P E R S P E C T I V E S
PHOENIX CENTER FOR ADVANCED LEGAL & ECONOMIC PUBLIC POLICY STUDIES

Form 477, Speed-Tests, and the American Broadband User's Experience

George S. Ford, PhD*

March 31, 2021

Twice each year the Federal Communications Commission ("FCC") releases data on the availability of broadband Internet services across the United States, eponymously referred to as "Form 477 data." Looking at the *fastest* available service tiers of Internet providers at the census block level—the smallest geographic area defined by the Census Bureau—the FCC uses these data to measure the share of persons with access to "broadband" service, which is now defined to be a service with a minimum of 25 Mbps download and 3 Mbps upload speeds.[1] In its latest *Broadband Deployment Report*, the Commission concluded that 95.6% of Americans had access to "broadband" service as of December-2019.[2]

Analysts and advocates criticize the Form 477 data by pointing out that consumers are not always receiving the maximum reported service speeds or even speeds meeting the 25/3 Mbps standard, a discrepancy resulting, in part, from the FCC's assumption that if one customer has access to broadband within a census block, then all customers in that block do so.[3] Data from the results of speed-tests are often used to support such claims.[4] But data on speed-tests from online services are measures of central tendency (means and medians) to a variety of unknown subscription levels (typically chosen by consumers), so there is no reason to expect that the Form 477's *maximum* reported speeds should be equal to summary statistics from user-based speed-tests.

Further, like the Form 477 data, the quality of speed-test data is subject to severe criticism. Speed-tests typically are not drawn from a random sample of consumers and are dependent on a variety of factors unrelated to the underlying connection speed including the quality of inside wiring, Wi-Fi equipment and connected devices, and other factors. As such, the test results are biased downward. Still, quality speed-test data may offer some insight, albeit a cloudy one, on consumer experience with broadband services.

... my analysis of the Ookla data indicates that Americans experience "broadband" speeds close to the share indicated by the FCC's Form 477 data.

Respecting the limitations of the speed-test data, in this PERSPECTIVE I analyze a sample of over 100 million speed-tests conducted in the U.S. in 2020. Through its Open Data Initiative, the data are made available by Ookla® (speedtest.net), arguably the world's preeminent speed-test firm. I also link the Ookla Speedtest® data to the FCC's Form 477 data for comparison purposes. This linkage allows me to explore how consumers experience broadband speeds and how such speeds compare to the maximum speeds recorded in the Form 477 data.

Results are as follows. First, the population-weighted average download and uploads speeds experienced by U.S. consumers using the Ookla service in 2020 is about 130 Mbps and 39 Mbps, respectively. Second, I find that the *average* tested speeds satisfy the 25/3 Mbps standard for census block groups where 95% of Americans live, a share comporting with the FCC's reported availability rate of 96.5% by year-end 2019. Third, I find that mean tested broadband speeds are correlated with maximum available speeds at the block-group level and a 100 Mbps increase in maximum download speed increases the average tested download speeds only by about 12 Mbps.

Note, however, that like the Form 477 data, it is not possible to see below the chosen level of geographic aggregation at individual customers' experience. Subject to that caveat and considering the inherent bias in speed-test results, my analysis of the Ookla data indicates that Americans experience "broadband" speeds close to the share indicated by the FCC's Form 477 data.

The Limits of Speed-test Data

In using speed-test data to characterize the average experience of broadband consumers, several important limitations of the test data must be acknowledged and understood. First, the speed-test results from online testing platforms do not represent a random sample of consumers, connections, or situations. Consumers choose when to conduct a speed-test, so the sample is a convenience sample. Speed-tests are often used, for instance, when an account is being setup or when a customer is experiencing technical problems. It also seems likely that more technically-savvy customers will use speed-testing more frequently.

Second, customers differ in the speed levels of their broadband service and the subscription level is often not known in collections of speed-test results. The subscribed level of services establishes (to an approximate degree) the *maximum* speed obtained from a speed-test. Feamster and Livingood (2020) describe a host of factors that may influence a speed-test results including, but not limited to: (1) the capabilities, software and settings of the device tested; (2) the modality of connectivity of the device such as Wi-Fi or wire; (3) the number of devices sharing a Wi-Fi connection; and (4) the adequacy of inside wiring and capacities of wire and wireless routers and switches.[5] Additionally, the service used to conduct the speed-test may affect the result. Several recent studies comparing Ookla's to M-Lab's speed-tests reveal significant shortcomings in the M-Lab approach and, consequently, its collection of speed-test data.[6] These factors, among others, will bias the test result downward since none of these factors can increase the base connectivity level that is governed at the modem.

