The contribution of US broadband infrastructure subsidy and investment programs to GDP using Input-Output modeling

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February 2024

Abstract

More than one-fifth of the US population does not subscribe to a fixed broadband service despite broadband being a recognized merit good. For example, less than 4% of citizens earning more than US $70k annually do not have broadband, compared to 26% of those earning below US $20k annually. To address this, the Biden Administration has undertaken one of the largest broadband investment programs ever via The Bipartisan Infrastructure Law, with the aim of addressing this disparity and expanding broadband connectivity to all citizens. We examine broadband availability, adoption, and need for each US state, and then construct an Input-Output model to explore the potential macroeconomic impacts of broadband spending to Gross Domestic Product (GDP) and supply chain linkages. Our analysis indicates that higher funding allocations do appear to be allocated to areas with poorer broadband. While this may be logical, as it illustrates funding going to areas most in need, this could not have been assumed *a priori* given politically-motivated funding is not always rationally allocated. In terms of macroeconomic impact, the total direct contribution to US GDP by the program could be as high as US $84.8 billion, $55.2 billion, and $5.99 billion for the BEAD program, ACP, and TBCP, respectively. Thus, overall, the broadband allocations could expand US GDP by $146 billion (0.13% of annual US GDP over the next five years). We contribute one of the first economic impact assessments of the US Bipartisan Infrastructure Law to the literature.

1 Introduction

Reliable high-speed broadband is crucial for economic growth and improving productivity. For example, a broadband connection gives firms access to a larger pool of resources, suppliers, and customers, enhancing business growth in both urban and rural regions (DeStefano et al., 2023; Prieger, 2017; Stockinger, 2019) and lowering input prices (LoPiccalo, 2021; Lumpkin & Dess, 2004). Communities desire broadband investments for a variety of reasons, but the economic development benefits are a key motivation, particularly for rural and remote locations that want to boost extra-regional trade (Kumar & Oughton, 2023; Malgouyres et al., 2021; Rodriguez-Crespo et al., 2021). Fledgling companies (as well as established firms) also benefit, as broadband provides entrepreneurs advantages in generating new customers and business opportunities, enabling revenue growth (Chen et al., 2023; Hasbi, 2020; Prieger, 2023; Stephens et al., 2022).

Given this context, broadband has been a regular news item in current affairs media in recent years across the political spectrum. CNN has reported that broadband infrastructure investment "could make a substantial dent in the country's digital divide" (CNN, 2021), with Fox News stating the plan would "expand broadband access to bring tech jobs to rural America" (Fox, 2020). While decision-makers from different political parties understand that high-speed, reliable broadband connectivity is crucial for societal and economic development, there are often disagreements. Contentions arise with regard to the magnitude of public spending, as well as how broadband infrastructure should be deployed (whether by market methods or government) (Alabama Political Reporter, 2023; Brookings, 2022).

Consumers also benefit from good quality broadband infrastructure. Indeed, consumers can access a broader selection of goods and services (Greenstein & McDevitt, 2011), possibly bolstering inter-regional transactions. Investments in broadband can enhance education (Cullinan et al., 2021; Graves et al., 2021; Gu, 2021), expand access to vocational training (Goulas et al., 2021; Rosston & Wallsten, 2020), and develop new ways to participate in the labor force, increasing the productivity of regional and national economies (Gallardo et al., 2021; Mukhalipi, 2018; Pelinescu, 2015).

Unfortunately, a significant economic divide exists between those with or without a high-speed broadband connection in US communities (Ali, 2022; Valentín-Sívico et al., 2023). Such divisions have become more apparent during the COVID-19 pandemic as rural communities struggled because they could be disproportionately less likely to have a reliable broadband connection (UCSB, 2022). These communities have also had difficulty participating in online commerce (Isley & Low, 2022), accessing essential services, and carrying out transactions online (Grubesic, 2006; Lai & Widmar, 2021).

In 2020, the Biden administration introduced the Bipartisan Infrastructure Law, which includes broadband infrastructure subsidies and resources to boost deployment. The Bipartisan Infrastructure Law consists of three key approaches to expanding broadband coverage and adoption, including (i) the Broadband Equity, Access, and Deployment (BEAD) program, (ii) the Affordable Connectivity Program (ACP), and (iii) the Tribal Broadband Connectivity Program (TBCP). Currently, the FCC defines broadband as a connection with a download speed of more than 25 Mbps and an upload speed of more than 3 Mbps (Broadband USA, 2016; FCC, 2022). However, an FCC inquiry recently recommended that the standard be increased to 100 Mbps download and 20 Mbps for upload (Gorscak, 2023).

Firstly, the BEAD program is the largest single congressional allocation to broadband, with $42.45 billion going to expanding broadband infrastructure (Congressional Research Service, 2023). The BEAD program's aim is to catalyze broadband infrastructure investment and improve accessibility to a reliable, fast Internet connection to qualifying US citizens. Past assessments of broadband investment programs have estimated Keynesian multipliers of up to 4.75 (Katz & Suter, 2009), indicating for every one unit of government spending (e.g., US$ 1), there is a commensurate increase of 4.75 units in the wider macroeconomy (e.g., US$ 4.75). In addition to infrastructure challenges, there are also barriers ranging from adoption to technology and implementation costs which need to be overcome (Canfield et al., 2019).

The Affordable Connectivity Program allocates a subsidy for households to purchase broadband connections; eligible families can receive a discount of up to US $30 per month, while those on tribal lands can receive up to US $75 per month. The program allocates US $14.2 billion for broadband investment and provides up to a US $100 discount for a computer or tablet (*Affordable Connectivity Program*, 2023). Decreasing broadband prices has been shown to be positively associated with increased broadband penetration (Abrardi & Cambini, 2019; Flamm & Chaudhuri, 2007; Rosston & Wallsten, 2020).

Finally, the Tribal Broadband Connectivity Program focuses on broadband deployment on tribal lands, which comprise approximately 2.3% of US land area, with the Bipartisan Infrastructure Law allocating $3 billion to invest in servicing these communities (Vincent et al., 2017). The TBCP targets increasing access in Tribal areas through awards, with one recent example being the allocation of $19.8 million to the Chippewa Indians living in Boise Forte to install fiber cables in their community (Oxendine, 2023). Grants for native territories have been found to positively affect broadband penetration (Korostelina & Barrett, 2023; Pipa et al., 2023).

With this context in mind, this paper subsequently analyzes the economic impact of these three broadband investment and subsidy programs. This is undertaken by first exploring the availability, adoption, and need for broadband on a state-by-state level. Then secondly, developing an Input-Output (IO) model to quantify the macroeconomic effects in GDP terms. Finally, the potential supply chain linkage effects are quantified for different industrial sectors. The research questions include the following:

1. To what extent does the Bipartisan Infrastructure Law allocate funding to unconnected communities in need?
2. What are the GDP impacts of the three funding programs within the Bipartisan Infrastructure Law?
3. How are supply chain linkages affected by allocations from the Bipartisan Infrastructure Law?

In Section 2, a literature review is carried out examining studies pertaining to the research questions, before a method is presented in Section 3. Modeling results will be presented in Section 4, and we then return to the research questions in Section 5 to discuss the ramifications of the findings in the broader policy context. Finally, the research conclusions, contributions to the literature, and limitations of the approach will be presented in Section 6.

2 Literature Review

2.1 Reviewing Broadband Infrastructure's Impact on the Economy

Access to broadband has many benefits, as examined in this review. While broadband is a necessary but not sufficient factor for development in modern economies, connecting more people to a faster Internet removes a significant barrier that constrains many communities, especially those rural and remote. However, it is also possible that broadband deployment could have a negative impact on employment in some industrial sectors (Zhou et al., 2022). In industries where Internet access cannot replace less efficient labor activities, such as manufacturing, increased broadband adoption positively affects productivity and output (Jung & López-Bazo, 2020; Zhang et al., 2022). However, the return from broadband investment generally depends on the wider level of availability and adoption within an economy. For example, regions with poorer broadband infrastructure generally see a greater contribution to employment and economic growth when finally deployed (Pradhan et al., 2018; Shideler & Badasyan, 2007). However, for regions that already have significantly comprehensive broadband infrastructure, there are generally diminishing returns to scale, with increased infrastructure spending leading to diminishing returns on investment (as is common in other infrastructure sectors such as transportation, energy, etc.).

In terms of macroeconomic impacts, the deployment of broadband infrastructure is generally found to have a positive effect on economic growth (Koutroumpis, 2009). Specifically, increased broadband penetration leads to positive impacts on GDP after more than half of the population has gained access to the Internet. For example, a 1% increase in broadband penetration yields a 0.02% increase in GDP in areas with low broadband penetration and 0.03% elsewhere. In contrast, one assessment estimates broadband's marginal effect on GDP using pricing models and "willingness-to-pay" estimates, finding that approximately $8.3-$10.6 billion was generated from US broadband investment prior to 2006. The study conclusions suggest that broadband growth results directly in economic benefits from improvements in public health, education, local growth, and employment (Greenstein & McDevitt, 2011).

