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Radio Spectra as Telecommunications Assets

Authors Rachel Soloveichik, U.S. Bureau of Economic Analysis (BEA)

Contact Rachel.Soloveichik@bea.gov

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Abstract This paper demonstrates that the measured wealth stock of the United States increases by $2 trillion in 2022 when radio spectra are included on the balance sheet. Furthermore, this paper also demonstrates that tracking radio spectra can impact the National Income and Product Accounts (NIPAs) noticeably. It may be true that radio spectra are not produced—and therefore do not impact measured investment. Similarly, radio spectra do not deteriorate with age—and therefore do not impact measured consumption of fixed capital. However, this paper argues that radio spectrum licenses that the federal government gives for "free" to the telecommunications industry should be tracked as a capital transfer in BEA's NIPA table 3.1. These capital transfers are targeted toward new entrants and new products, and so they increase the competitiveness of the telecommunications industry.

Keywords Natural resource, telecommunications, radio spectra, wealth, capital transfer

JEL Code E01, L96, H25

Introduction

Natural resources are a key component of national wealth, and the official national accounting guidelines explicitly recommend that they be tracked on country balance sheets (U.N. Statistics Division 2008, sec. 10.166–185). Previous research at the U.S. Bureau of Economic Analysis (BEA) has focused on measuring land as a natural resource. That research shows that the measured wealth stock of the United States increases by approximately $25 trillion when land is tracked on the balance sheet (Larson 2015) (Wentland et al. 2023). This paper extends natural resource measurement research to show that the measured wealth stock increases by another $2 trillion in 2022 when radio spectra are also tracked on the balance sheet.

One might think that radio spectrum licenses have no impact on the National Income and Product Accounts (NIPAs). It is true that radio spectra are not produced—and therefore do not impact measured investment. Similarly, radio spectra do not deteriorate with age—and therefore do not impact measured consumption of fixed capital. However, BEA already tracks radio spectrum licenses to a limited extent. Licenses that are auctioned by the government are currently tracked as a negative net purchase of nonproduced assets by the government in NIPA table 3.1 (line 41). Furthermore, this paper will argue that radio spectrum licenses that the federal government gives for "free" to the telecommunications industry should be tracked as a capital transfer from the government in NIPA table 3.1 (line 40). That tracking would not change measured telecommunications output or measured gross domestic product (GDP). But it would change both measured telecommunications industry assets and measured government policy towards the telecommunications industry.

This paper focuses on radio spectra because they are relatively easy to track and value. However, the same basic ideas that will be discussed in this paper apply to other natural resources as well. Future research may study other natural resources such as mineral reserves, easements, water, wildlife, and so on. It is likely that the measured wealth stock and measured capital transfers would rise by even more if those natural resources were also tracked using the same techniques used for radio spectra.

This paper is divided into four sections. Section 1 describes the current system and the historical system in which radio spectrum licenses were created, transferred, and used. Section 1 then argues that radio spectrum licenses that were given for free to the telecommunications industry can be tracked as capital transfers. Section 2 uses historical data from the Federal Communications Commission (FCC) and other sources to calculate both the quantity of radio spectrum licenses that were given for free to the telecommunication industry and the quantity of each radio spectrum licenses that were purchased by the telecommunications industry from 1925 onward. Section 3 estimates the value per unit of radio spectra from 1925 onward. It then combines those estimated values with the quantities from section 2 to calculate capital transfers of spectra, purchases of spectra, and the private stock of spectra. Section 3 also presents estimates of the government stock of radio spectra. Finally, section 4 presents the revision to productivity for the telecommunications industry when the capital services from both free and purchased radio spectrum licenses are included in total capital services.

Section 1: Purchases and Allocations of Radio Spectrum Licenses

The official guidelines for national accounting, *System of National Accounts 2008* (*SNA 2008*), are very clear that radio spectra are nonproduced natural resources (U.N. Statistics Division 2008, sec. 10.185). At the same time, radio spectra cannot be used until the FCC licenses them. One could argue that the FCC's licensing process is equivalent to land surveying, which is considered a land improvement, and therefore should be tracked as produced capital (U.N. Statistics Division 2008, sec. 10.51 and 10.97). Or one could argue that the FCC's licensing process is equivalent to land reclassification, which is normally not considered a land improvement, and therefore should not be tracked as produced capital (U.N. Statistics Division 2012, sec. 5.297). In practice, the private wealth stock is the same whether radio spectrum licenses are partially produced by the FCC or are a pure natural resource.

Tracking radio spectra raises measured wealth by the value of the radio spectra that are newly included on the balance sheet. A simple method to valuing spectra would be to value all radio spectra units at the average auction price. That method would yield a value of $5.8 trillion for all radio spectra [(1,724 spectra units) times ($3.4 billion per spectrum unit)]. This paper uses a more complex method that values purchased radio spectra based on their actual price with an adjustment for inflation and values other radio spectra based on an imputed price that takes into account the frequency of the radio spectra, the purpose for which it is used, and other factors. Auctioned radio spectra are generally higher quality than other radio spectra – so imputed prices are generally lower than actual prices. Based on the more complex method, this paper calculates that radio spectra purchased by the telecommunications industry had a value of $0.2 trillion in 2022, radio spectra allocated for free to the telecommunications industry had a value of $0.1 trillion in 2022, and radio spectra retained by the government had a value of $1.4 trillion in 2022. In total, tracking radio spectra raises the measured wealth stock in 2022 by nearly $2 trillion.

Radio Spectrum License Purchases

The current system for purchasing radio spectrum licenses is simple. The FCC announces that specific frequencies will be auctioned by a particular date and then invites companies to bid on those frequencies (FCC 2023). Between 1994 and 2022, the telecommunications industry paid a total of $259 billion for frequencies that they use or plan to use for cellular services. Consistent with general national accounting practices, this paper uses the winning auction bid to value purchased spectra as of the date that the auction concluded.[1] This paper then deflates each winning auction bid by a price index that will be described later to calculate the real value of purchased spectra.

A few auctions appear to report negative spectrum license prices. These apparent negative prices can be explained by specific programs that encourage companies to provide telecommunications services in underserved areas. The FCC uses a reverse auction to distribute the funds associated with those specific programs: companies bid on the amount of funding required to provide services and the lowest bidder wins the spectra together with the obligation to provide services (Gallagher 2023). This paper assumes that the market value of spectra whose usage must be subsidized in this way is zero—and therefore ignores those spectrum licenses when calculating the aggregate value of all radio spectrum licenses.

Purchases of radio spectra, like purchases of other natural resources, do not impact the total wealth stock (U.N. Statistics Division 2008, sec. 10.171). The auctioned spectra had been an asset on the seller's balance sheet and now are an asset on the purchaser's balance sheet. In other words, purchases lower the wealth stock of the government and raise the wealth stock of the private telecommunications sector by precisely equal amounts. In practice, radio spectra prices are volatile, and so each observed purchase has the potential to change the calculated price index. So, a particular purchase could change the measured nominal wealth stock if the actual price observed is not precisely equal to the previously imputed price. But the real wealth stock is not impacted by purchases by the private sector from the government sector or vice versa.

BEA currently tracks auctions of radio spectra as a component of the broader line "net purchase of nonproduced assets" for the government in NIPA table 3.1 (line 41). The FCC's auctions involve a sale of radio spectra from the government to the private sector—so they are tracked as negative net purchases. This paper does not recommend any changes to the tracking of auctioned radio spectra.