There are also reasons outside the consumer's location that affect speed-test results, such as network congestion in the provider's network, the capacity and congestion on the testing site's network, or even transport networks. Acknowledging these influences, during the Obama-era the FCC initiated the use of "whitebox" speed-testing that relies on a hardware solution to avoid many of the biases that may arise from software-based tests.[7] These tests show that consumers typically receive their subscribed speeds. Tested speeds vary considerably by the time of day they are run. A speed-test result, therefore, equals the connection speed plus some non-positive bias.[8]

To illustrate the sort of data speed-testing produces, I conducted several experiments using my home broadband connection. Note that for none of these experiments was there an effort on my part to maximize the speeds for the test results and family members may have been online at the time. A wireline ethernet connection was used and tests were conducted using the Google Chrome browser or the Speedtest application (for Windows).[9] My broadband plan is nominally a 100/10 Mbps service.

First, I generated two samples of 50 speed-tests each using the Ookla and M-Lab services. These tests were run sequentially between services on a Monday morning. Results are summarized in Table 1.

Table 1. Average Download Speeds (Mbps)

	Average	St. Dev.	Min	Max
Download				
Ookla	93.3	3.66	79.4	96.2
M-Lab	89.6	6.61	73.5	94.2
Average	91.5	5.63	73.5	96.2
Upload				
Ookla	8.69	1.36	4.82	10.2
M-Lab	8.29	1.28	4.37	9.67
Average	8.49	1.33	4.37	10.2

Both sets of test results are very close to the nominal level of service (100/10 Mbps), averaging across all tests a download speed of 91.5 Mbps and an upload speed of 8.5 Mbps. As might be expected, the average speeds are below the base-level speeds of the service plan. The range of results between services are likewise similar, with minimum download speeds in mid-70's and maximums near 100 Mbps. M-Lab's results have a higher variance: Coefficient-of-Variation (the standard deviation divided by the mean) for the Ookla data is 0.039 for downloads but for M-Lab is 0.074.

Figure 1. Download Speeds (Mbps)

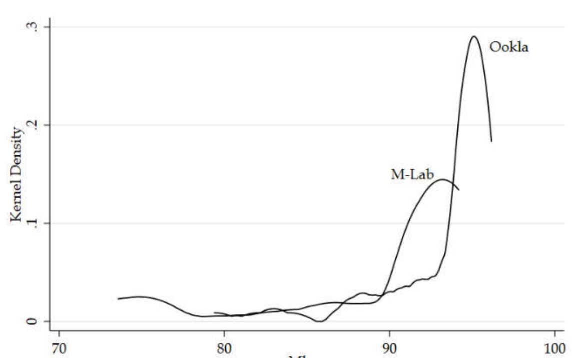


Figure 1 illustrates the Kernel Density Functions for the download data. The lower test scores provided by the M-Lab test are shown clearly in the figure, which most of the test results falling below the Ookla mean. Darr (2020) reports much larger variations in the Ookla and M-Lab results using larger samples than my simple experiment.[10]

A speed-test result … equals the connection speed plus some non-positive bias.

An interesting observation from the test results is the indicated location of the tested site (my home). For the Ookla results, the geographic coordinates are about 0.4 miles from the tested site. For the M-Lab results, the coordinates are about 30 miles from my home. Consequently, merging the M-lab results with census data based on the geo-spatial data provided by M-Lab may result is mis-matched geographies.

In a separate experiment conducted at a different time, I conducted thirty tests using Ookla's service on wired and Wi-Fi connections. Here, the average download speed for the wired connection was 87.8 Mbps and for the Wi-Fi connection was 65.9 Mbps. This is a large difference (statistically different at the 1% level), and the Wi-Fi tests were much more variable; the Coefficient-of-Variation for the wired connection was 0.06 but 0.25 for the Wi-Fi connection. Presumably, better speeds for the Wi-Fi connected computer may have been obtained by moving the computer closer to the Wi-Fi device, but there is no reason to suspect consumers try to maximize their speed results in everyday practice. A severe downward bias in speed-test results for Wi-Fi connected devices seems plausible.