Moreover, another approach utilizing a Cobb-Douglas production function alongside a Generalized Least Squares model to obtain regression specifications quantifies the impacts of broadband on total output (Ghazy et al., 2022). The analysis finds that broadband has a significant positive association with economic output at the 1% significance level. Furthermore, the regression also estimates a 1% increase in connectivity leads to a 0.63% increase in new business entry into the market, concluding that a secure, dependable broadband connection provides entrepreneurs more incentive to enter a market, as increases in broadband penetration lead to an improved business development environment.

Broadband infrastructure investment expands opportunities for entrepreneurs and encourages business creation (Deller et al., 2022; Luo et al., 2022; Stephens et al., 2022). For example, improvements in broadband infrastructure are found to have enhanced firm formation throughout a wide variety of business sectors (Duvivier et al., 2021). This is for two key reasons. Firstly, access to broadband encourages entrepreneurs to enter the market. Secondly, broadband can relieve positional barriers that discourage entry into the market. Therefore, when regressed against entrepreneurial measures, like project investment, broadband infrastructure investment indicates a significantly positive effect with a coefficient of 0.03. The analysis also suggests there are benefits to innovation from broadband investment (Han et al., 2023; Rampersad & Troshani, 2020; Xu et al., 2019), with an additional 1% penetration associated with an increase of up to 1.4% in filed patents (analogous to innovation) (Yang et al., 2022).

To conclude, there is strong evidence that investing in broadband infrastructure positively affects a range of economic metrics, including industrial output, productivity, entrepreneurship, and innovation.

2.2 Previous Research into IO Modeling of Broadband Investment

Input-Output (IO) Modeling is a macroeconomic method developed by Wassily Leontief and awarded the Nobel Prize in Economic Sciences in 1973. The approach defines economies through a matrix where the rows represent sectoral outputs and the columns sectoral inputs. Assuming constant economic returns, one splits an economy into *n* sectors to analyze intersectional demand. The final economic output is represented in the dollar value of the goods and services that a sector produces. The value is calculated by summing the amount purchased as an input by other sectors of the economy and the amount purchased as a final good by consumers. When incorporating imports, government spending, value-added analysis, and other factors into separate rows and columns, it is possible to use this matrix to analyze the total output of an economy. When adjusting the inputs for each sector, it is possible to quantify the marginal effects of policy and investment either for a specific industry or the wider macroeconomy (Leontief, 1986).

Infrastructure investment impacts the economy through discrete sectoral spillovers (Schreiner & Madlener, 2022; Välilä, 2020). A quantifiable metric for identifying these spillovers is the analysis of the sectoral impacts on each other (Jimmy & Falianty, 2021). For example, the economic consequences of infrastructure development can be considered through the lens of Macroeconomic Growth Theory (Carlsson et al., 2013). Investment is represented within these models as structural changes to those sectoral effects by amplifying some sectors and damping others (Nieto et al., 2020; Sievers et al., 2019).

This approach has been used to quantitatively analyze broadband investment appropriations in the American Recovery and Reinvestment Act 2009. A measure of proportional growth can be captured for the interactions between industrial sectors resulting from additional investment (R. Katz & Suter, 2009). This enables direct, indirect, and induced effects to be quantified for the total output of each sector. One study finds the spillover effects of infrastructure projects and uses them to explore future economic outputs (Dimitriou et al., 2015). For example, business services were found to have a growth multiplier of 2.2, while post and telecommunications would potentially see a growth multiplier of 1.50. These figures represent how much these sectors' output would benefit from the project construction. Additionally, one assessment uses an IO model to evaluate German broadband investment, finding that an investment of 36 billion (euros) could increase GDP by approximately 171 billion (euros) (R. L. Katz et al., 2010).

Government investment in broadband, Internet, and mobile networking infrastructure has been shown to have a range of positive economic growth impacts through GDP, labor, and other heuristics (Abrardi & Cambini, 2019; Kim et al., 2021). Contemporary studies have used IO models for similar investment analysis for different infrastructure systems (Appiah-Otoo & Song, 2021; Vu & Nguyen, 2024; Zhang et al., 2022). For example, investment impacts on regional economic sectors are estimated using an IO model for US energy infrastructure investment via supply and use tables from the Bureau of Economic

Analysis and the IELab US Multi-Regional IO database (Faturay et al., 2020). Another study uses IO modeling to assess port infrastructure on other sectors of the Chinese economy. The methodology allowed the researchers to separate economic effects between industries, showing that the construction, chemical, and transportation sectors would be affected the most by port closures, with overall GDP reducing as much as US $90 billion (Wang & Wang, 2019).

These sources illustrate that IO modeling is an established approach for evaluating the macroeconomic impacts of infrastructure investment, especially when considering inter-industry linkages.

2.3 Context of the Bipartisan Infrastructure Act through Previous Research

Policy choices can help maneuver broadband networks to achieve more positive outcomes (Oughton et al., 2023; Oughton, 2023), but efforts to close broadband gaps have not yet managed to do so (King & Gonzales, 2023). Currently, only 77% of people in the United States subscribe to a broadband connection (Pew Research Center, 2021). Many unconnected Americans lack access because of connection prices, insufficient technology, scarce information, and inadequate government policies (Bauer, 2023; Oughton et al., 2022; Rosston & Wallsten, 2020). A significant divide exists between urbanization and income levels in US households (Rothschild, 2019). For example, with 82% of urban households having a fixed broadband connection, only about 70% of rural areas have the same connection available (Li et al., 2023; United States Census Bureau, 2021).

Most Native Americans living in tribal areas do not have access to the same broadband infrastructure that other communities have. There are numerous reasons - progress is hampered by a lack of trust, social structure, limited resources, and insufficient education (Korostelina & Barrett, 2023). Government investment could lead to increases in broadband connectivity, but substantial disparities still prevail (Andres et al., 2024; Healy et al., 2022). For example, 55.6% of Native American tracts have seen an expansion in broadband providers between 2004 and 2014, with 27.7% of Native American tracts now having an above-average number of providers (Mack et al., 2022). However, the percentage of Native households with Internet access is still 21% lower than in the surrounding areas (Bauer et al., 2022). For the US government to ensure everyone can participate in a modern online economy, there needs to be more infrastructure built to support tribal broadband and investment in education and awareness (Duarte et al., 2021; Hudson et al., 2021; Mack et al., 2023).

As found in previous studies, Figure 1 emphasizes empirically the association between broadband inequality and income level (Deng et al., 2023; Houngbonon & Liang, 2020; Wolfson et al., 2017). This problem is exacerbated as broadband adoption has been found to increase wages and hiring in a community (Poliquin, 2021; Yin & Choi, 2023). Thus, communities with reliable broadband connectivity often have higher earnings and more opportunities, aggravating the inequality shown in the figure (Consoli et al., 2023; Mathews & Ali, 2023). Figure 1 (A) shows that, on average, communities with a mean income of less than $20,000 have poorer access to broadband than wealthier communities. This can constrain economic opportunities in poorer areas, meaning citizens in these areas are disadvantaged in seeking new employment options and adapting to changing labor markets. Figure 1 (B) shows us that the disparities in connectivity, separated by income, are present when we compare regions with larger broadband allocations. 69.3% of those making under US $20k in states receiving over US $1,350 have access, whereas 75.1% have access in states receiving less than US $50k.