Radio Spectra Allocations for Free

Since 1925, the federal government has allocated free radio spectra for many different purposes. This paper focuses on the four main purposes: radio broadcasting, television broadcasting, cellular service, and satellite service. Users who are allocated spectra for one purpose are not allowed to use those

[1] It may be true that some economics papers have suggested changes to the FCC's auction design that could increase the competitiveness of auctions (Banks et al. 2003). But national accounts generally use market prices to value both competitive and noncompetitive transactions (U.N. Statistics Division 2008, sec. 3.119). Hence, radio spectra values do not need to be adjusted for auction design issues.

spectra for another purpose. Accordingly, the exact same spectrum frequency can have a different market value if it is allocated for one purpose rather than another.

The historical system for allocating free broadcast radio spectra was targeted toward first users. To be clear, broadcasters could not use a particular frequency without complementary assets like communications equipment and land for a broadcast tower. Accordingly, there was generally a small gap between the date a broadcast station was first granted a spectrum license and the date the broadcast station actually used those spectra (FCC 2021). Nevertheless, policymakers wanted radio spectra to be used—and so they generally allocated radio spectra to companies with both specific plans and the financial capability to quickly implement those plans (Code of Federal Regulations 1939). Furthermore, companies that did not start a broadcast station quickly enough could forfeit their license (FCC 1959).

The historical system for allocating free cellular service spectra was less targeted. Almost any entity could apply for a license, and then the FCC used a lottery to choose between applicants. Companies needed neither specific plans nor the financial capability to quickly implement those plans to be allocated radio spectra. So many lottery winners quickly resold their spectrum to more prepared firms (Milgrom 2003).

Free radio spectrum licenses originally conveyed substantial but not complete ownership rights. The written law stated that radio spectra were government property and broadcast stations were required to serve the public interest in return for their usage (FCC 1946). These public interest requirements were extensively discussed in the legal literature (Barron 1961, Houser 1972, and McCoy 1989), and there is evidence that they influenced coverage of politically sensitive topics (Hazlett and Sosa 1997) and increased coverage of local news (McGowan et al. 1972). One analysis in the 1970s estimated that the economic cost of influenced coverage of politically sensitive topics was minimal but the economic cost of increased coverage of local news might have been as high as 18.3 percent of revenue (Crandall 1978). This paper rounds that analysis to an assumption that the federal government originally retained ownership of 20 percent of allocated free radio spectra. Accordingly, this paper treats the original allocation as a capital transfer equal to 80 percent of the licensed radio spectrum and the removal of public interest requirements in the 1980s (Read and Weiner 1997) as a capital transfer of the remaining 20 percent of licensed radio spectrum.

Just like purchases of radio spectra, transfers of radio spectra do not impact the total wealth stock. Instead, allocations of free radio spectra lower the wealth stock of the giver and raise the wealth stock of the receiver by precisely equal amounts. Unlike purchases of radio spectra, allocations of free spectra do not normally change the calculated price index either. So, allocations of free radio spectra rarely change the measured nominal wealth stock and never change the real wealth stock.

BEA currently does not track allocations of free radio spectra in the NIPAs. The next subsection of this paper will recommend tracking these allocations as capital transfers. If that recommendation were implemented, they would be included as a component of the broader line "capital transfer payments" for the government in NIPA table 3.1 (line 40).

Accounting for Radio Spectrum Licenses Purchased or Allocated

Both purchased and allocated radio spectrum licenses have nearly infinite lives. It may be true that the official license term for purchased licenses is only 10 to 15 years and the written law stated that allocated licenses only lasted a few years with no renewal rights (Gehring 1976). In practice, purchased licenses are always renewed upon request (Milgrom et al. 2017) and the FCC almost always renewed allocated licenses for functioning broadcast stations (House of Representative 1974). Consistent with those practices, generally accepted accounting principles recommend that companies treat radio spectrum licenses as assets with an indefinite lifespan (Schenk 1966 and Randolph 2017). National accounting theory also reflects those principles and recommends that radio spectrum license holders should be treated as radio spectrum owners:

> *When sale of an asset applies and when the life span of the licenses and of the spectrum coincide, the payment for a license is treated as the sale of the spectrum itself. The latter situation applies always when licenses are granted indefinitely (U.N. Statistics Division 2008, sec 17.323)*

Consistent with *SNA 2008*'s clear recommendation, this paper treats a radio spectrum license auction as a government asset sale and a telecommunications industry asset purchase. BEA also follows that treatment when calculating net purchases of nonproduced assets by the government in NIPA table 3.1.

However, national accounting theory is not so clear about the recommended treatment of licenses that were allocated for free. In theory, they could be treated as a subsidy, a capital transfer, or a current transfer. Measured GDP in market prices and measured wealth by sector do not change regardless of which treatment is chosen. But the choice of treatment impacts NIPA table 3.1, which shows the three types of government spending on separate lines. *SNA 2008* defines subsidies, capital transfers, and current transfers:

Subsidies are current unrequited payments that government units, including nonresident government units, make to enterprises on the basis of the levels of their production activities or the quantities or values of the goods or services that they produce, sell, or import. (sec. 7.98)

Capital transfers are unrequited transfers where either the party making the transfer realizes the funds involved by disposing of an asset (other than cash or inventories), by relinquishing a financial claim (other than accounts receivable) or the party receiving the transfer is obliged to acquire an asset (other than cash or inventories) or both conditions are met. Capital transfers are often large and irregular but neither of these are necessary conditions for a transfer to be considered a capital rather than a current transfer. (sec. 10.200)

Current transfers consist of all transfers that are not transfers of capital. They directly affect the level of disposable income and should influence the consumption of goods and services. In practice, capital transfers tend to be large, infrequent and irregular, whereas current transfers tend to be comparatively small and are often made frequently and regularly. (sec. 8.39)

Reading these three definitions, radio spectra that are allocated for free match the definition of capital transfers closely and therefore probably should be tracked as capital transfers. After all, the radio spectrum licenses given for free are clearly capital assets. And unlike subsidies, spectra allocations were not explicitly linked with either the level of production activities or the value of goods or services that they produce, sell, or import. Furthermore, free spectra allocations were experienced by individual broadcasters as large transfers that occurred infrequently. Accordingly, this paper tracks spectra allocations as capital transfers.

Capital transfers are not associated with current production and are therefore excluded from NIPA measures of income and savings (BEA 2022). Of course, allocations of free radio spectrum license did have indirect associations with various government goals. Early television licenses were allocated to maximize the population with any television service rather than maximize the number of television stations in urban areas (McGowan et al. 1972). Politically connected individuals or companies sometimes got favorable treatment from the FCC (Russell 1999). In some years, minority applicants for a radio spectrum license were preferred over other applicants (FCC 1978). Complexities like this are common in government programs (Acemoglu and Verdier 2000), so this paper's exclusion of free radio spectrum license allocations from the telecommunications industry current accounts is consistent with BEA's exclusion of other capital transfer programs from other industry accounts.