This analysis is not, obviously, an exhaustive analysis of speed-test results or of different testing services. My experiments simply demonstrate that speed-test results do not match exactly the subscription level of service, that there is variation in user-based speed-tests and that results will generally fall below the nominal subscription speed. Results may differ by testing service, may differ materially between wired and Wi-Fi connections, and may differ for a host of other reasons (not demonstrated here). Care, then, must be taken when interpreting speed-test results and when comparing them to what broadband services are available.

Data

Quarterly data on speed-tests conducted across the globe are obtained from Ookla's Open Data Initiative for the four quarters of 2020.[11] Ookla's data are presented as averages for "geographic tiles," which are rectangular areas of varying sizes based on latitude-longitude but not linked to census cartographic boundaries. For the Open Data Initiative, the *fixed* speed-test data is obtained from Android and iOS mobile devices (permitting better location accuracy) using the Speedtest application, so all tested devices connect via a Wi-Fi connection (which, if anything, will bias the measured speed of affixed connection downward).

For each tile, the Ookla data include the *averages* of download speed, upload speed, and latency, as well as the number of tests and devices used to construct these averages. (Medians are not provided.) These tiles are geographically small and, as a result, often have samples of very few test results. One-quarter of the observations are based on a single test and about one-third on two or fewer tests. Also, many tiles have very few devices tested, with one-third having only one device and 45% having two or fewer devices.

Ookla's tiles are not based on census cartographic boundaries and thus the required population data are not available to measure the experiences of Americans (*i.e.*, a population-weighted mean). To address both the small samples of tests in many tiles and to link the test results to population data (and then to the Form 477 data), the Ookla tiles are linked to census block-groups for the 48 contiguous states and the District of Columbia.[12] On average, a census block group includes 14 tiles (minimum 1, maximum 453). The final sample includes 195,030 census block groups (91% of the U.S. population) with 105.6 million speed-tests on 29.1 million devices.[13]

The Ookla data is richer for more populous block groups: tests ($\rho = 0.67$), and devices tested ($\rho = 0.69$). Tests and devices are highly correlated ($\rho = 0.96$). Average download speed is mildly and positively corrected with block-group population ($\rho = 0.16$).

Broadband availability is measured using the Form 477 data for December-2019 (the latest available).[14] The broadband availability data are native to the census block but is aggregated to the census block group using 2010 population data. The Form 477 data are then merged with the Ookla data for the 48 contiguous states and the District of Columbia.

Descriptive Statistics

At the block-group level, the population-weighted mean download and upload speeds from the Ookla tests are 130.3 Mbps and 38.7 Mbps, respectively.[15] With such large samples, the confidence intervals are tight (standard errors are 0.112 and 0.081, respectively), but note that the distributions are not normally distributed (see Figure 2). Median download speeds are 137.5 Mbps and 21.1 Mbps.

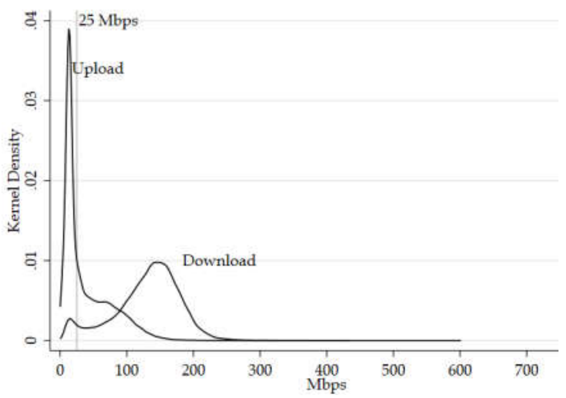
Table 2. Average Speeds (Mbps)

	Average	St. Dev.	Median
Down	130.3	49.5	137.5
Up	38.7	35.7	21.1

The population-weighted Kernel Density Functions for download and upload are illustrated in Figure 2. The upload speed distribution is high peaked and is skewed right. Despite this high peak, the Coefficient-of-

Variation is larger for upload than download speeds.

Figure 2. Speed (Mbps) Density Functions



Download speeds have, unsurprisingly, a larger mean, though the distribution is bimodal with a peak at about 150 Mbps and a second peak at about 15 Mbps. The mean download speed rarely exceeds 200 Mbps. Certainly, many consumers have download speeds higher than 200 Mbps, but these data represent average speeds for multiple tests and devices and not the results for individual consumers. Upload speeds are likewise highly peaked around 15 Mbps.

Meeting the "Broadband" Threshold

For each census block group, I construct an indicator variable for census block groups that meet the FCC's definition of broadband of 25/3 Mbps. Dichotomizing a continuous variable suffers from a threshold problem. That is, a hard threshold at 25/3 Mbps would declare an average speed of 24.9/2.9 Mbps non-compliant with the standard. Considering that speed-tests typically embed a downward bias are subject to some variability, some care should be taken in constructing such an index. Thus, three indicators are created at different thresholds: (1) 25/3 Mbps; (2) 23/2 Mbps; and (3) 20/2 Mbps. Admittedly, the two additional thresholds are arbitrarily chosen.

As a reference, the percent of population with access to a network meeting the FCC's broadband definition in this sample is 96.4% as of December-2019 (96.5% nationally). We can then use speed-test data to determine whether the FCC's estimate of broadband deployment is wildly over-estimated as some claim or whether the fraction of the population experiencing *at least* broadband speeds aligns with the fraction said to have access to broadband speeds.

Based on the Ookla data, the share of American consumers living in census block groups where the average speeds equal or exceed the FCC's definition of broadband (25/3 Mbps) is 95.0%.

In describing the results, it is important to keep in mind that the Ookla data provide average speeds—often for multiple tests, devices, and consumers—within a geographic area. My description of the results, therefore, is worded carefully:

> Based on the Ookla data, the share of American consumers living in census block groups where the average speeds equal or exceed the FCC's definition of broadband (25/3 Mbps) is 95.0%.

This share of population is very close to the estimates from the Form 477 data. Like the Form 477 data, however, it is not possible to peek inside a pre-formulated geographic area at individual consumers. Interpreting these results as representing the experience of each and every consumer is an ecological fallacy. Like the Form 477 data, this 95% share is an overstatement of actual experience.

The different thresholds do alter the results; the share of persons living in census block groups where the average speeds satisfy 20/2 Mbps threshold is 96.2% and 95.5% at the 23/3 Mbps threshold. There is a small yet noticeable difference between the shares. The similarity in the outcomes suggests that that average speeds at the block group level do not cluster at the 25/3 Mbps threshold.

From this analysis, the FCC's finding that 25/3 Mbps broadband is available for 96.5% of the persons in the U.S. comports with the observed experience of consumers in 2020, where this "experience" is measured using results from a large sample of Ookla's speed-tests.

Speeds and Maximum Available Speeds

Maximum available broadband speeds reported in the FCC's Form 477 data need not coincide with consumer experience. In fact, it would be surprising if in most cases speed-test averages were anywhere near the maximum deployed speeds.[16] Most consumers do not purchase the fastest plans as many consumers do not see enough benefit from higher speeds given the associated higher costs of the service.[17] The relationship between actual and maximum speeds may be evaluated by assessing the relationship between average tested download speeds and the maximum speeds available.

The correlation coefficient between the average tested download speed and maximum download speed at the block group level is 0.62, so the two measures of speed are positively correlated.[18]

Alternately, consider the least-squares regression,

$$S_g = \beta_0 + \beta_1 M_g + e_g \qquad (1)$$

where S_g is the average speed in block group g, M_g is the maximum advertised speed in g, and e_g is the econometric disturbance term.[19] The estimate of β_0 is 29.07 and β_1 is 0.117. This result suggests that, on average, every 100 Mbps increase in maximum speed increases the average tested download speed by 12 Mbps. The R^2 of the regression, however, is 0.37, which is reasonably large for cross-sectional data. Still, the maximum speed is not a super accurate predictor of average speeds, at least as measured by Ookla's speed-test.

From this analysis, the FCC's finding that 25/3 Mbps broadband is available for 96.5% of the persons in the U.S. comports with the observed experience of consumers in 2020, where this "experience" is measured using results from a large sample of Ookla's speed-tests.

Conclusion

In this PERSPECTIVE, data on speed-tests results from Ookla's Open Data Initiative are used to assess the broadband experience of consumers in the United States in 2020. After discussing the limitations of using speed-test data for assessing the typical experience, some statistics are computed from the data and reported.

On average, the tested speeds of broadband service are about 130 Mbps for downloads and 39 Mbps for uploads. About 95% of persons live in census block groups with average speeds satisfying the FCC's broadband definition of 25/3 Mbps, matching closely the 95.6% availability rate of the same population from the Form 477 data. Also, average tested broadband speeds are correlated at the block-group level with maximum advertised available speeds. A 100 Mbps increase in maximum speeds increases average speeds by about 12 Mbps.

NOTES:

* **Dr. George S. