legal Services	0.03464	0.03653	1.05457	0.00189
35	Technical Services	0.17082	0.21004	1.22960	0.03922
36	Management	0.06064	0.07086	1.16849	0.01022
37	Administrative and waste management services	0.10090	0.11578	1.14749	0.01488
38	Educational Services	0.03533	0.03779	1.06962	0.00246
39	Health and Social Assistance	0.24136	0.28841	1.19494	0.04705
40	Arts, entertainment, and recreation	0.03003	0.03441	1.14575	0.00438
41	Accommodation and food services	0.11227	0.12352	1.10016	0.01124
42	Other Services	0.40522	0.43679	1.07791	0.03157

Note: Ratio > 1 implies increasing trend in Marginal Benefits in post 2005 period.

second effect is known as the 'output expansion effect', which is derived from the cost-savings (or productivity gains) effects of an increase in communications infrastructure.[19] The net effect on factor demand depends on the combined effect of the above two effects, which in turn changes the industry production structure[20]. The elasticities of factor demand at the economy level are obtained by aggregating the industry-level elasticity estimates using appropriate weights. (Industry level cost elasticities and conditional input demand from communications infrastructure are summarized in Table A2).

6.5. Impact on demand for labor input

The effect of the communication infrastructure services appears to be labor saving for all industries with variable effects across industries. The estimated elasticities of substitution between labor and communication infrastructure services range from −0.0031 to – 0.0165 across industries, with relatively larger magnitudes for service industries. We organized all industries into 3 groups (see Table A3.1 in appendix) of equal size, where industries are ranked by the magnitude of the substitution effect (high negative to positive values of substitution elasticities) between labor and communication infrastructure capital. Industries in Group 1 are

[19] If private inputs are substitute for infrastructure capital, then an increase in use of such infrastructure capital is always cost saving.

[20] We estimate the net effect on demand for factor j in industry i as: $\eta^i_{js1} = \eta_{ijS1} + \eta_{ijYi} * \eta_{YiS1}$ for j = L.M, K where in R.H.S., η_{ijS1}(substitution/complementary effect) = $\propto_{jG} \frac{1}{S_{ij}} + \eta_{CiS1}$ and second term represents the 'output expansion effect' which consists of: η_{ijYi} (factor demand elasticity with respected to Yi) = $\propto_{jYi} \frac{1}{S_{ij}} + \eta_{CiS1}$ and η_{YiS1}(increase in Y_i due to cost reduction effect of infrastructure S_1) = .– η_{CiS1}/η_i.

associated with relatively higher magnitudes of the substitution effect between labor and communication infrastructure capital (the average elasticity of substitution is about −0.0153 and thus reduces the demand for labor to produce a fixed amount of output. These industries are primarily service industries. In Group 2, industries are associated with a moderate substitution effect on labor demand (the average elasticity of substitution is about −0.0136 and consists of both manufacturing and service industries. In Group 3, industries are associated with a relatively lower substitution effect on labor demand (the average elasticity of substitution is about −0.0098 and are primarily manufacturing industries.

Even though the pure substitution effect (holding output fixed) had negative value for all industries, when we take into account the 'output expansion effect' of communications infrastructure, we find that for a sub-section of industries in each of the 3 groups, the positive output expansion effect exceeds negative substitution effect and results in a net positive effect on labor demand. These sub-sections of industries belong primarily to the service sector (Kolko, 2011)[21] and are listed below.

Group	Industry Name
1	Health and Social Assistance (ID = 39)
1	Retail trade (ID = 24)
1	Technical Services (ID = 35)
1	Wholesale trade (ID = 23)
2	Administrative and waste management services (ID = 37)
2	Bank, funds, Security (ID = 30)
2	Construction (ID = 4)
2	Management (ID = 36)
2	Transportation and warehousing Services (ID = 25)
3	Chemicals (ID = 21)
3	Real estate (ID = 32)
3	Rental and leasing services (ID = 33)
3	Utilities (ID = 3)

For the remainder of the industries, the negative substitution effect is stronger than the output expansion effect resulting in net reduction in labor demand. Thus, our analysis shows that, apart from a few growing service industries, the negative substitution effect exceeds the positive output expansion effect, which generates net savings in labor costs by reducing the demand for labor in private sector. All these results are summarized in Table 5 below.