Section 2: Quantity, Quality, and Price for Private Spectrum Licenses

The FCC currently regulates all frequencies in the United States between 9 kilohertz and 275 gigahertz. Radio frequencies are often shown with a log scale (Corporation for Public Broadcasting 2014), and so this paper defines the number of frequency units in a license as the natural log of the highest frequency included minus the natural log of the lowest frequency included.[2] All else equal, the number of frequency units included in the license determines the quantity of content that can transmitted using the radio spectra. And all else equal, the area covered by a license determines the quantity of content that can be received using the radio spectra. This paper defines 1 unit of spectrum as 1 frequency unit for 1 percent of the U.S. land mass. In total, this paper calculates that there are 1,724 spectrum units [(natural log of 275,000,000,000 minus natural log of 9000)*(100 percent of the U.S. land mass)] that are included in the natural resource category "radio spectra."

Radio frequencies are not interchangeable commodities. Lower frequencies typically travel longer distances but carry less information (Sobolewski 2001). Furthermore, communications equipment is often customized for a particular frequency range and cannot be easily used for frequencies outside that range (Corporation for Public Broadcasting 2014). This paper follows the literature (Laflin and Dajka 2007) and divides those radio spectra into eight separate types: very low frequency (VLF), low frequency (LF), medium frequency (MF), high frequency (HF), very high frequency (VHF), ultra high frequency (UHF), super high frequency (SHF), and extremely high frequency (EHF).

Quantity of Radio Spectrum Units Owned by the Telecommunications Industry

Commercial radio started in the late 1910s, and the federal government quickly set up an agency to license spectrum users. By the time the NIPAs started in 1929, the federal government's control of radio spectra was well established (Zollman 1927). Unlike the United Kingdom's pirate radio stations, unlicensed radio stations in the United States have always been very small compared to licensed radio stations (Stone 1988). Hence, this paper only includes spectra that have been explicitly licensed to the telecommunications industry in its measures of radio spectra owned by the U.S. telecommunications industry.

This paper uses detailed FCC records to estimate the number of spectrum units transferred by type and year. The FCC's auctions all have precise end dates, and so it is straightforward to determine when each spectrum unit was purchased. In contrast, the FCC's allocations are vaguer. It may be true that individual broadcast construction permits were granted on a specific date—but the spectrum did not actually

[2] Some licenses have gaps between frequencies. The units in the gaps are subtracted to get only the included units.

become private property until the broadcaster provided satisfactory service to the public. To remind readers, an earlier section of this paper calculated that the removal of the public interest requirements represented a gradual transfer of 20 percent of broadcast spectra from the government to private companies. This paper assumes that the removal happened smoothly throughout the 1980s. This paper then imputes earlier allocations using the industry literature. AM radio spectra are assumed to have been allocated over the 1924–1943 period, and FM radio spectra are assumed to have been allocated over the 1963–1978 period. Information on the number of radio broadcasting stations operating each year was not located, so this paper assumes a smooth allocation process during the periods given earlier. VHF television spectra are assumed to have been allocated during the 1946–1959 period, and UHF television spectra are assumed to have been allocated over the 1946–1980 period. Information on the number of television broadcasting stations operating each year is used as an interpolator to estimate annual allocation rates. Finally, VHF cellular spectra are assumed to have been allocated smoothly over the 1980–1989 period. A more detailed analysis might estimate slightly different annual quantities, but the qualitative trends would be similar.

Figure 1: Radio Spectrum Units Owned by the Telecommunications Industry

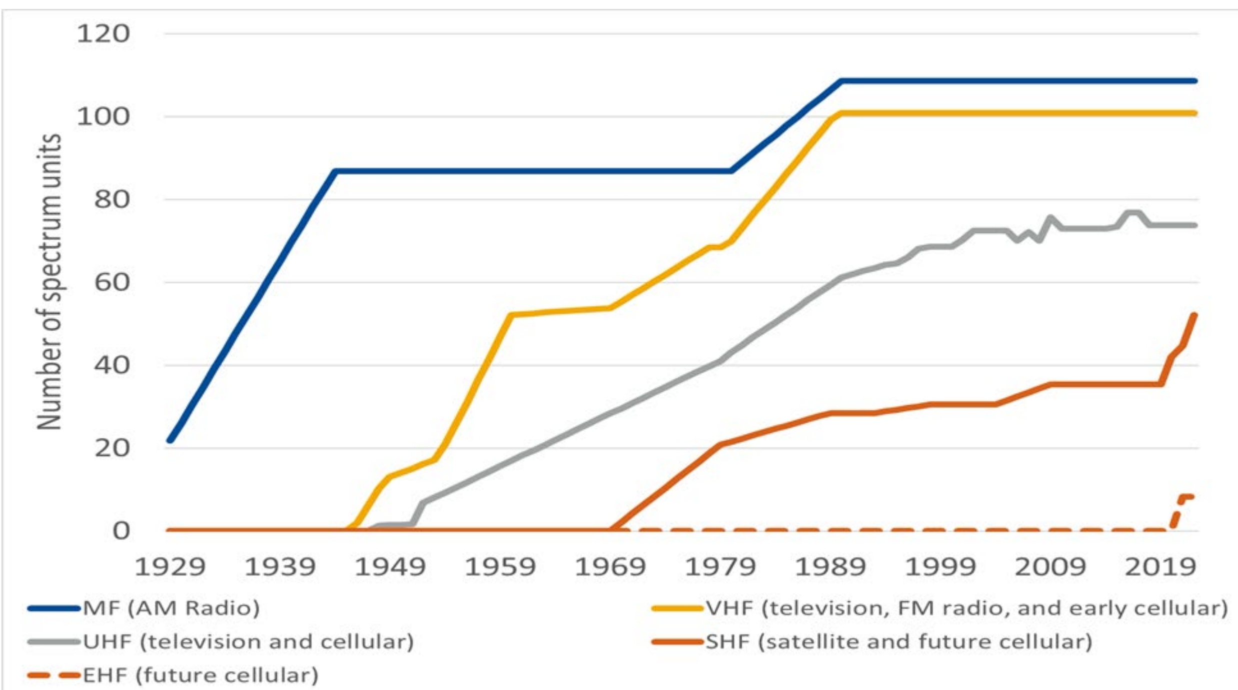

Figure 1 shows that the telecommunications industry has been consistently expanding its ownership of radio spectra. When the NIPAs started in 1929, the telecommunications industry held only 22 units of radio spectra that were all allocated to AM radio stations. By 2022, the telecommunications industry held a total of 344 radio spectrum units. Interestingly, the pace of spectrum acquisition appears to have slowed around the time that the FCC started auctioning spectra rather than allocating spectra for free. However, more research would be needed before a causal link between FCC policy and telecommunications asset growth could be established conclusively.

This paper assumes that no radio spectra are owned by private entities outside the telecommunications industry. It may be true that the FCC has allocated frequency units for private users outside the telecommunications industry. For example, taxi companies once used radios to notify drivers of a service request (FCC 1950). This type of communication can be very useful for industries without other communication alternatives. Similarly, this type of communication can be enjoyable for amateur radio hobbyists (Rappaport 2022). But the radio spectra used by private entities outside the telecommunications industry are almost always available to multiple firms or individuals simultaneously, and so they are not privately owned in the same way that telecommunications frequencies are privately owned. Conceptually, those radio spectra are analogous to roads and other government infrastructure. Accordingly, this paper treats those radio frequencies as government assets. Furthermore, radio frequencies that have been set aside for scientific uses like radio astronomy (National Research Council 2007) or public safety uses like police communication (Government Accountability Office 2019) are definitely government assets.