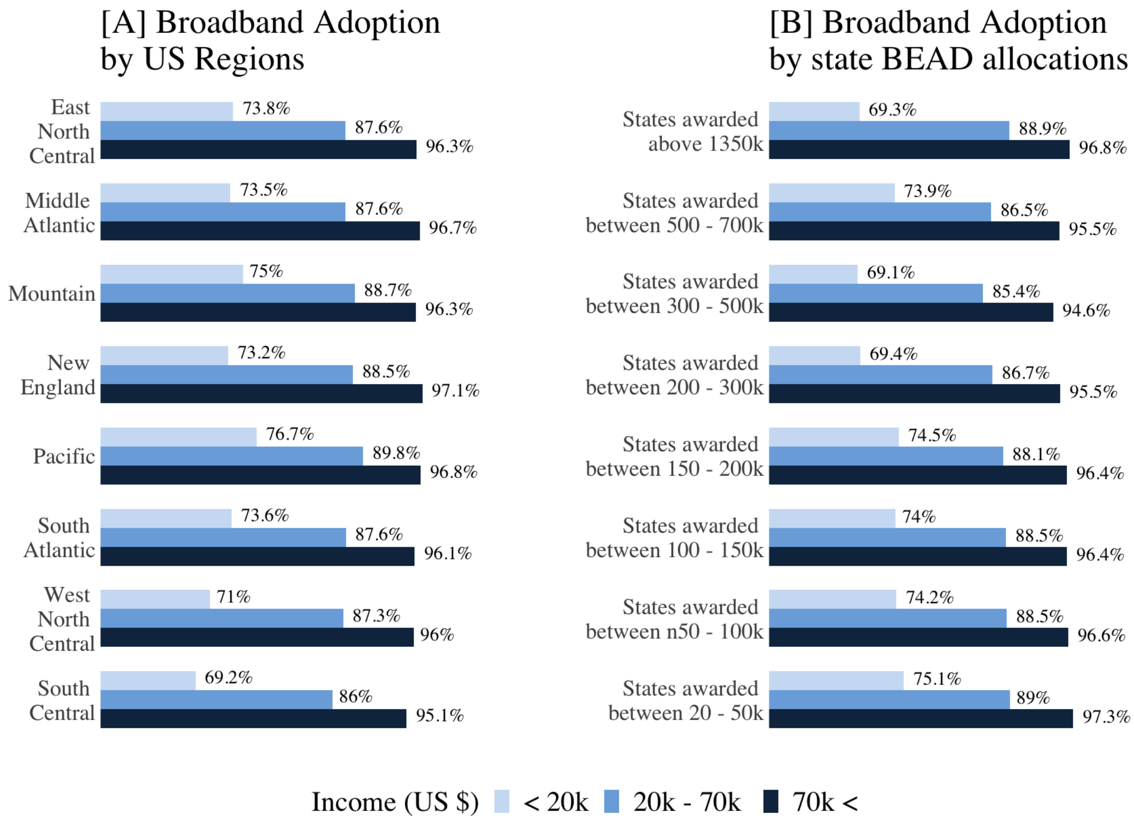

Figure 1: Regardless of location, income is one of the key determinants of broadband inequality (A),(B): U.S. Census Bureau, 2021 American Community Survey (UCSB, 2022)

Finally, 20.9% of Tribal lands still lack access to reliable broadband (Hutto & Wheeler, 2023). The adverse effects of the lack of reliable broadband were shown throughout the COVID-19 pandemic when many tribal communities were restricted from accessing schools and working opportunities because they did not have a reliable connection to broadband infrastructure (Kroll, 2023; Le-Morawa et al., 2023; Levin et al., 2023). Broadband connectivity can be efficiently implemented through inter-tribal communication throughout the community and community-specific broadband dissemination (Gellman et al., 2021). The Tribal Connectivity Program's awards aim to support the deployment of required broadband infrastructure by working in tandem with affected communities (*Tribal Broadband Connectivity Program*, 2023).

Now that a thorough literature review has been undertaken, the methods for analysis will be presented.

3 Methods

In this section, various macroeconomic methods for assessing the contribution of infrastructure to the economy will be assessed. We begin by articulating a general macroeconomic system model based on IO, before detailing different demand-side and supply-side evaluation methods for broadband infrastructure.

3.1 Leontief Input-Output (IO) Modeling

The IO approach begins by dividing the economy into n sectors, such as agriculture, manufacturing, energy, telecommunications, and other such industries. The model denotes inter-sectoral transfers as z_{ij}, representing the dollar value of transfers from sector i to sector j. For example, if sector 1 is electricity and sector 2 is telecommunications, z_{12} represents the dollar value of electricity sold to the telecommunications industry as an input. The other metric is f_i, which denotes the final demand for the good or service from sector i. The final demand includes purchases by consumers, investments from businesses, purchases from the government, and net exports.

The final output of sector i is denoted as x_i, measured here in dollars, and represents the sum of all monetary values of the transactions from other inter-industry sectors, as well as the final demand for goods or services, stated in equation (1) as follows.

$$x_i = \sum_{j=1}^{n} (z_{ij}) + f_i \tag{1}$$

Thus, we can list the linear equations of all n industries in rows, as detailed in equation (2).

$$\begin{aligned} x_1 &= z_{11} + \cdots + z_{1j} + \cdots + z_{1n} + f_1 \\ &\vdots \\ x_i &= z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i \\ &\vdots \\ x_n &= z_{n1} + \cdots + z_{nj} + \cdots + z_{nn} + f_n \end{aligned} \tag{2}$$

Moreover, the vector for the final output is x, as outlined in equation (3).

$$x = \begin{bmatrix} x_1 \\ \vdots \\ x_i \\ \vdots \\ x_n \end{bmatrix} \tag{3}$$

Likewise, the matrix of inter-industry transactions and final demand can be represented as Z and F, respectively, as we present in equations (4) and (5).

$$Z = \begin{bmatrix} z_{11} + \cdots + z_{1j} + \cdots + z_{1n} \\ \vdots \\ z_{i1} + \cdots + z_{ij} + \cdots + z_{in} \\ \vdots \\ z_{n1} + \cdots + z_{nj} + \cdots + z_{nn} \end{bmatrix} \tag{4}$$

$$F = \begin{bmatrix} f_1 \\ \vdots \\ f_i \\ \vdots \\ f_n \end{bmatrix} \tag{5}$$

As each sector of the economy can be modeled in a row of the matrices above, the total expression for the total n industries in the economy can be modeled in a system of linear equations represented in equation (6).

$$x = Zi + F \tag{6}$$

Where i represents an identity matrix of dimensions n by n.

Each row of the matrix Z represents the aggregate output of its respective sector. To measure spillovers across industries, we can analyze technical coefficients $a_{ij} = z_{ij} / x_j$. For two industries i and j, the technical coefficient a_{ij} is equal to the dollar's worth of input from i to the output of sector j.

Because $z_{ij} = a_{ij} * x_j$, we can replace the respective coefficients algebraically, as detailed in equation (7).

$$\begin{aligned} x_1 &= a_{11}x_1 + \cdots + a_{1j}x_j + \cdots + a_{1n}x_n + f_1 \\ &\vdots \\ x_i &= a_{i1}x_1 + \cdots + a_{ij}x_j + \cdots + a_{in}x_n + f_i \\ &\vdots \\ x_n &= a_{n1}x_1 + \cdots + a_{nj}x_j + \cdots + a_{nn}x_n + f_n \end{aligned} \tag{7}$$

Distributing, as per equation (8).

$$\begin{aligned} x_1 - a_{11}x_1 - \cdots - a_{1j}x_j - \cdots - a_{1n}x_n &= f_1 \\ &\vdots \\ x_i - a_{i1}x_1 - \cdots - a_{ij}x_i - \cdots - a_{in}x_n &= f_i \\ &\vdots \\ x_n - a_{n1}x_1 - \cdots - a_{nj}x_i - \cdots - a_{nn}x_n &= f_n \end{aligned} \tag{8}$$

Factoring, as per equation (9).

$$\begin{aligned} (1 - a_{11})x_1 - \cdots - a_{1j}x_j - \cdots - a_{1n}x_n &= f_1 \\ &\vdots \\ -a_{i1}x_1 - \cdots + (1 - a_{ij})x_i - \cdots - a_{in}x_n &= f_i \\ &\vdots \\ -a_{n1}x_1 - \cdots - a_{nj}x_j - \cdots + (1 - a_{nn})x_n &= f_n \end{aligned} \tag{9}$$

Thus, as per the system of linear equations (10).

$$(I - A)x = F \tag{10}$$

Where *A* is the n by n matrix of technical coefficients as represented below, in equation (11).

$$A = \begin{bmatrix} a_{11}, \cdots a_{1j}, \cdots a_{1n} \\ \vdots \\ a_{i1}, \cdots a_{ij}, \cdots a_{in} \\ \vdots \\ a_{n1}, \cdots a_{nj}, \cdots a_{nn} \end{bmatrix} \tag{11}$$

And the inverse of *(I-A)* is denoted as L, the Leontief-inverse matrix, as per equation (12).

$$x = LF \tag{12}$$

Therefore, we can use this formula to quantify the output generated by a shift in final demand for individual industrial sectors, or the whole economy.

3.2 Ghosh Supply-Side Assessment Methods for Infrastructure

The Ghosh Supply-Side model measures the changes in availability of inputs on industrial output. While the Leontief matrix relies on technical coefficients a_{ij}, the Ghosh matrix relies on allocation coefficients $b_{ij} = z_{ij} / x_i$. The allocation coefficient measures the value of transactions from sectors i to j divided by the output of sector i.