By summarizing the results across all industries, we find that an increase of 1% in the use of communication infrastructure services accounts for a ***reduction*** in demand for labor by about 0.00023% in private sectors of the economy (excluding communication industry sector).[22] This result differs from the findings of Nadiri et al. (2009), where it was reported that the net effect on producer demand for labor in private sector ***increased by*** 0.0095% for an increase of 1% use of communication infrastructure services. Even though the magnitude of the net negative elasticity of demand for labor at the aggregate level is not very high in the current study, with more recent data, this magnitude could change. The more efficient is the modern communications system, the more job loss is a possibility with the existing skill set. This could result in less employment growth in the economy which is a cause for concern. Many researchers[23] have already expressed their concerns about such a net negative or zero effect of modern communication infrastructure on labor demand. A possible solution to avoid such a net negative effect on labor demand could be to adopt appropriate policies to encourage production and output growth of existing industries, the growth of new industries that deploy more labor-intensive technologies in production and to upgrade the skills of the labor force to be compatible with evolving technology.

6.6. *Impact on demand for materials and capital*

In case of materials and capital, using a similar method, we again rank the industries based on the magnitude of the substitution effect and group them into 3 groups of high, medium and low in term of substitutability with communications infrastructure. (See Table A3.2 in the appendix).

In case of materials, the substitution effect appears to be negative for all industries with very similar behavior as we observe in case of labor input. However, the positive output expansion effect appears to be weaker than the substitution effect in all industries, resulting in a net reduction in demand for material inputs in all industries across the three groups. At the aggregate economy level, the net effect of material savings is about 0.0049% for a 1% increase in use of communication infrastructure services. The results are summarized in Table 6.

As shown in Table 7, the demand for the capital input has a complementary relation with communication infrastructure services for most of the industries and this generates a net increase in the demand for capital input. However, we find negative substitution

[21] Kolko's analysis (2011) of zip code level data for US found that employment effects tend to be stronger in industries where information technology service represents a large share of an industry's input.

[22] By endogenizing the communication infrastructure and including the cost function of the communications industry, we could measure the total effect on the labor demand of the entire private sector, which is an area of research we could explore in the future.

[23] see Kolko (2011) and Wieck and Miguel (2010), Summers (2013).

Table 5
Net effects of communication infrastructure use on demand for labor by industry group.

Group of Industries	Type of Industries	Substitution Effects	Output Expansion Effect	Net Effect
Group-1a	Primarily Service*	−0.01493	0.01502	0.00008
Group-1b	Primarily Service #	−0.01551	0.01503	−0.00048
Group-2a	Manufacturing & Service *	−0.01407	0.01414	0.00007
Group-2b	Manufacturing & Service #	−0.01359	0.01319	−0.00039
Group-3a	Primarily Manufacturing*	−0.00713	0.00743	0.00030
Group-3b	Primarily Manufacturing#	−0.01100	0.01063	−0.00037
Total		**−0.01299**	**0.01275**	**−0.00023**

Note: * Expansion effect > Substitution effect, # Expansion effect < Substitution effect.

Table 6
Net effects of communication infrastructure use on demand for materials by industry group.

Group of Industries	Type of Industries	Substitution Effects	Output Expansion Effect	Net Effect
Group-1	Primarily Service	−0.02951	0.02333	−0.00618
Group-2	Manufacturing & Service	−0.02623	0.02167	−0.00456
Group-3	Primarily Manufacturing	−0.02423	0.02050	−0.00373
Total		**−0.02672**	**0.02187**	**−0.00485**

Table 7
Net effects of communication infrastructure use on demand for capitals by industry group.

Group of Industries	Type of Industries	Substitution Effects	Output Expansion Effect	Net Effect
Group-1a	Manufacturing & Service*	−0.00464	0.01551	0.01088
Group-1b	Manufacturing & Service	0.00500	0.01405	0.01905
Group-2	Manufacturing & Service	0.01544	0.01172	0.02716
Group-3	Manufacturing & Service	0.05960	0.00322	0.06282
Total		**0.02425**	**0.010052**	**0.03430**

Note: * Negative Substitution Effect on Capital Demand.

effects for a few industries within Group 1 and these industries are primarily service industries such as Mining (2), Rental and Leasing (33), Utilities (3), Publishing (26), Motion Picture and Sound Recording (27), Petrolium and Cole (20) and Bank, Funds and Security (30). It is possible that, for these industries, the proper use and application of modern communication infrastructure service may require replacement of the existing capital with new capital which is compatible with modern communication infrastructure. At the aggregate level, we find that the demand for capital has increased by 0.0343% in response to a 1% increase in use of communication infrastructure capital.

7. Impact at the aggregate economy level

An increase in the communication infrastructure capital increases the production efficiency of all industries and thereby increases productivity at the national level. The contribution of communications infrastructure to the aggregate economy has been evaluated by computing the following average elasticities for the entire panel of 41 industries: (i) η_{cS1}; the aggregate cost elasticity with respect

Table 8
Aggregate Elasticities and Relation with Communications Infrastructure Capital, Mean Values: 1987–2008.

Panel A: Scale and Cost Elastcities			
$1/\eta$	$1/\eta_{S1}$	$1/\eta^*$	η_{CS1}
1.062	1.081	1.253	–0.018
Panel B: Factor Demand Elasticities (Output Fixed)			
η_{LS1}	η_{KS1}	η_{MS1}	
–0.012	0.024	–0.027	
Panel C: Factor Demand Elasticities (Output Varies)			
$\bar{\eta}_{LS1}$	$\bar{\eta}_{KS1}$	$\bar{\eta}_{MS1}$	
–0.00023	0.0343	–0.0049	

to communication infrastructure, S_1 (ii) η; aggregate cost elasticity of output, holding S_1 and S_2 fixed, $(iii)\eta_{s1}$; the cost elasticity of output when input S_1 is allowed to change; and (iv) η^* , the cost elasticity of output when both inputs S_1 and S_2 are allowed to change. By taking inverse of these elasticities presented in (ii) to (iv), we obtain the respective scale elasticities, where the scale elasticity itself represents the internal returns to scale or the effect on output of an equal proportional increase in all inputs. (v) Finally we estimate the aggregate level substitution elasticities (η_{jS1}) keeping output fixed and net elasticities ($\overline{\eta}_{jS1}$) of demand allowing output to vary (output expansion effect) for input j with respect to S_1 for j = L, K and M. To obtain such aggregate level average elasticities, we weight the industry level estimates by their respective cost shares. All these elasticity estimates are shown in Table 8.

7.1. Cost elasticity

The average elasticity of cost with respect to telecommunications infrastructure, η_{CS1}, for the full industry panel is -0.0181 and shown in column 4 of Panel-A in Table 8.[24] This cost savings is enhanced further by the incremental contribution from BB penetration at the national level. The combined estimate of cost elasticity from a 1% increase in use of infrastructure capital services and a 1% increase in BB penetration at national level is about - 0.0216.

7.2. Scale elasticity

Columns 1–3 of Panel-A of Table 8 reports the estimate for aggregate scale elasticities: (i) $1/\eta$, the scale elasticity of output, holding S_1 and S_2, is estimated as 1.0623; (ii) $1/\eta_{s1}$, the scale elasticity which allows S_1 to change, is estimated as 1.0814; and (iii) $1/\eta*$, the scale elasticity which allows both S_1 and S_2 to vary, is estimated as 1.2529. This reported estimate of 1.2529 scale elasticity leads us to conclude that both public and private infrastructures play key roles in increasing the degree of economies of scale experienced in the production process.

7.3. Elasticity of factor demand

Panel-B and Panel-C of Table 8 lists the elasticities of factor demand with respect to changes in communications infrastructure capital at the aggregate level. Panel-B lists the elasticities of factor demand when output remains fixed. The largest savings is recorded for material input followed by labor. On average, with fixed output, the elasticity of demand for labor with respect to S_1, $\eta_{LS1} = -0.012$ and that for material, η_{MS1} = - 0.027. For capital, the results are somewhat mixed at the firm level but the overall impact is positive (η_{KS1}= 0.0242). The magnitudes for most of the factor demand elasticities, however, change when the output level is allowed to vary to take into account of output expansion effects on input demands. These net elasticities are shown in Panel-C of Table 8. The sign of the net elasticity of demand for labor and material remains negative even after allowing for output expansion effect, whereas the net effect on demand for capital is positive. Thus, the effect of an increase in communication infrastructure capital on the production structure of the economy is not neutral but is biased against the demand for labor and materials and increases the demand for capital.

If we compare the current results with that of our previous study (Nadiri et al., 2009) we observe a net increase in labor demand in previous study whereas the current study reports a net reduction in aggregate demand for labor in private sector. Thus, we can argue that modern communication infrastructure capital with its advanced features appears to be more labor savings than the traditional communications infrastructure capital. Moreover, the net effect on demand for private capital is relatively higher in current study which reflects strong complementarity between modern communication infrastructure capital and private capitals.

7.4. Average annual marginal benefits

The contributions of the communication infrastructure capital at the economy level are estimated by aggregating the industry-level estimates. The social marginal benefits derived from S_1 are computed by summing the average annual marginal benefit estimates for all industries and is given by:

$$SMBS_1 = \sum_i \left(\frac{\partial C_i}{\partial S_1}\right) \quad \text{for (i= 1 to 41)} \tag{11}$$

In addition, the net rate of return to telecommunication infrastructure investment is calculated by using the following formula:

$$NRRS_1 = \sum_f \left(\frac{\partial C_f}{\partial S_1}\right)/P_{S1} - \delta \tag{12}$$

where P_{S1} denotes the acquisition price and δ is the depreciation rate of the telecommunications infrastructure capital.

Using the above formula, we obtain the sum of the marginal benefits of all industries $SMBS_1$ = 0.3685 for the base year 2005. The net rate of return for communication infrastructure investment ($NRRS_1$) is about 0.2751 for the same year.[25] The estimated value of

[24] The magnitude of cost elasticity η_{CS1} is about the same as it was reported in previous study by Nadiri et al., 2009.

[25] The magnitude of $NRRS_1$ in current study is slightly lower than that obtained in the work of Nadiri et al. (2009). The primary reasons behind this observation is the higher depreciation rate of infrastructure capital in recent times in the face of rapid technological innovations.

Table 9
Rates of return on communications infrastructure capital, values in base year (2005).

SMBS1	GRRS1	NRRS1
0.3685	0.3438	0.2751

$NRRS_1$ indicates a sizeable social rate of return on communications infrastructure investment. These results are summarized in Table 9.

8. Conclusion

This study investigates the impact of modern communications infrastructure on productivity growth, input demands and the structure of production in US industries as well as for the aggregate economy. The study uses detailed industry-level data for the period 1987–2008. The purpose is to evaluate the broad impact of modern communication infrastructure characterized by high speed fixed as well as wireless broadband (BB) access networks on industry and aggregate economy.

The results suggest that the increased use of communication infrastructure services generate positive productivity gains through cost savings in all industries. In addition, the BB penetration rate entering as a shift factor in the production function benefits all industries positively by further reducing their production costs. An increasing trend in benefits from BB adoption is observed in the post-2005 period. The impact varies significantly across industries. The top five industries that are benefitting most from the use of communications infrastructure service and increasing BB penetration are: Health and Social Associates, Bank, Fund and Security, Retail Trade, Construction and a selected group of service industries. After summing the marginal benefits of all industries and adjusting for cost, we also estimate the social rate of return on investment in communications infrastructure at the aggregate economy level, the magnitude of which appears to be significant. These results should provide useful information for national infrastructure investment decisions.

Second, we studied the impact of use of communication infrastructure services on the demand for various traditional inputs such as labor, capital and materials. Our results reveal that in general, communication infrastructure service is labor- and materials-saving but capital-using for industries in the private sector (composed of 41 industries). These effects impact the structure of production of the industries and are likely to change the composition of labor skills and the type of capital formation at the aggregate economy level.

Regarding the impact on labor demand, the situation is unique. Even though the substitution effect of communication infrastructure is negative in all industries, for a sub-section of industries, the higher growth rate of output successfully compensated for the negative substitution effects of communication infrastructure and thus generated a net positive effect on labor demand. However, the number of such industries is limited and this resulted in a net reduction in labor demand at the aggregate level for the private sector. This aggregate level estimate excludes the communication industry itself.[26] Following John Maynard Keynes (1930), we can describe such a reduction in demand for labor as 'technological unemployment'. Besides the reduction in demand for labor, the innovative use and application of modern communications infrastructure service are also changing the structure of the labor market due to changes in skill requirements of new jobs, which will be compatible with evolving technology[27] (Mokyr, 2014). Therefore, further in depth research in this area could help national level policy decisions.

Appendix

Table A1
Industry Grouping for Current Study and NAICS Industry Classification.

Industry ID	Industry Classification	NAICS Classification
1	Agriculture, forestry, fishing	Farms, Forestry, fishing, and related activities
2	Mining	Oil and gas extraction, Mining, except oil and gas Support activities for mining
3	Utilities	Utilities
4	Construction	Construction
5	Lumber and Wood Products	Wood products

(*continued on next page*)

[26] Thus change in demand for labor in communication industry, which incorporates the demand for labor for the construction of communication infrastructure capital, is not reflected in the reported results.
[27] Economist and historian Joel Mokyr (2014) mentioned that "technological changes do not affect all workers the same way. Some find that their skills are complementary to new technologies and others find themselves out of work".

Table A1 (*continued*)

Industry ID	Industry Classification	NAICS Classification
6	Stone, Clay, glass	Nonmetallic mineral products
7	Primary Metals	Primary metals
8	Fabricated Metal	Fabricated metal products
9	Industrial machinery, equipment	Machinery
10	Computer and electronic equipment	Computer and electronic products
11	Electrical equipment	Electrical equipment, appliances, and components
12	Transportation equipment	Motor vehicles, bodies and trailers, and parts and Other transportation equipment
13	Furniture	Furniture and related products
14	Misc. manufacturing	Miscellaneous manufacturing
15	Food and beverage and tobacco products	Food and beverage and tobacco products
16	Textile Mill Products	Textile mills and textile product mills
17	Apparel and leather and allied products	Apparel and leather and allied products
18	Paper and allied	Paper products
19	Printing, Publishing and allied	Printing and related support activities
20	Petroleum and Coal Products	Petroleum and coal products
21	Chemicals	Chemical products
22	Rubber and misc. plastics	Plastics and rubber products
23	Wholesale trade	Wholesale trade
24	Retail trade	Retail trade
25	Transportation and warehousing Services	Air transportation, Rail , Water & Truck transportation, Transit and ground passenger transportation, Pipeline & other transportation and support activities, Warehousing and storage
26	Publishing	Publishing industries (includes software)
27	Motion picture and sound recording industries	Motion picture and sound recording industries
28	Communications	Broadcasting and telecommunications
29	Information	Information and data processing services
30	Bank, Funds, Security	Federal Reserve banks, credit intermediation, and related activities Securities, commodity contracts, and investments Funds, trusts, and other financial vehicles
31	Insurance	Insurance carriers and related activities
32	Real estate	Real estate
33	Rental and leasing services and lessors of intangible assets	Rental and leasing services and lessors of intangible assets
34	Legal services	Legal services
35	Scientific and Technical Services	Computer systems design and related services Miscellaneous professional, scientific, and technical services
36	Management of companies and enterprises	Management of companies and enterprises
37	Administrative and waste management services	Administrative and support services Waste management and remediation services
38	Educational Services	Educational Services
39	Health and Social Assistance	Ambulatory health care services Hospitals and nursing and residential care facilities Social assistance
40	Arts, entertainment, and recreation	Performing arts, spectator sports, museums, and related activities, Amusements, gambling, and recreation industries
41	Accommodation and food services	Accommodation Food services and drinking places
42	Other services, except government	Other services, except government

Table A2

Cost Elasticities and Conditional Input Demand from Communications Infrastructure (Mean Values: 1987–2008)