Section 3: Radio Spectrum License Prices and Values

FCC's Auction Prices Relative to Telecommunications Industry Revenue

The auction data are taken directly from the FCC's website. When accessed on December 14, 2023, that website listed 113 completed spectrum auctions. The previous section calculated the quantity of radio spectrum licenses sold in each of those 113 auctions. This section calculates relative prices dividing the auction price for spectra with the nominal net present value of revenue associated with the purchased spectra.

The FCC's auction data show that the auction price for cellular spectra was about 5 cents for every dollar in net present value of revenue. Between 1994 and 2017, carriers paid a total of $137 billion for 37 units of UHF spectrum. Over the same period, cellular carriers averaged about $5 billion in cellular service revenue per spectrum unit per year. This paper assumes a 3-year lag between spectrum purchase and spectrum usage and that revenue growth after 2022 will be similar to historic revenue growth. Using a discount rate of 7 percent real, this paper calculates a net present value of revenue about $80 billion per spectrum unit. Based on that calculation and the exact timing of each purchase, this paper calculates ratio of spectrum value to net present value of revenue of 4.54 percent. To be clear, the remaining

95.46 percent of cellular service revenue is not necessarily profit. Cellular carriers have capital costs like cellular service towers and equipment, labor costs like customer service workers, and intermediate costs like electricity. This paper focuses on radio spectra as a natural resource, and therefore does not study any of those costs.

Radio spectrum license prices are often quoted on a MHz per population basis. This method of quoting prices implicitly assumes that the capital services from radio spectrum are linear with number of potential customers. Hence, one could interpret the population density in an area as a measure of radio spectrum license quality. If that interpretation were followed, then average radio spectrum quality would be increasing due to population growth. This paper does not follow that interpretation but rather assumes that the quality of spectrum has been constant from 1924 onward. However, the transaction price for individual licenses may be adjusted for the population associated with that license. Such an adjustment does not change long-term price trends but can reduce short-term volatility.

The FCC's auction data also show that television broadcasters earned about 6 cents for every dollar in net present value of revenue associated with spectra. In 2017, a reverse auction asked UHF broadcasters to voluntarily sell frequencies that they had been allocated for free decades earlier. Broadcasters earned a total of $10.05 billion in return for giving up 14 spectrum units in the 600 MHz frequency range (Gilroy 2017). Based on television industry revenue and the same assumptions made earlier for cellular service, this paper calculates a net present value of revenue about $12 billion per spectrum unit. Accordingly, this paper calculates a ratio of spectrum value to net present value of revenue of 6.15 percent. Just like with cellular service, the remainder of broadcaster revenue is assumed to be associated with other inputs not studied in this paper.

The two ratios calculated earlier for cellular carrier spectra and television broadcast spectra are close enough that the differences may be due to either random price volatility or slight methodological issues. Furthermore, the FCC's auction data do not yield reliable ratios for radio broadcasters or SHF spectra. It may be true that the FCC occasionally auctioned AM radio broadcast spectra—but those auctions are too small to calculate ratios for this paper's usage. Similarly, the FCC's large auctions of SHF spectra are too recent to determine the revenue that cellular carriers will be able to get from those spectra. For now, this paper uses the average of the two ratios calculated earlier, 5.34 percent (4.54+6.15)*0.5, to convert all types of telecommunications revenue into a natural resource value.

Historical Spectra Values, Imputed From Historical Industry Revenue

Information on prices before 1994 was not located. It may be true that private companies have bought and sold individual broadcast stations for decades (Senate 1987). However, those transactions generally bundled radio spectra with tangible capital like broadcast towers and intangible capital like entertainment originals (Krasnow et al. 2010). Hence, it is difficult to calculate values for radio spectrum licenses alone. Economic theory suggests that the value of a capital asset equals the net present value of its capital services (Jorgenson 1963). Precise information on the capital services associated with each radio spectrum unit could not be located. For now, this paper divides total revenue by spectra type with the number of spectrum units of that type to calculate revenue per unit, sums future revenues to calculate the net present value of future revenue per unit, and then uses that calculated net present value of revenue per unit as a proxy for spectrum prices.

Data on broadcast revenue are taken from previous research on the advertising industry (Sveikauskas et al. 2023). That paper reports radio advertising revenue back to the 1920s and television advertising revenue back to the 1940s. This paper supplements those advertising time series with information on noncommercial radio and television broadcasting expenditures from the Economic Census, the Service Annual Survey, and published budgets of the Corporation for Public Broadcasting (Corporation for Public Broadcasting 2024). This paper splits radio revenue between AM radio and FM radio using estimates of the FM share of radio advertising from multiple sources (Statistical Abstract of the United States 1969, 1974, 1979, and 1984; National Telecommunications and Information Administration 1988; Greenberg 2012; and Insider Radio 2017). Finally, this paper splits television revenue between VHF television and UHF television[3] using historic reports on broadcast television financials (FCC 1952–1981) and recent counts of television stations by type (Levy et al. 2002 and Statistical Abstract of the United States 2012).

Data on cellular service revenue are taken from BEA's published gross output numbers for the industry wireless telecommunications, excluding satellite; the Service Annual Survey; the Annual Survey of Communication Services; and BEA's published estimates of personal consumption expenditures on cellular services. Previous research has shown that cellular service is often bundled with phone hardware sales (Aizcorbe et al. 2019). Based on that paper, this paper multiplies total cellular carrier

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[3] Most viewers of broadcast television stations receive their signal through cable subscriptions (Television Bureau of Advertising 2023)—and therefore might be able to access television shows even if the broadcaster lost its spectrum licenses. In practice, FCC rules heavily encourage cable networks to carry local broadcast stations (Perry 2009), and so broadcast spectra have value even if they are not used directly. Conceptually, this is like zoning rules that impact residential land values (Glaeser and Gyourko 2003). BEA's existing estimates of land values include both direct and indirect land values in their totals (Larson 2015 and Wentland et al. 2023). Hence, this paper's inclusion of both direct and indirect values of radio spectra is consistent.

revenue by 0.75 to get an estimate of revenue associated with cellular services alone. Information on the share of revenue associated with VHF spectra, UHF spectra, and SHF spectra was not located. For now, this paper uses the share of cellular revenue associated with paging services as a proxy for the share of cellular service revenue associated with VHF spectra. This paper also uses a recent industry report on the future potential of SHF cellular service (Grandview 2023) to estimate the share of future cellular revenue that will be associated with SHF spectra. The remainder of cellular revenue is assumed to be associated with UHF spectra.

Data on satellite revenue are taken from BEA's published space economy satellite account (Highfill and Surfield 2023), estimates of the worldwide satellite service revenue published by Satellite Industry Association (2010 and 2013), satellite communication industry revenue reported by the Service Annual Survey, BEA's published estimates of personal consumption expenditures on subscription television (NIPA table 2.4.5U, line 219), and industry data on the share of television subscribers who get their signal from unwired sources (Television Bureau of Advertising 2023). The industry literature suggests that commercial services like satellite television generally use SHF spectra (Weeden 2013). Accordingly, this paper assumes that all satellite telecommunications revenue is associated with SHF bands.