The allocation coefficients can be made into a matrix B similar to A, as detailed in equation (13).

$$\begin{aligned}
\begin{bmatrix} \frac{1}{x_1} & 0 & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{x_i} & 0 & 0 \\ 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{x_n} \end{bmatrix}
\begin{bmatrix} z_{11} & \cdots & z_{1j} & \cdots & z_{1n} \\ \vdots & & \vdots & & \vdots \\ z_{i1} & \cdots & z_{ij} & \cdots & z_{in} \\ \vdots & & \vdots & & \vdots \\ z_{n1} & \cdots & z_{nj} & \cdots & z_{nn} \end{bmatrix}
&= \begin{bmatrix} \frac{z_{11}}{x_1} & \cdots & \frac{z_{1j}}{x_1} & \cdots & \frac{z_{1n}}{x_1} \\ \vdots & & \vdots & & \vdots \\ \frac{z_{i1}}{x_i} & \cdots & \frac{z_{ij}}{x_i} & \cdots & \frac{z_{in}}{x_i} \\ \vdots & & \vdots & & \vdots \\ \frac{z_{n1}}{x_n} & \cdots & \frac{z_{nj}}{x_n} & \cdots & \frac{z_{nn}}{x_n} \end{bmatrix} \\
&= \begin{bmatrix} b_{11} & \cdots & b_{1j} & \cdots & b_{1n} \\ \vdots & & \vdots & & \vdots \\ b_{i1} & \cdots & b_{ij} & \cdots & b_{in} \\ \vdots & & \vdots & & \vdots \\ b_{n1} & \cdots & b_{nj} & \cdots & b_{nn} \end{bmatrix} \\
&= B
\end{aligned} \tag{13}$$

Thus, as per equation (14).

$$\begin{aligned} \hat{x}^{-1} Z &= B \\ Z &= \hat{x} B \end{aligned} \tag{14}$$

From the previous section, we know that Ax = Z, as in equation (15).

$$\begin{aligned} Ax &= \hat{x} B \\ \hat{x}^{-1} A x &= B \end{aligned} \tag{15}$$

The summation of the inputs of an industry plus its value added is equal to its output, per the IO table.

Thus, as per equation (16).

$$x_j = \sum_{i=1}^{n}(z_{ij}) + v_j \tag{16}$$

Similarly, as per equation (17).

$$\begin{aligned} x' &= i'Z + v' \\ x' &= i'xB + v' \\ x' - x'B &= v' \\ x'(I - B) &= v' \\ x' &= v'(I - B)^{-1} \\ x' &= v'G \end{aligned} \tag{17}$$

The Ghosh matrix, G, is equal to $(I\text{-}B)^{-1}$ and allows us to see the changes in final output from the changes in value added.

3.3 Data and Application

We will source IO tables from the Bureau of Economic Analysis (*Input-Output Data Tables*, 2023). The sector for broadband spending is Telecommunications (NAICS 517) (US Census Bureau, 2023). For our augmented final demand/value-added vectors, we can isolate the investments and introduce them into their respective sectors by entering 0 for all other sectors. We can calculate broadband's final demand/value-added by summing the government's subsidies and the increased household spending on broadband connections because they can now afford those services.

Program	Purpose	Budget	Household Contribution	Model Employed
BEAD	To expand broadband equity and access throughout the United States and to deploy broadband service to unserviced homes	\$42.45 billion	0	Ghosh
ACP	To provide a subsidy (\$30+) for connected homes to buy broadband service	\$14.2 billion	\$14.9 billion	Leontief
TBCP	To deploy broadband to tribal regions without broadband access	\$3 billion	0	Ghosh

Table 1: The constituent programs of the Bipartisan Infrastructure Law's funding and modeling method.

According to the ACP, US \$14.2 billion is available in subsidies (FCC, 2023). As these are awarded as subsidies, each allocation leads to some household spending, which also contributes to the final demand. In total, if each subsidy is about US \$30 per month, or US \$360 a year, then there will be 39.4 million household recipients throughout the course of the program, assuming we treat this as though households must re-enroll each year. Thus, each of these 39.4 million households will contribute about US $30 themselves, as the average price of broadband is approximately US $61 (*Broadband Affordability*, 2023; Shevik, 2023; Wilson, 2023), minus the subsidy, which is about US $360 a year. So, households will provide an additional US $14.9 billion in spending, and the final demand increase for the ACP will be US $29.1 billion.

The upstream effects of the ACP can be modeled with the Leontief IO method, as described in subsection 3.1. The downstream effects can be modeled using the Ghosh method described in section 3.2 for the BEAD program and the TBCP (*Mathematical Derivation of the Total Requirements Tables for Input-Output Analysis*, 2017). Using this methodology, we can also produce, analyze, and contextualize the multipliers for each program, where an economic multiplier represents the GDP change per $1 of direct investment.

As an effect of the three programs within the Bipartisan Infrastructure Law, the total direct impact on US GDP is $74.5 billion (comprised of $59.6 billion from government investment and $14.9 billion from additional household consumer spending) (*Affordable Connectivity Program*, 2023; *Broadband Equity Access and Deployment Program*, 2023; *Tribal Broadband Connectivity Program*, 2023). Now that our methods are established, we can examine the results of our study.

4 Results

The results are reported for the three research questions defined in the introduction. In section 4.1, we will discuss which states receive broadband investment, in section 4.2, we will report the GDP estimates of our models, and in section 4.3, we will examine the supply-chain linkages associated with the telecommunications sector.

4.1 To what extent does the Bipartisan Infrastructure Law allocate funding to unconnected communities in need?

Figure 2 (A) indicates that the states with the highest total BEAD allocation are Texas ($3.31 Bn, 7.80%), California ($1.86 Bn, 4.39%), Missouri ($1.74 Bn, 4.09%), Michigan ($1.56 Bn, 3.67%), and North Carolina ($1.53 Bn, 3.61%). The states with the least include the District of Columbia ($.101 Bn, .24%), Delaware ($.108 Bn, .25%), Rhode Island ($.108 Bn, .26%), and North Dakota ($.130 Bn, .31%).

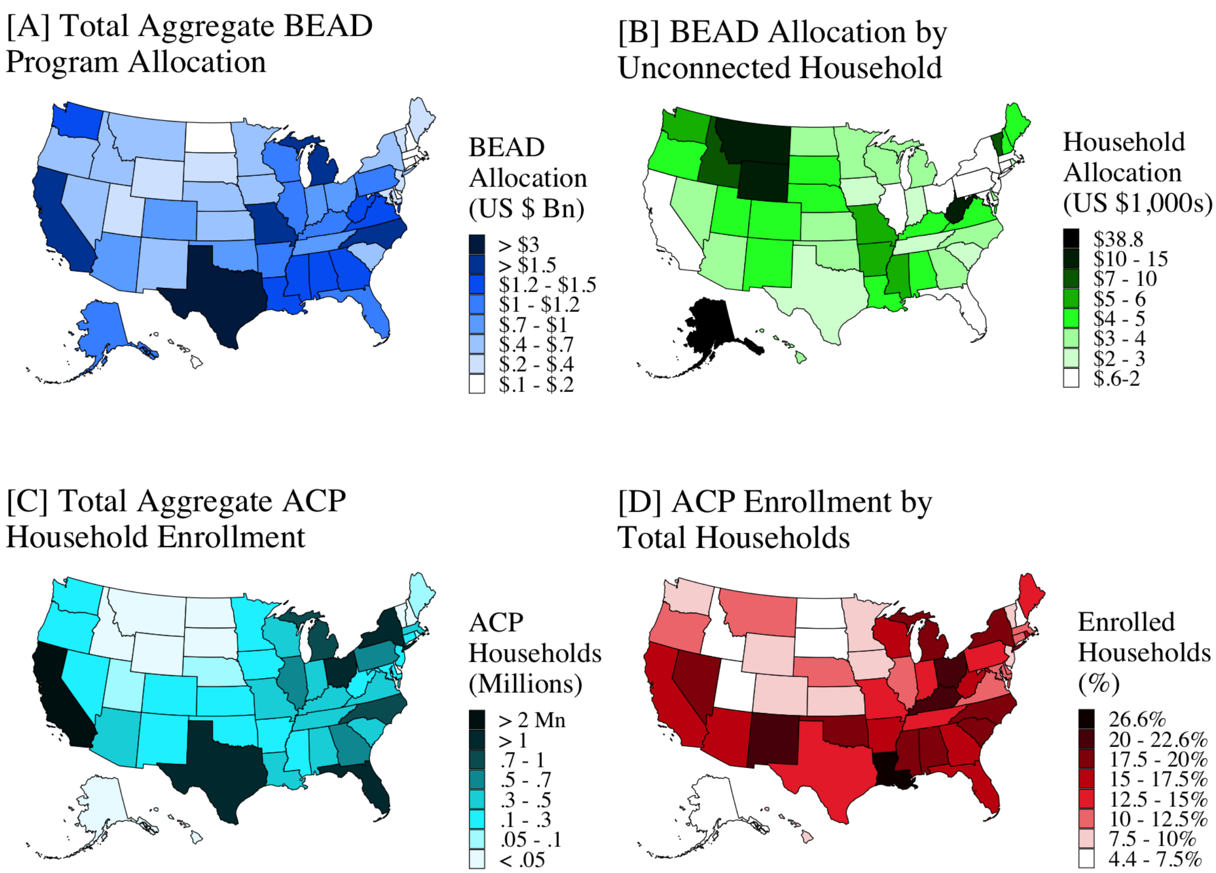

Figure 2: Visualization of absolute and relative BEAD and ACP allocations by state

Figure 2 (B) presents the BEAD allocation using the number of unconnected households as the denominator. Alaska is an outlier, spending US $38,802 per unconnected household (729% higher than the mean per household). Now, Texas and California rank towards the lower end of the spectrum, spending US $2,900 and US $1,796 (38.1% and 61.6% lower than the mean per household). States with a larger rural population, like West Virginia (51.3% Rural), Montana (44.1% rural), and Wyoming (33.2% rural), rank higher now, as they are spending on average US $11,960 per home. Only Alabama (41.0% rural) and Missouri (29.6% rural) rank high by both absolute and relative measures of investment.

ACP Household Enrollment is highly correlated with states that have higher populations, as shown in Figure 2 (C), seeing as states like California (2.30 mn), Texas (1.49 mn), Florida (1.39 mn), New York (1.43 mn), and Ohio (1.00 mn) are those with higher enrollment. However, when we measure enrollment using total households as the denominator in Figure 2 (D), we see a different ranking. High-enrollment states show relatively average enrollment per household, like California (2.30 mn, 17.1%), Texas (1.49 mn, 13.8%), and New York (1.43 mn, 18,7%). However, states across the South have relatively high enrollment rates driven by lower incomes and higher per-capita poverty rates. This trend is exemplified in states like Mississippi (.218 mn, 19.3%), Alabama (.366 mn, 18.6%), and an extreme outlier, Louisiana (.474 mn, 26.6%). The Rust-belt region also has high enrollment, including states like Ohio (1.00 mn, 20.7%) and Kentucky (.404 mn, 22.6%).

Furthermore, states like Ohio (20.7%), New Mexico (20.2%), and Kentucky (22.6%) have greater enrollment, which is also an indicator of improved broadband access (comparatively with the pre-ACP period). Households without access to broadband providers gain no additional utility in enrolling in a subsidy program for broadband.

From this, we see that there is a relationship - states like Montana ($11,900 per unenrolled household, 10.7% ACP enrollment), Wyoming ($13,800 per unenrolled household, 7.63% ACP enrollment), and West Virginia ($10,300 per unenrolled household, 15.5% enrollment) are receiving a large amount of funds to deploy broadband while having relatively low ACP enrollment.

This pattern persists through other states, with BEAD funding per unenrolled household higher than the mean of $4,681, with an extreme case being Alaska ($38,800 per unenrolled household, 7.22% ACP enrollment). Households in states with higher-than-average BEAD funding are not enrolling in ACP because they do not have a wireline broadband connection to subscribe to. This pattern shows that the BEAD program is directing funds to provide broadband to states that lack access. In states that are receiving less BEAD funding per household than the mean, like California ($1,800 per household, 17% ACP enrollment) and Ohio ($1,400 per household, 20.7% enrollment), there is often higher ACP enrollment because the barrier becomes the price of broadband rather than access to it.

This trend continues in states that are smaller and wealthier, like Maryland ($1,300 per household, 11.5% ACP enrollment), New Jersey ($848 per household, 7.75% ACP enrollment), and Massachusetts ($609.70 per household, 11.5% ACP enrollment) because there is established broadband infrastructure and households are more able to pay for these services.

Then, there are several states with low median incomes, low BEAD allocation, and low ACP enrollment, like Iowa ($2,600 per household, 8% enrollment) and Illinois ($1,900 per household, 11.6% enrollment). These states could be outliers for several reasons, including low awareness of BEAD and ACP opportunities, low broadband demand, or lack of information about enrollment.

Nevertheless, we note a general pattern: Wealthy states often have low BEAD allocation and low ACP enrollment, suggesting high broadband connectivity and affordability. Some states have high BEAD allocation and low ACP enrollment, suggesting that many households are not connected to wireline broadband and that investments focus on broadband infrastructure. Other states have low BEAD allocation and high ACP enrollment, suggesting that the infrastructure is present, but a connection is not affordable.

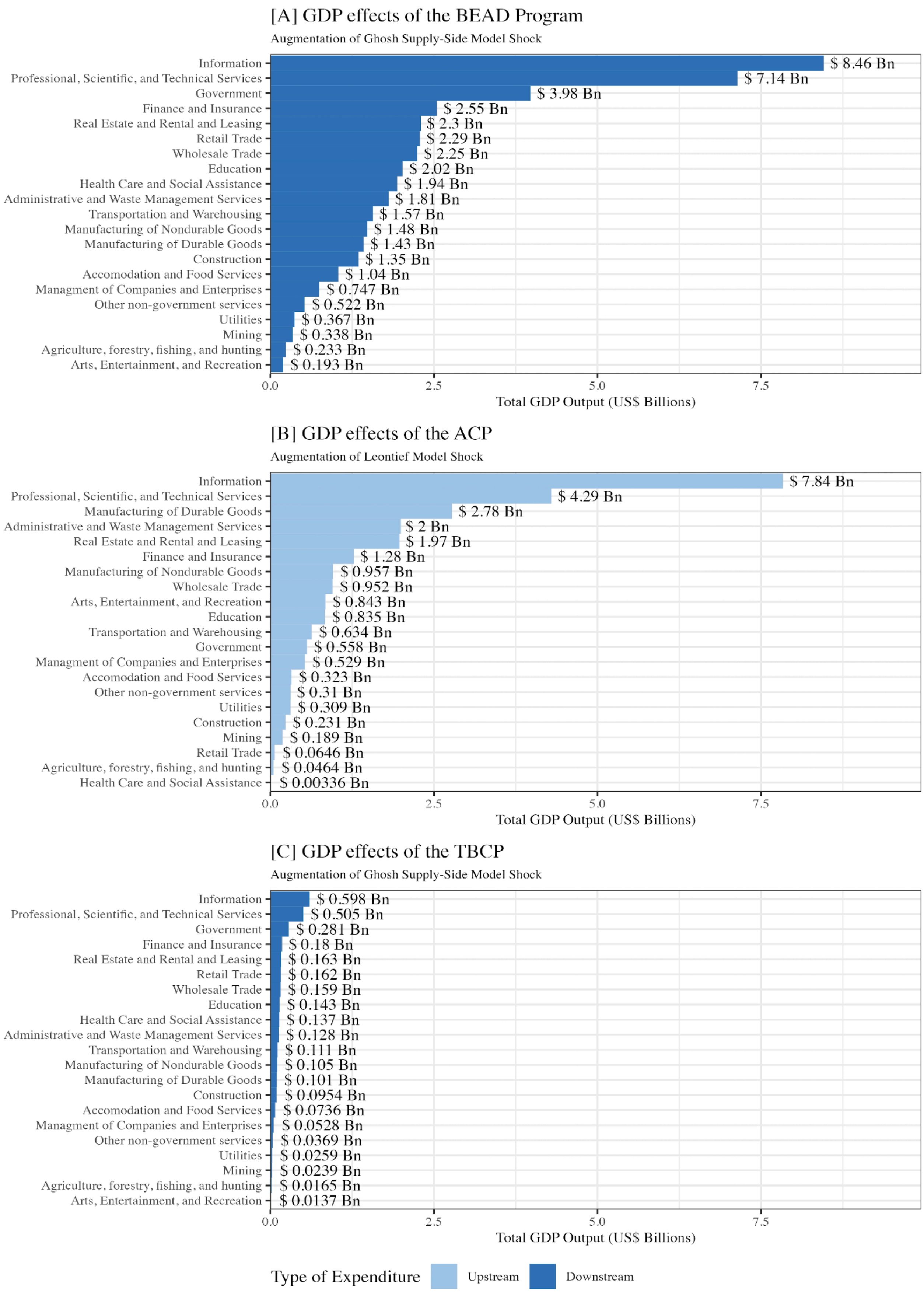
[A] GDP effects of the BEAD Program
Augmentation of Ghosh Supply-Side Model Shock
Information $ 8.46 Bn
Professional, Scientific, and Technical Services $ 7.14 Bn
Government $ 3.98 Bn
Finance and Insurance $ 2.55 Bn
Real Estate and Rental and Leasing $ 2.3 Bn
Retail Trade $ 2.29 Bn
Wholesale Trade $ 2.25 Bn
Education $ 2.02 Bn
Health Care and Social Assistance $ 1.94 Bn
Administrative and Waste Management Services $ 1.81 Bn
Transportation and Warehousing $ 1.57 Bn
Manufacturing of Nondurable Goods $ 1.48 Bn
Manufacturing of Durable Goods $ 1.43 Bn
Construction $ 1.35 Bn
Accomodation and Food Services $ 1.04 Bn
Managment of Companies and Enterprises $ 0.747 Bn
Other non-government services $ 0.522 Bn
Utilities $ 0.367 Bn
Mining $ 0.338 Bn
Agriculture, forestry, fishing, and hunting $ 0.233 Bn
Arts, Entertainment, and Recreation $ 0.193 Bn
0.0
2.5
5.0
7.5
Total GDP Output (US$ Billions)
[B] GDP effects of the ACP
Augmentation of Leontief Model Shock
Information $ 7.84 Bn
Professional, Scientific, and Technical Services $ 4.29 Bn
Manufacturing of Durable Goods $ 2.78 Bn
Administrative and Waste Management Services $ 2 Bn
Real Estate and Rental and Leasing $ 1.97 Bn
Finance and Insurance $ 1.28 Bn
Manufacturing of Nondurable Goods $ 0.957 Bn
Wholesale Trade $ 0.952 Bn
Arts, Entertainment, and Recreation $ 0.843 Bn
Education $ 0.835 Bn
Transportation and Warehousing $ 0.634 Bn
Government $ 0.558 Bn
Managment of Companies and Enterprises $ 0.529 Bn
Accomodation and Food Services $ 0.323 Bn
Other non-government services $ 0.31 Bn
Utilities $ 0.309 Bn
Construction $ 0.231 Bn
Mining $ 0.189 Bn
Retail Trade $ 0.0646 Bn
Agriculture, forestry, fishing, and hunting $ 0.0464 Bn
Health Care and Social Assistance $ 0.00336 Bn
0.0
2.5
5.0
7.5
Total GDP Output (US$ Billions)
[C] GDP effects of the TBCP
Augmentation of Ghosh Supply-Side Model Shock
Information $ 0.598 Bn
Professional, Scientific, and Technical Services $ 0.505 Bn
Government $ 0.281 Bn
Finance and Insurance $ 0.18 Bn
Real Estate and Rental and Leasing $ 0.163 Bn
Retail Trade $ 0.162 Bn
Wholesale Trade $ 0.159 Bn
Education $ 0.143 Bn
Health Care and Social Assistance $ 0.137 Bn
Administrative and Waste Management Services $ 0.128 Bn
Transportation and Warehousing $ 0.111 Bn
Manufacturing of Nondurable Goods $ 0.105 Bn
Manufacturing of Durable Goods $ 0.101 Bn
Construction $ 0.0954 Bn
Accomodation and Food Services $ 0.0736 Bn
Managment of Companies and Enterprises $ 0.0528 Bn
Other non-government services $ 0.0369 Bn
Utilities $ 0.0259 Bn
Mining $ 0.0239 Bn
Agriculture, forestry, fishing, and hunting $ 0.0165 Bn
Arts, Entertainment, and Recreation $ 0.0137 Bn
0.0
2.5
5.0
7.5
Total GDP Output (US$ Billions)
Type of Expenditure
Upstream
Downstream

Figure 3: Sectoral GDP impacts of the Bipartisan Infrastructure Law, separated by program

4.2 What are the GDP impacts of the three funding programs within the Bipartisan Infrastructure Law?

Via the model we specify, we estimate that the total macroeconomic impact of the US $59.7 billion direct federal investment allocated through programs of the Bipartisan Infrastructure Law could result in a total US $146 billion increase in GDP (subject to the methodology employed in this paper, and limitations discussed later). This constitutes .657% of the US GDP.

We visualize the potential upstream and downstream effects in Figure 3 by relevant NAICS code for the absolute macroeconomic impact in Billions, US$ (sectoral results reported in section 4.3). The upstream output consequences indicate industries that receive a positive economic activity impact as a result of increasing broadband demand. These are the industries that provide production impacts to the telecommunications sector to produce more infrastructure, from civil engineering (e.g., installing trenching/ducting) to electronics (active equipment, such as fiber optic, routers, etc.) to basic resource inputs (concrete, steel, etc.). In contrast, the downstream output consequences indicate industries that gain positive economic activity by utilizing broadband as a production input.
Our estimate suggests a direct impact of US $74.5 billion (0.319% of US GDP) from the three broadband investment programs and household spending, a US $90.7 billion (0.408%) implicit downstream benefit, and a US $ 26.1 billion (.117%) implicit upstream benefit.

Moreover, the model estimates that the BEAD Program may increase GDP by as much as US $84.8 billion (.381%), compared to a GDP increase for the American Connectivity Program by up to US $55.2 billion (.248%), and a GDP increase for the TBCP up to US $5.99 billion (.0269%).

When considering the package of all three initiatives, Figure 4 visualizes the total indirect macroeconomic impacts, reaching as much as US $116.8 billion. This translates to a Keynesian multiplier of 2.45 for the broadband investment associated with the Bipartisan Infrastructure Law. Specifically, this relates to Keynesian multipliers for the BEAD program of 2.00, the ACP program of 3.89, and the TBCP program of 2.00.

We can attribute ACP's high multiplier to the independent household investment that arises from the subsidy, as 48.8% is provided by the government and 51.2% is spent by households. When accounting for this, the overall Keynesian multiplier for the program and independent investment is 1.90, and the package has an estimated Keynesian multiplier of 1.96.

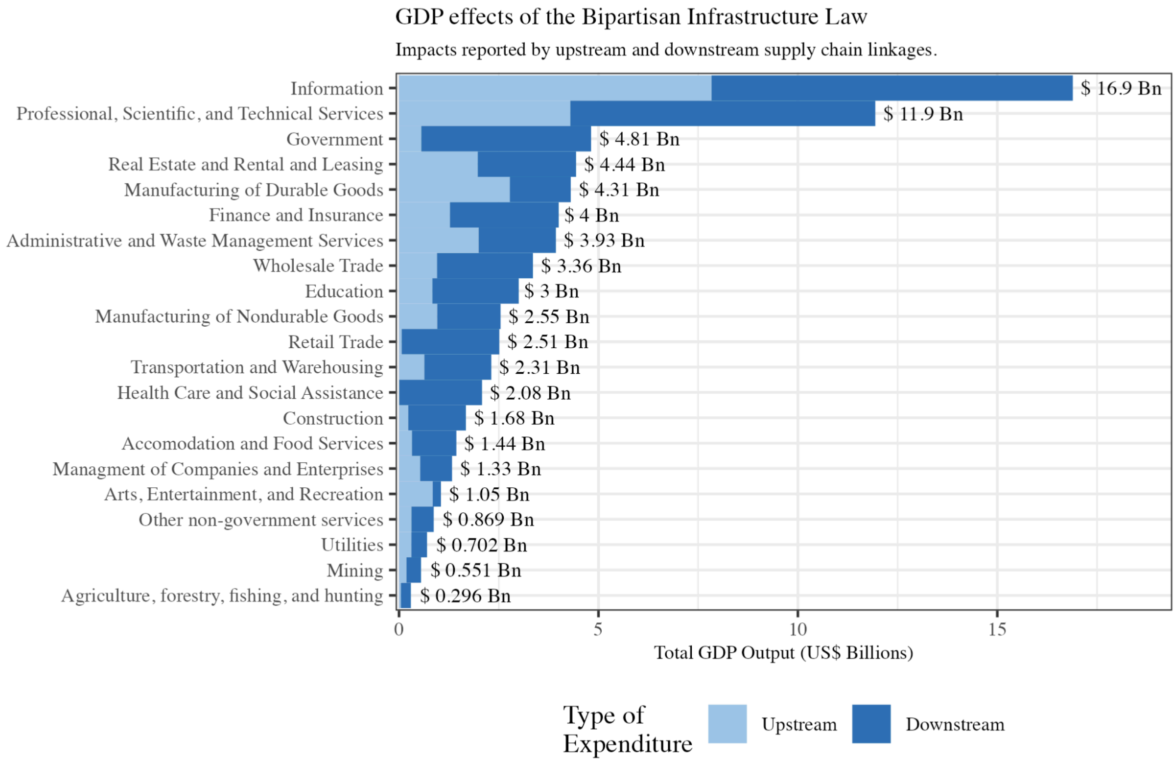

Figure 4: Total estimated sectoral output from the Bipartisan Infrastructure Law

4.3 How are the supply chain linkages affected by allocations from the Bipartisan Infrastructure Law?

A Sankey diagram is presented in Figure 5 visualizing the key linkage impacts of these three initiatives. As illustrated, the indirect benefits ripple throughout all industries, and the overall benefit of broadband infrastructure investments through the BEAD program is greater than that of subsidies in the ACP. Figure 3 displays the inter-sectoral impacts of each bill. Overall, the investment will increase Manufacturing output by US $6.85 billion, which will grow the manufacturing sector by 0.0951% over the next five years.

Other than the Information sector, the Professional, Scientific, and Technical Services sector will increase by US $11.9 billion, or 0.146% over the next five years. Other sectors impacted the most are Real Estate, Rental, and Leasing; Finance and Insurance; and Administrative and Waste Management Services. The Professional, Scientific, and Technical Services sector is currently the fourth largest economic sector, behind Wholesale trade and Construction as defined by the Bureau of Economic Analysis. Those two sectors are projected to grow by US $3.36 billion (.0348%, annually) and US $1.68 billion (.0216%, annually), respectively.

Sectors that are closely dependent on telecommunications are projected to grow, too. Arts, Entertainment, and Recreation, an industry that is linked to advertisement, video streaming, and other resources that depend on reliable Internet connection, are projected to grow by US $1.05 billion (.137%), Although this is one of the smallest sectors of the US economy, new connections to the Internet will spur demand for new goods and services from this sector.

Sectors that are affected the least include Agriculture, Forestry, Fishing, and Hunting ($296 Mn, .0456% growth), Mining ($551 Mn, .0789% growth), and Utilities ($702 Mn, .1068% growth). All three industries are not closely related to the telecommunications industry, with most relying on broadband for sales, input goods, and purchase of capital goods. The relatively high growth rate speaks more to the size of the sectors in comparison to others, as these are also relatively small sectors in the US economy.

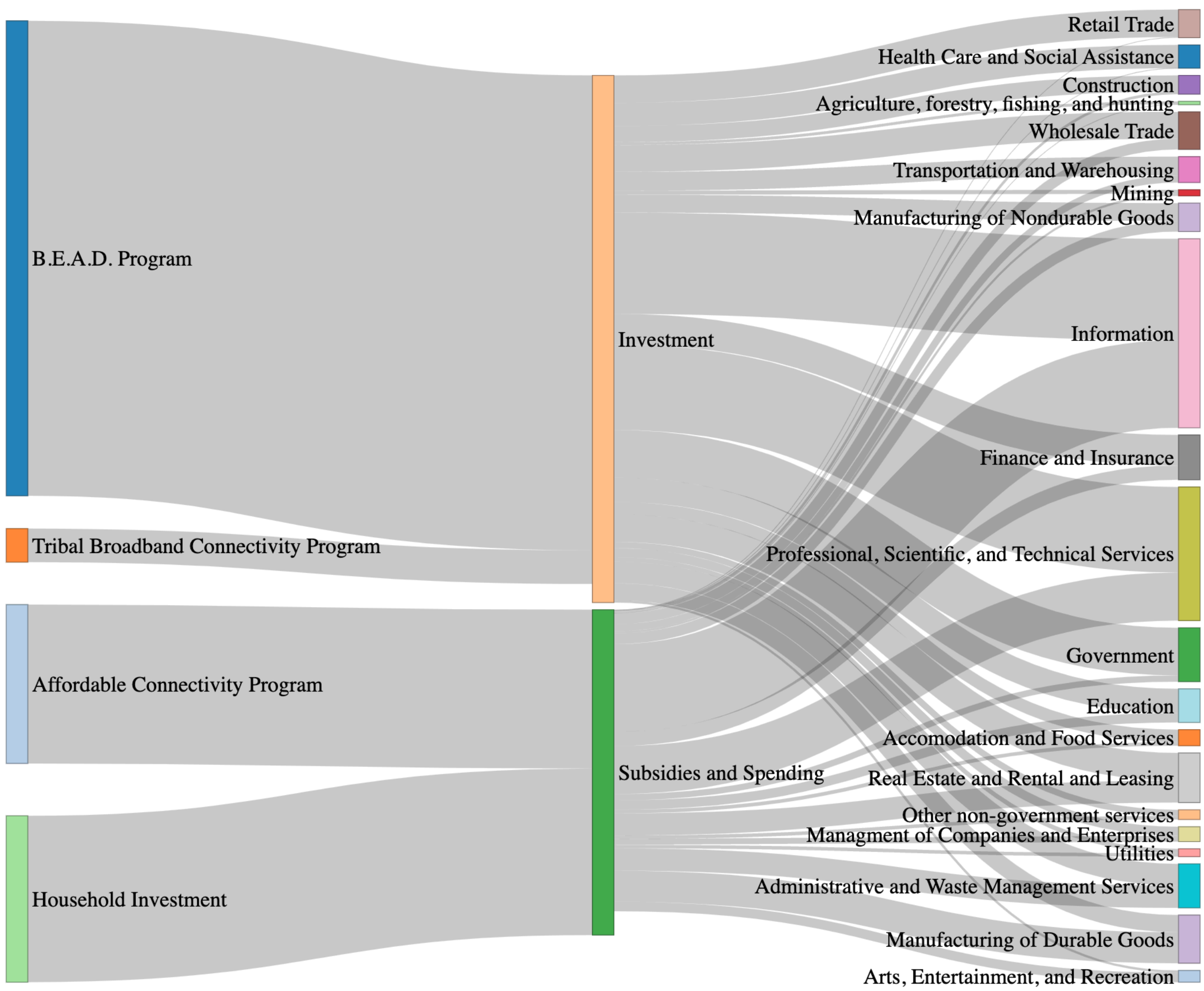

Figure 5: Sankey Diagram illustrating input flows from the various programs, translating to GDP impacts across a wide range of industrial sectors.

5 Discussion

In this section, a discussion will be undertaken where the previously articulated results are evaluated within the broader context of the research questions.

5.1 To what extent does the Bipartisan Infrastructure Law allocate funding to unconnected communities in need?

Generally, most states are organized inversely between BEAD Allocation and the supply of existing broadband infrastructure, indicating that the broadband investment programs in the Bipartisan Infrastructure Law allocate funding effectively, targeting communities without broadband supply or those with a significant price barrier. Indeed, our analysis finds that regions with poorer broadband infrastructure receive commensurate broadband investment via the programs available, generally suggesting the allocated capital is likely to go where there is a clear need (as opposed to politically motivated capital allocation). For example, states with lower-than-average ACP enrollment see a greater BEAD allocation, and this may be explained by the fact that households in poorly connected areas have less reason to enroll in a substandard service. Equally, areas with higher-than-average ACP enrollment see fewer BEAD resources allocated.

While this pattern is consistent, there is one extreme outlier whereby the BEAD program intends to spend almost US $40k to connect each Alaskan household to broadband. Alaska adheres to the general trend we established in section 4.1, whereby only about 7.2% of Alaskan homes have enrolled in the ACP, which could suggest fewer households have broadband access. Due to the low population density in Alaska, deploying broadband infrastructure will take significantly more time and investment (Espín & Rojas, 2024). Instead of connecting to existing broadband networks within the continental United States, Alaskan providers often need to lay large quantities of greenfield infrastructure over long distances within the Alaskan wilderness. To put this investment into perspective, US $38,802 is more than half of the median household income (56%) in the United States (US $69,600) (Guzman, 2022). Connecting Alaskan households to fixed broadband rather than exploring satellite broadband access could prove costly. An Alaskan community with ten unconnected homes could receive an average of roughly US $390,000 to connect to wireline broadband, broadly equating with hiring a teacher for five years (US Bureau of Labor Statistics, 2022) or establishing scholarships for about 50 students to attend the University of Alaska (University of Alaska, 2024).

Another outlying case is Texas, where a significant rural population lowers its per-capita allocation relative to other rural states. Even though Texas will receive the largest grant by far, each unconnected household will only see about US $2-3k to connect to broadband. This per-capita allocation is lower than average, and the ACP connectivity (13.8% enrollment) is approximately average. The discrepancy could result from the high number of unconnected households in Texas - which means the high allocation disperses over a greater number of houses than in other states. Additionally, the spatial distribution of homes in Texas is likely to be denser than in Alaska, and most homes will be closer to an urban area or major highway with substantial local or long-distance fiber infrastructure to connect to. These conditions make it less costly to connect Texan households to the state's broadband network.

Some states, like Ohio and New York, have high ACP enrollment and low BEAD allocations, indicating that a significant barrier to broadband adoption is potentially from lower-income households being unable to afford the service (rather than a lack of existing infrastructure). ACP enrollment in Louisiana is encouraging and shows considerably higher registration than in other states. For example, over 26% of households are enrolled in the program, compared to the nationwide average of 13.3%. Similarly, Ohio (20.7%), Kentucky (22.6%), and New Mexico (20.2%) stand out as states that have succeeded in efforts to ensure that their communities connect to the ACP. States with very high enrollment levels should be concerned as to whether this program may secure longer-term funding into the future, beyond the current administration.

5.2 What are the GDP impacts of the three funding programs within the Bipartisan Infrastructure Law?

We find that the US $59.7 billion investment from the Biden administration's Bipartisan Infrastructure Law could lead to a total macroeconomic impact of up to $146 billion, given an indirect impact of $86.3 billion (59.1%). This is based on the direct investment being spent on building out (predominantly) new fixed broadband infrastructure for cost items such as civil engineering, active equipment deployment, and the associated labor necessary to connect households to high-speed broadband Internet. Whereas, the indirect investment represents both industries utilizing broadband to grow their customer base and the multiplier effects of employed labor undertaking secondary spending in the economy.

Our research estimates that overall, the BIL investment may reach a return multiplier as high as 2.45, which is slightly larger than other infrastructure investment estimates in the literature, such as by Dimitriou (2.2) (Dimitriou et al., 2015). Therefore, this spending could boost GDP growth, while also potentially providing long-term opportunities for (particularly rural) households at a time when our reliance on high-speed broadband connectivity is growing. Thus, there is a strong need to overcome market failure in areas of current poor broadband service. Proponents argue that the lack of infrastructure necessitates the passage of the BIL, as the return on investment to national GDP outweighs the cost to the taxpayers. Additionally, as the estimated $146 billion in GDP trickles through the macroeconomy, there may be other economic benefits, ranging from productivity gains to increased entrepreneurship.

The broadband programs within the Bipartisan Infrastructure Law are the largest federally-directed investment in broadband infrastructure to date. The program's goals are similar to those of the Rural Electrification Act (REA) in the 1930s, established by Franklin D. Roosevelt as an investment associated with the New Deal (*Record Group 221*, 1934). At the time, many detractors argued that the program was too expensive. However, as evidence has shown, the investment laid the foundation for nearly a century of economic development, improving the quality of life of citizens and expanding business opportunities, especially for rural regions (Bouzarovski et al., 2023; Olanrele, 2020; Tierney, 2011).

Similarly, many critics of the programs take issue with the significant government investment at a time when fiscal headroom is at a minimum. Recently, many congressional representatives have voiced their concerns about government spending, stating "...we have no money" and "there's no money in the house" (Davis, 2023; Sforza, 2023). Concern has been growing about the current administration financing government spending through deficit spending, for example, with the US budget deficit effectively doubling in 2023, with the ongoing expansion of a range of federal programs, such as BEAD, ACP, and the TBCP (Gopinath, 2023; Rappeport & Tankersley, 2023).

5.3 How are supply chain linkages affected by allocations from the Bipartisan Infrastructure Law?

Undertaking a key linkage analysis of the industrial sectors most affected from this investment, we quantify the impacts on both upstream and downstream industries (depending on whether the investment is targeted at the supply-side or demand-side). The information sector (NAICS 51) is expected to grow the most, by as much as US $16.9 billion, compared to all other industries. This growth is distinguished by up to $9.06 billion (53.6%) in downstream impact and $7.84 billion (46.4%) in upstream impact. The BIL investment would see this sector increase by over 0.15% over the next five years, due to greater reliance on Internet services, thanks to expanded access to wireline broadband.

The sector with the second-largest growth is estimated to be the Professional, Scientific, and Technical Services sector (NAICS 54). Growing by as much as $11.9 billion, through $7.65 billion downstream (64.3%) and $4.29 billion upstream (36.1%). As businesses and economies gain access to wireline broadband and high-speed Internet, they can use these services to organize and communicate, contributing to the upstream effects. The large downstream quantity is likely because of broadband's dependency on this sector for development and service.

Interestingly, in sectors such as Retail Trade (NAICS 44-45, $2.51 billion) and Health Care and Social Assistance (NAICS 62, $2.077 billion), downstream effects ($2.45 billion, 97.7% and $2.08 billion, 99.8%, respectively) outweigh the upstream effects ($0.065 billion, 0.03% and $.0034 billion, 0.163%, respectively), possibly because these industries are more reliant on broadband as a production input. Even though post-COVID trends suggest consumers are generally returning to physical brick-and-mortar stores, more consumers now value the access and convenience of online retail and purchasing, so the retail industry is becoming increasingly reliant on broadband connectivity to make sales (Brüggemann & Olbrich, 2023; Inoue & Todo, 2023; Sen et al., 2023). Likewise, Health Care is also becoming more reliant on broadband for record storage and interhospital communication. The growth in these sectors implies that they stand to gain significantly more from an increased availability of broadband rather than the increased demand for broadband.

The opposite is true for the Arts, Entertainment, and Recreation Services (NAICS 71), a sector that is affected more by the upstream effect ($0.843 billion, 80.3%) rather than the downstream ($0.207 billion, 19.7%). As consumers connect to new or faster broadband, they also connect to online content sources. However, instead of the Entertainment industry relying on broadband, the consumer utilizes these services to access content. Therefore, it is reflected in the demand-side of the model rather than the supply-side, as Entertainment benefits more from the increased demand for broadband rather than from its increased availability. A similar rationale is likely the cause for the opposite split in the Agriculture, Forestry, Fishing, and Hunting sector (NAICS 11, $.296 billion), which is also the sector that is projected to grow the least, with the downstream impact ($0.250 billion, 84.6%) far outweighing the upstream impact ($0.046 billion, 15.4%).

In general, the results we find here suggest that the most interconnected industries are projected to see the largest increase in growth from the investment programs, such as the Information sector (NAICS 51, \$16.9 billion) and Professional, Scientific, and Technical Services (NAICS 54, \$11.9 billion).

6 Conclusion

In this paper, we assessed the macroeconomic impacts of the Broadband, Equity, Access and Deployment program, American Connectivity Program, and Tribal Broadband Connectivity Program. We firstly evaluated the program allocation and enrollment on a state-by-state basis, Secondly, we estimated the national GDP impact by using national accounting data to report the downstream impacts via the Ghosh Supply-side model and upstream impacts via the Leontief Demand-side model. To our knowledge, this is the first macroeconomic assessment of the broadband infrastructure programs within the Bipartisan Infrastructure Law.

In general, we found that higher BEAD allocations target areas with poor current broadband supply. While this may be logical, as it illustrates funding going to areas most in need, this could not have been assumed *a priori* given politically-motivated funding is not always rationally allocated. We also found some outliers with BEAD allocations, for example, with Alaska receiving roughly US \$39,000 per unconnected household. Moreover, Louisiana ACP enrollment is twice as high as the mean state enrollment, with around 26.6% of homes enrolling (versus a mean of 13.3%).

In terms of macroeconomic impact, the total direct contribution to US GDP by the program could be as high as US \$84.8 billion, \$55.2 billion, and \$5.99 billion for the BEAD program, ACP, and TBCP, respectively. Overall, the broadband allocations could expand US GDP by \$146 billion, with a multiplier of 2.45. The NAICS industries that may benefit the most from these programs include the Information sector (NAICS 51, \$16.9 billion), the Professional, Scientific, and Technical Services Sector (NAICS 54, \$11.9 billion), and the Manufacturing Sector (NAICS 31-33, \$6.85 billion). Insights about the supply-chain industry were also evaluated, including the relative interdependencies of sectors on broadband telecommunications and how certain sectors were more reliant on high-speed, reliable Internet as a value-added input good than other sectors (Agriculture, forestry, fishing, and farming; NAICS 11; 84.6% downstream and Retail Trade; NAICS 44-45; 99.8% downstream).

As with any method, there are relevant limitations which are worth highlighting. Firstly, the IO approach in this paper is static and does not account for potential dynamic impacts in the macroeconomy as supply and demand forces play out in a market environment. Thus, we do not account for structural changes or how measured stimulus would alter sectoral interdependencies. Like other IO approaches, we assume constant proportionality of industry inputs, so there are no changes to the original technical coefficients matrix regardless of sectoral augmentation from additional output, increased productivity, or novel technologies (Galbusera & Giannopoulos, 2018; Miernyk, 1966). Moreover, this approach depends on constant returns to scale, with no decreasing marginal cost of production as output increases. Importantly, this IO model approach produces the upper bound on GDP impacts, so growth could be lower than projected (Jones, 1968; Oosterhaven, 1988; Walheer, 2020). One real benefit of an IO approach is understanding potential inter-sectoral interactions, which has driven the focus of this paper to supply linkage analysis.

Future research could expand the methodology in this paper to focus on dynamic macroeconomic modeling strategies to study how spending increases from building new broadband infrastructure compares to the estimates produced here. Additionally, future studies could examine how to better allocate funding towards future infrastructure investments, ideally maximizing the effectiveness of allocations through the BEAD and ACP enrollment programs.

7 Acknowledgements

We thank Tony To for reviewing an earlier version of this manuscript and providing comments.

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