Industry Code	Industry Title	η_{CS1}	η_{LS1}	η_{KS1}	η_{MS1}
1	Agriculture, forestry, fishing	−0.01801	−0.00667	0.00295	−0.02421
2	Mining	−0.01858	−0.01152	−0.01083	−0.03020
3	Utilities	−0.01593	−0.00796	−0.00552	−0.02467
4	Construction	−0.01786	−0.01436	0.05298	−0.02572
5	Lumber and Wood Products	−0.01781	−0.01224	0.03263	−0.02428
6	Stone, Clay, glass	−0.01817	−0.01335	0.00722	−0.02570
7	Primary Metals	−0.01917	−0.01215	0.01046	−0.02564
8	Fabricated Metal	−0.01802	−0.01381	0.01195	−0.02583
9	Industrial machinery,equipment	−0.01777	−0.01339	0.02659	−0.02509
10	Computer and electronic equipment	−0.02171	−0.01468	0.00340	−0.02861
11	Electrical equipment	−0.01722	−0.01247	0.01876	−0.02442
12	Transportation equipment	−0.01846	−0.01238	0.03351	−0.02474
13	Furnitures	−0.01852	−0.01455	0.02582	−0.02613
14	Misc. manufacturing	−0.01881	−0.01441	0.00390	−0.02691
15	Food and beverage and tobacco products	−0.01803	−0.00813	0.01506	−0.02388
16	Textile Mill Products	−0.01909	−0.01338	0.01813	−0.02570
17	Apparel and leather and allied products	−0.01738	−0.01254	0.05745	−0.02411
18	Paper and allied	−0.01798	−0.01170	0.00745	−0.02478
19	Printing, Publishing and allied	−0.01637	−0.01245	0.06706	−0.02360
20	Petroleum and Coal Products*	−0.01861	−0.01213	0.02425	−0.02672
21	Chemicals	−0.01721	−0.00929	0.00720	−0.02365
22	Rubber and misc plastics	−0.01771	−0.01176	0.01432	−0.02437
23	Wholesale trade	−0.01770	−0.01472	0.01071	−0.02794
24	Retail trade	−0.01770	−0.01499	0.01743	−0.02853
25	Transportation and warehousing Services	−0.01734	−0.01337	0.00798	−0.02569
26	Publishing	−0.01999	−0.01495	−0.00460	−0.02856
27	Motion picture and sound recording industries	−0.01970	−0.01544	−0.00337	−0.02891
28	Communications	NA	NA	NA	NA
29	Information and data processing services	−0.01970	−0.01544	−0.00337	−0.02891
30	Bank, funds, Security	−0.01833	−0.01433	−0.00035	−0.02770
31	Insurance	−0.01791	−0.01438	0.02335	−0.02630
32	Real estate	−0.01837	−0.00314	0.01971	−0.02384
33	Rental and leasing services	−0.01576	−0.00813	−0.00621	−0.02590
34	Legal Services	−0.01793	−0.01571	0.04016	−0.03102
35	Technical Services	−0.01763	−0.01516	0.01856	−0.02981
36	Management	−0.01621	−0.01405	0.04183	−0.03032
37	Administrative and waste management services	−0.01687	−0.01427	0.02411	−0.02789
38	Educational Services	−0.01874	−0.01646	0.06090	−0.03065
39	Health and Social Assistance	−0.01727	−0.01488	0.03889	−0.02896
40	Arts, entertainment, and recreation	−0.01746	−0.01462	0.02089	−0.02755
41	Accommodation and food services	−0.01851	−0.01499	0.00888	−0.02739
42	Other Services	−0.01809	−0.01590	0.27370	−0.02991

*For data issue, used average value across industries.

Table A3.1

Industry Grouping and Ranking Based on Substitution Effect (labor vs. Communications Infrastructure Service)

Group-1 (Industries With Relatively Higher Substitution Effect on Labor Demand)
Information & Data Processing (ID = 29)
Educational Services (ID = 38)
Other Services (ID = 42)
Legal Services (ID = 34)

(*continued on next page*)

Table A3.1 (*continued*)

Motion picture and sound recording industries (ID = 27)
Technical Services (ID = 35) #
Retail trade (ID = 24) #
Accommodation and food services (ID = 41)
Publishing (ID = 26)
Health and Social Assistance (ID = 39) #
Wholesale trade (ID = 23) #
Computer and electronic equipment (ID = 10)
Arts, entertainment, and recreation (ID = 40)
Group-2 (Industries With Relatively Moderate Substitution Effect on Labor Demand)
Furniture (ID = 13)
Misc. manufacturing (ID = 14)
Insurance (ID = 31)
Construction (ID = 4) #
Bank, funds, Security (ID = 30) #
Administrative and waste management services (ID = 37) #
Management (ID = 36) #
Fabricated Metal (ID = 8)
Industrial Machinery, Equipment (ID = 9)
Textile Mill Products (ID = 16)
Transportation and warehousing Services (ID = 25) #
Stone, Clay, glass (ID = 6)
Apparel and leather and allied products (ID = 17)
Electrical equipment (ID = 11)
Group-3 (Industries With Relatively Moderate Substitution Effect on Labor Demand)
Printing, Publishing and allied (ID = 19)
Transportation equipment (ID = 12)
Lumber and Wood Products (ID = 5)
Primary Metals (ID = 7)
Rubber and misc. plastics (ID = 22)
Paper and allied (ID = 18)
Mining (ID = 2)
Chemicals (ID = 21) #
Food and beverage and tobacco products (ID = 15)
Rental and leasing services (ID = 33)
Utilities (ID = 3) #
Agriculture, forestry, fishing (ID = 1)
Real estate (ID = 32) #

*: Industries are ranked within a group based on high negative to positive values of substitution elasticities).
#: Industries for which Output expansion effect > Negative substitution effect on labor demand.