Average prices are calculated as the weighted mean of the imputed prices for each product within the frequency type. In general, spectra that are allocated to cellular service have higher imputed prices than similar frequencies that are allocated to radio or television. As a result, the average price per spectrum unit generally increases when cellular carriers acquire more units. This increase is particularly noticeable for the SHF spectra because cellular carriers acquired their spectrum units in a few large auctions. In other words, this paper shows an average price series rather than a price index that adjusts for the changing composition of spectrum licenses.

Figure 2: Average Prices for Telecommunications Industry Spectrum

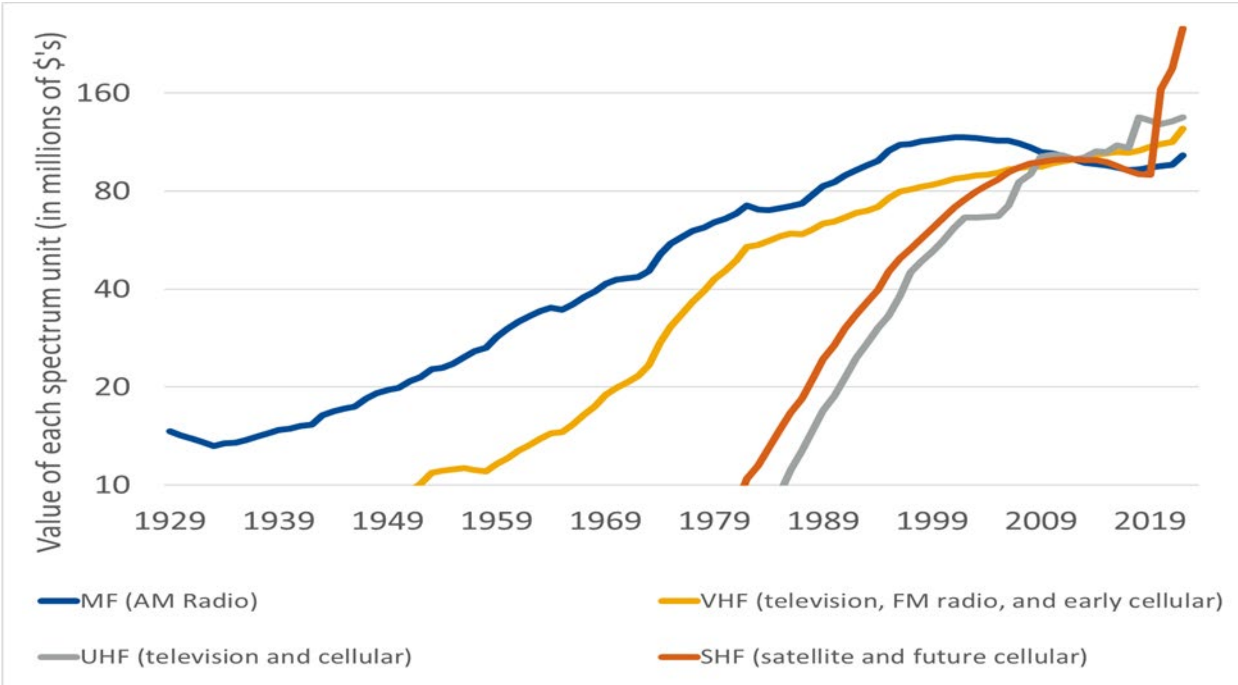

Figure 2 shows all spectra have appreciated since 1925—but higher frequency spectra experienced faster appreciation. The different rates of price growth are likely due to changes in product mixes over time. First, Americans switched from listening to AM radio to watching television (Schwoch 1990). More recently, both radio listeners and television viewers have started switching from broadcast content to downloaded content (Rosenblatt 2020 and McKay 2023). And cellular carriers are starting to switch from VHF and UHF spectra to SHF spectra (Grandview 2023). Previous research has shown that the cellular switch impacts the relative value of those spectrum types (Connolly et al. 2022). Hence, it is plausible that the earlier switches also impacted the relative value of those spectra.

Valuing the Free Radio Licenses Given to the Telecommunications Industry

This section values radio spectrum licenses provided for free to the telecommunications industry by multiplying the quantity of these radio spectrum units by the value of spectrum units of corresponding purchased licenses. The exact level of capital transfers in each year depends on the precise date at which a radio spectrum license is assumed to transfer from the federal government to the telecommunications industry, but the long-term average transfer rate is more robust.

Figure 3: Telecommunications Industry Capital Transfers as a Share of Telecommunications Revenue

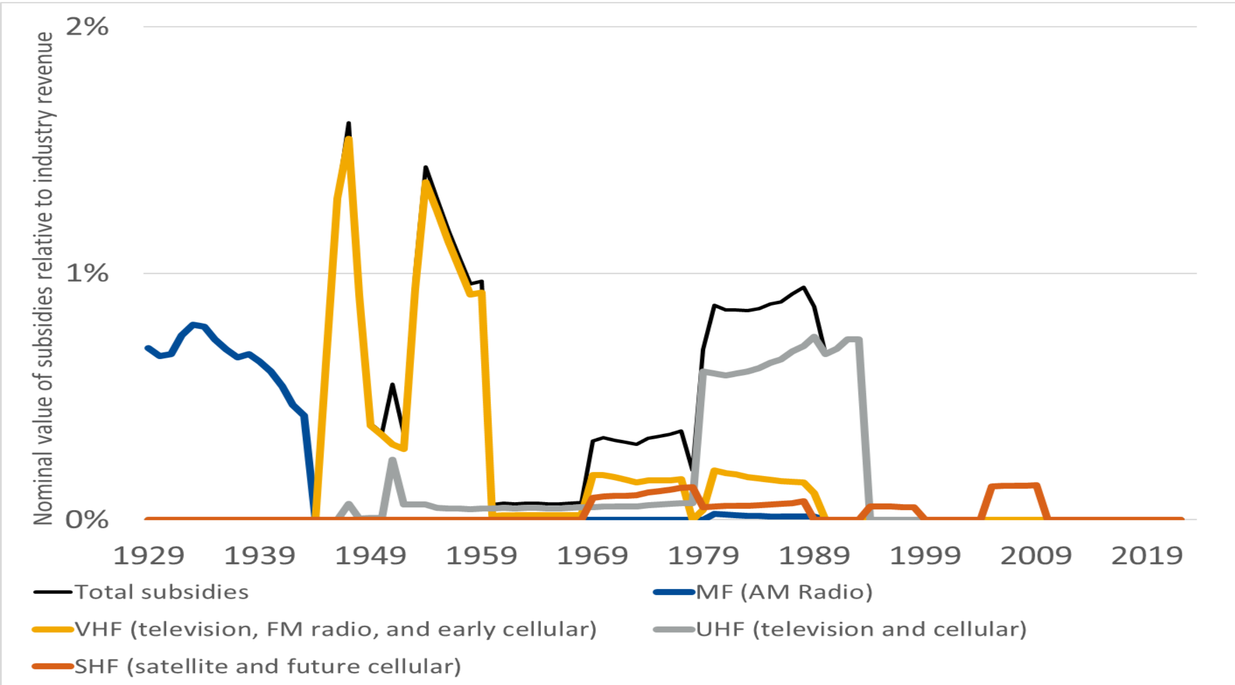

Figure 3 shows that the capital transfers associated with allocated radio spectrum licenses that were provided for free have never been a large share of telecommunications industry revenue. Accordingly, those capital transfers were unlikely to have had much direct effect on overall telecommunications output or prices. But it is possible that they had important indirect effects. To start out, capital transfers that are targeted toward new telecommunications providers may have increased competition and thereby lowered overall prices (Anderson 1995). Similarly, capital transfers that are targeted toward new products that are substantially different from existing products could have increased product variety (Bresnahan and Gordon 1996). Finally, allocated radio spectra may influence either the free entertainment services provided by broadcasters (Kubey and Csikzentmihalyi 1990) or the political influence associated with broadcasters (Stromberg 2004 and Wang 2021). These potential indirect effects may explain why policymakers chose to allocate free radio spectra in the way that they did.

Measured GDP in market prices does not change when capital transfers are tracked. When calculating GDP by industry, output is valued at purchaser prices. Those purchaser prices already include any price response to the allocated radio spectra.

Nominal Stocks of Radio Spectra

Figure 4: Telecommunications Industry: Free Allocated Spectra Stock Relative to Produced Capital

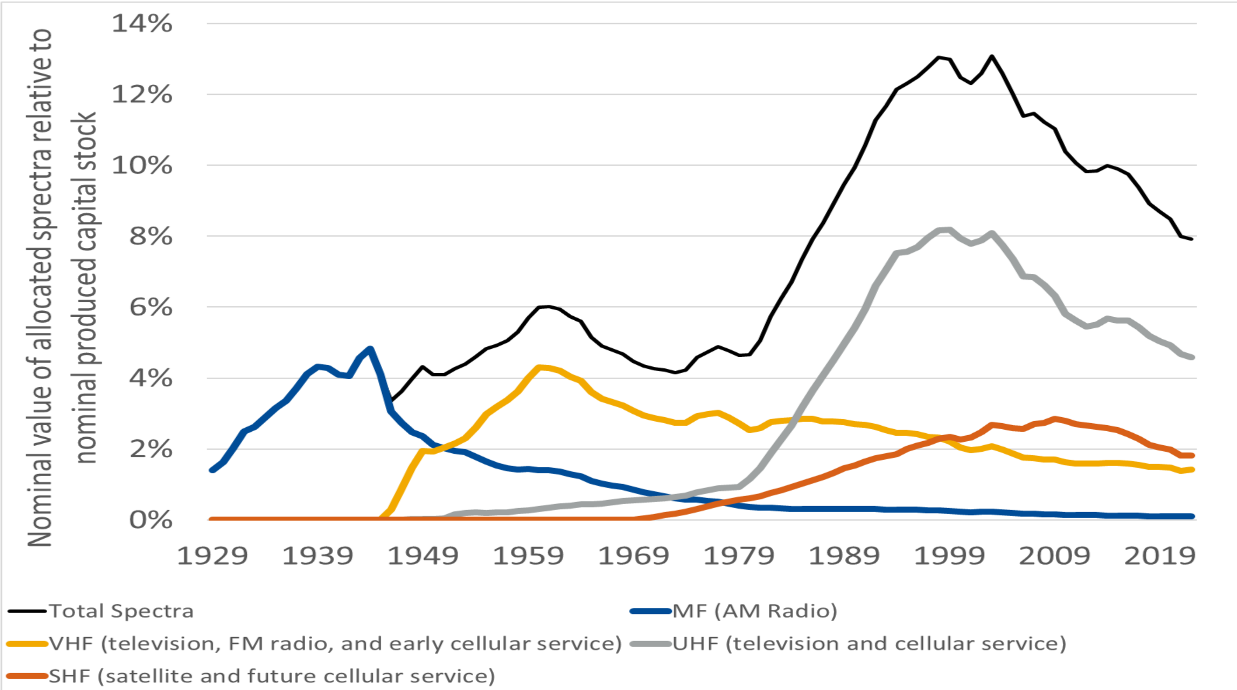

Figure 5: Telecommunications Industry: Purchased Spectra Stock Relative to Produced Capital

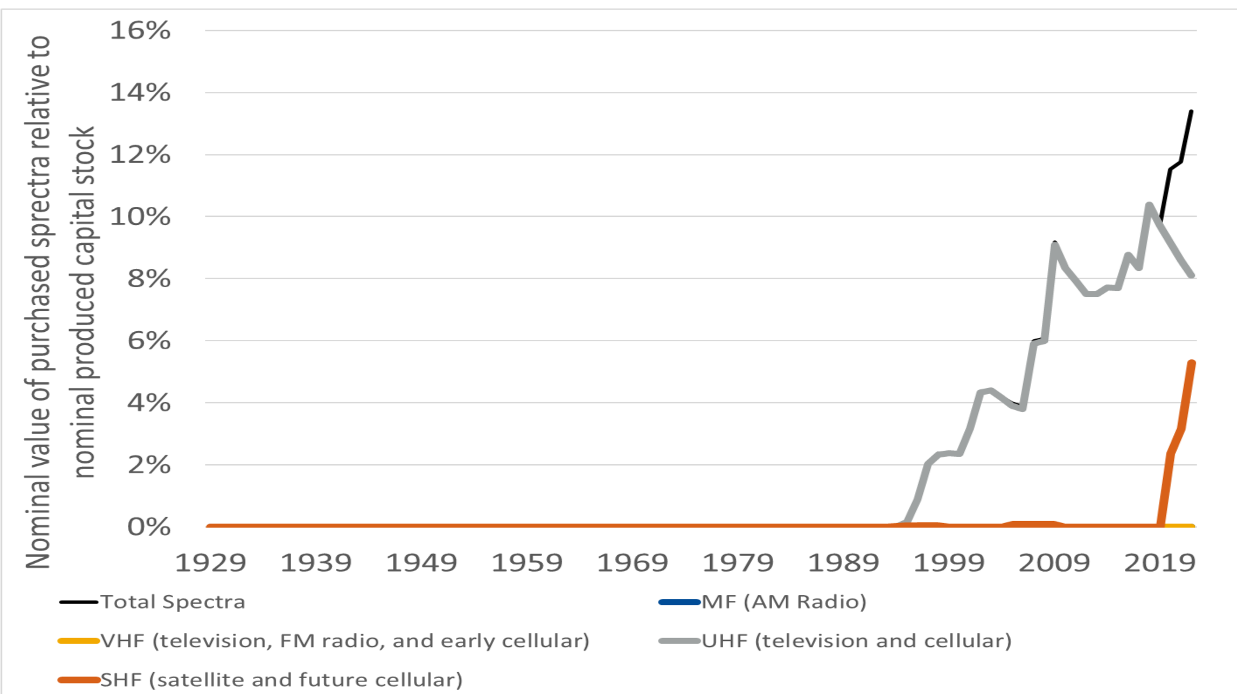

Figure 4 shows that radio spectra that were originally allocated for free have always accounted for a noticeable share of telecommunications industry assets. If an allocated radio spectrum license was resold by the original recipient to another telecommunications company in the past, it might be already tracked on company balance sheets (Courtnage and Halligan 2016). Nevertheless, it is likely that measured telecommunications assets would increase if free allocated spectrum licenses were tracked using national accounting principles. In addition, figure 7 shows that measured productivity growth increases slightly when the capital services from free allocated MF and VHF radio spectra are tracked in the joint BEA/U.S. Bureau of Labor Statistics production accounts.

Figure 5 shows that radio spectrum purchases were minimal before the 1990s but grew rapidly after the FCC started auctioning licenses in 1994. These purchased licenses are already tracked on company balance sheets and in BEA's NIPA table 3.1. Hence, it is likely that neither measured telecommunications assets nor measured aggregate wealth stock would change much if these purchased licenses were tracked using national accounting principles. Furthermore, figure 7 shows that measured productivity growth is almost unchanged when the capital services from UHF and SHF radio spectra are tracked in the joint BEA/U.S. Bureau of Labor Statistics production accounts.

This paper values government-owned spectra by multiplying the average prices for privately owned telecommunications spectra with the number of spectrum units owned by the government. To remind readers, there are eight spectra type that can be ordered by frequency: VLF, LF, MF, HF, VHF, UHF, SHF, and EHF. Private telecommunications firms only use MF, VHF, UHF, and SHF regularly—and so figure 2 only showed average prices per spectrum unit for those types. This paper imputes a price for HF units that is midway between the price of MF units and the price of VHF units. For the remaining types, this paper assumes that prices decrease as frequencies get farther from those used commercially. Based on that assumption, this paper imputes a price to VLF units of 25 percent of the price of MF units, a price to LF units of 50 percent of the price of MF units, and a price to EHF units of 50 percent of the price of SHF units. To avoid the volatility in private prices that was created by weighting, this paper imputes government spectrum prices based on the unweighted private prices.

Figure 6. Government Sector: Spectra Stock Relative to Produced Capital Stock

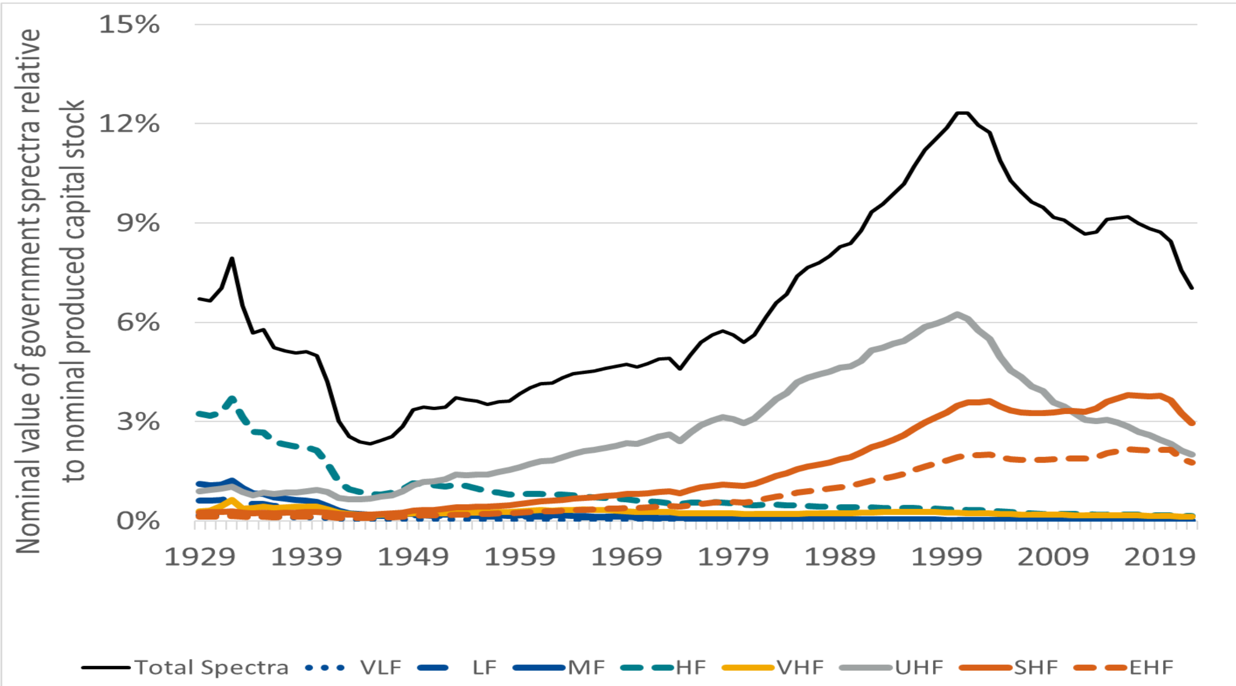

Figure 6 shows that radio spectra account for a noticeable share of government assets. Interestingly, the relative value of government radio spectra peaked during the dot-com bubble and has been decreasing since. This relative decrease is due to a combination of FCC auctions, relative price changes, and real growth in other assets. BEA's current formula to calculate government output does not include any services from nonproduced natural resources (BEA 2022), and so including these government spectra on the balance sheet would not change either measured government output or measured GDP. However, the upcoming guidelines for national accounting, *System of National Accounts 2025*, are likely to recommend including a measure of natural resource services that is based on an assumed rate of return (Smith 2023). If that recommendation were implemented, then including radio spectra on the government balance sheet might raise measured government output and measured GDP.

To be clear, the values for government radio spectrum shown in Figure 6 are very approximate. On the one hand, some spectra are not used by the private telecommunications industry because they are known to be less suitable for surface communication. For example, HF radio spectra are affected by solar weather and therefore may not be useful during an emergency (Frissell et al. 2019). On the other hand, the U.S. government uses radio spectra outside the nation's borders. For example, military satellites collect information worldwide (Abbany 2020). If those spectra were included in the stock of government-owned radio assets, then the total number of government spectrum units might be much higher than the number calculated with a simple residual method (1,724 total spectrum units in the United States minus how many spectrum units are owned by the private telecommunications industry). Given these two possible biases, it is not possible to determine whether the values presented in figure 6 are an overestimate or an underestimate.

Section 4: Impact of Radio Spectrum Licenses on Productivity

The productivity calculations presented in this paper are based on existing industry-level production accounts that track labor, capital services, and intermediate inputs for 61 separate private business sector industries (Garner et al. 2020). The telecommunications industry is the only industry that owns radio spectrum licenses, and so the graphs in this paper only show revisions to measured productivity for that industry. The aggregate revision to measured productivity can be calculated by multiplying the revision to telecommunications industry productivity with that industry's Domar weight.

Tracking radio spectrum services changes real capital service growth for the telecommunications industry. The current measures of real capital services include land services together with produced capital services (Eldridge et al. 2020) but do not include radio spectra services. Hence, this paper's inclusion of radio spectra services in its real capital service measure does not require any adjustment to the existing measure of real capital services. Instead, radio spectra services are simply added to other capital services to get a fuller picture of all capital service inputs into telecommunication production. By construction, nominal capital services are held fixed so that adding radio spectra services to other capital services lowers the cost per unit of capital services.

One might worry that tracking allocations of free radio spectra license could change nominal capital services. It is true that nominal capital services would rise if radio spectra licenses that are allocated for free were tracked as output subsidies (Garner et al. 2024). Such a tracking would be inconsistent with the standard formulas that are used to calculate industry value added and industry productivity. After all, the FCC's allocation process was not explicitly tied with either industry outputs or industry inputs and therefore do not change either the marginal revenue associated with output, or the marginal costs associated with inputs. Hence, the standard formulas are clearly applicable. Nevertheless, one could argue that the FCC's allocation process was economically equivalent to output subsidies and should therefore be tracked like output subsidies when calculating productivity. As a robustness test, figure 8 shows how measured productivity would change if that argument was accepted. This figure is presented for discussion purposes only.

Figure 7. Impact on Telecom Productivity From Including Radio Spectra Services in Capital Services

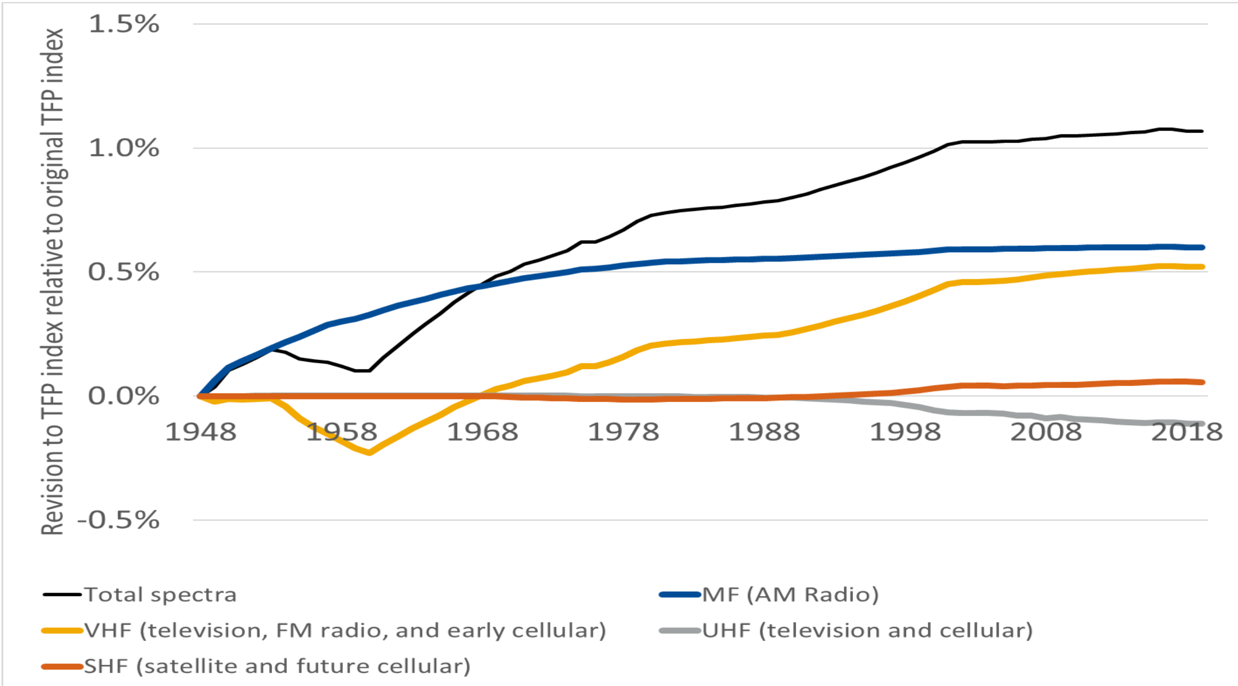

Figure 8. Impact on Telecom Productivity From Tracking Allocated Radio Spectra as an Output Subsidy

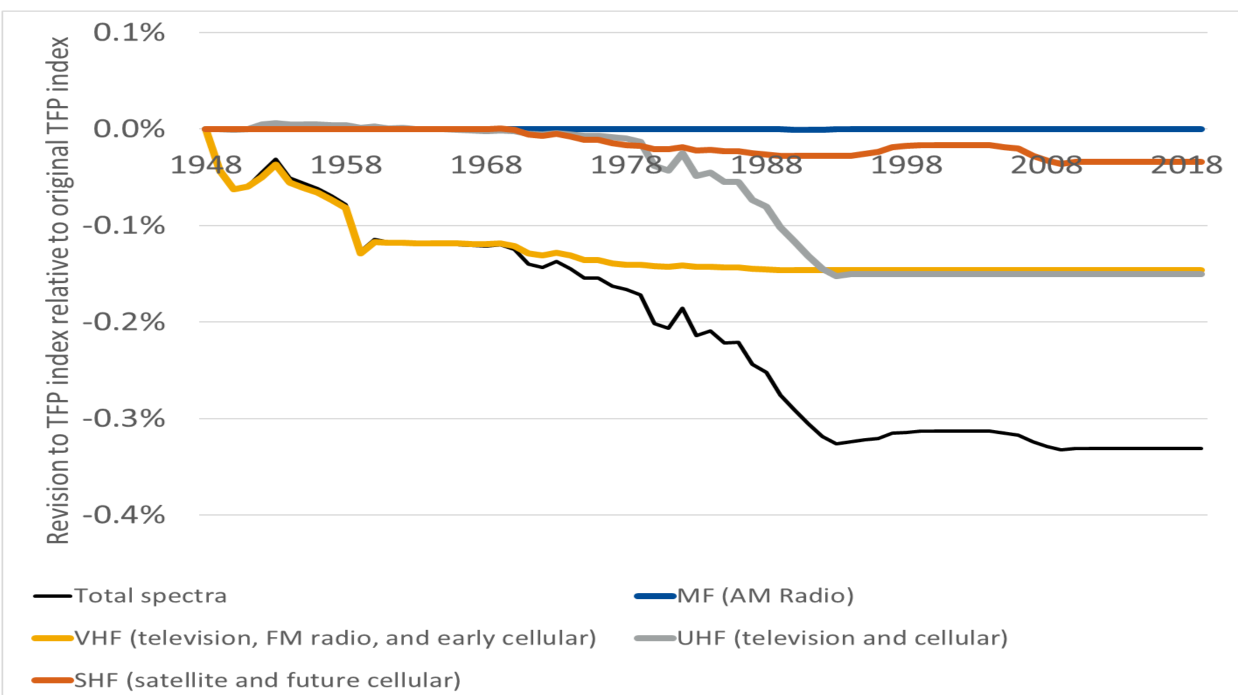

Figure 7 shows that the large asset increase that was shown in figures 5 and 6 has a very modest positive impact on measured industry productivity growth. The precise point estimates shown in figure 7 are somewhat sensitive to the exact parameters assumed. However, no plausible parameters change measured productivity for the telecommunications industry noticeably.

Figure 8 shows that tracking the capital transfers shown in figure 4 as output subsidies would have a very minimal impact on measured industry productivity growth. This null result suggests that the published joint BEA/BLS production accounts are very robust.

Conclusion

This paper demonstrated that the measured wealth stock of the United States increases by $2 trillion in 2022 when radio spectra are included in the balance sheet. Furthermore, this paper also demonstrated that tracking radio spectra can impact the NIPAs noticeably. It may be true that radio spectra are not produced—and therefore do not impact either measured investment or measured consumption of fixed capital. However, auctioned radio spectra are currently tracked as a negative net purchase of nonproduced assets by the government in BEA's NIPA table 3.1. Additionally, this paper argued that radio spectrum licenses that the federal government gives for free to the telecommunications industry should be tracked as capital transfers in BEA's NIPA table 3.1.

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