Table A3.2
Industries are ranked based on substitution effect (Communication Infrastructure service vs. Material and Capital)

Material vs. Communications Infrastructure Service #	Capital vs. Communications Infrastructure Service ##
Group-1 (Substitution Effect is Relatively Higher)	**Group-1** (Substitution Effect is Relatively Higher **)**
Information (ID = 29)	Mining (ID = 2)*
Legal Services (ID = 34)	Rental and leasing services (ID = 33)*
Educational Services (ID = 38)	Utilities (ID = 3)*
Management (ID = 36)	Publishing (ID = 26)*
Mining (ID = 2)	Motion picture and sound recording industries (ID = 27)*

(*continued on next page*)

Table A3.2 (*continued*)

Material vs. Communications Infrastructure Service #	Capital vs. Communications Infrastructure Service ##
Other Services (ID = 42)	Petroleum and Coal Products (ID = 20)*
Technical Services (ID = 35)	Bank, funds, Security (ID = 30)*
Health and Social Assistance (ID = 39)	Information (ID = 29)
Motion picture and sound recording industries (ID = 27)	Agriculture, forestry, fishing (ID = 1)
Computer and electronic equipment (ID = 10)	Computer and electronic equipment (ID = 10)
Publishing (ID = 26)	Misc. manufacturing (ID = 14)
Retail trade (ID = 24)	Chemicals (ID = 21)
Wholesale trade (ID = 23)	Stone, Clay, glass (ID = 6)
Administrative and waste management services (ID = 37)	Paper and allied (ID = 18)
Group-2 (Substitution Effect is Medium)	**Group-2** (Substitution Effect is Medium)
Bank, funds, Security (ID = 30)	Transportation and warehousing Services (ID = 25)
Arts, entertainment, and recreation (ID = 40)	Accommodation and food services (ID = 41)
Accommodation and food services (ID = 41)	Primary Metals (ID = 7)
Misc. manufacturing (ID = 14)	Wholesale trade (ID = 23)
Insurance (ID = 31)	Fabricated Metal (ID = 8)
Furnitures (ID = 13)	Rubber and misc. plastics (ID = 22)
Rental and leasing services (Id = 33)	Food and beverage and tobacco products (ID = 15)
Fabricated Metal (ID = 8)	Retail trade (ID = 24)
Construction (ID = 4)	Textile Mill Products (ID = 16)
Stone, Clay, glass (ID = 6)	Technical Services (ID = 35)
Textile Mill Products (ID = 16)	Electrical equipment (ID = 11)
Transportation and warehousing Services (ID = 25)	Real estate (ID = 32)
Primary Metals (ID = 7)	Arts, entertainment, and recreation (ID = 40)
Industrial machinery &equipment (ID = 9)	Insurance (ID = 31)
Group-3 (Substitution Effect is Relatively Low)	**Group-3** (Substitution Effect is Relatively Low)
Paper and allied (ID = 18)	Administrative and waste management services (ID = 37)
Transportation equipment (ID = 12)	Furnitures (ID = 13)
Utilities (ID = 3)	Industrial machinery & equipment (ID = 9)
Petroleum and Coal Products (ID = 20)	Lumber and Wood Products (ID = 5)
Electrical equipment (ID = 11)	Transportation equipment (ID = 12)
Rubber and misc. plastics (ID = 22)	Health and Social Assistance (ID = 39)
Lumber and Wood Products (ID = 5)	Legal Services (ID = 34)
Agriculture, forestry, fishing (ID = 1)	Management (ID = 36)
Apparel and leather and allied products (ID = 17)	Construction (ID = 4)
Food and beverage and tobacco products (ID = 15)	Apparel and leather and allied products (ID = 17)
Real estate (ID = 32)	Educational Services (ID = 38)
Chemicals (ID = 21)	Printing, Publishing and Allied (ID = 19)
Printing, Publishing and Allied (ID = 19)	Other Services (ID = 42)

Note: #: Fpr Material input, Negative substitution effect is > output Expansion Effect for all industries.
##: For Capital input, substitution effect is positive (Complementary to Communications Infrastructure), except for few industries with '*' and ordered negative substitution to positive substitution effect.(numerical ordering).

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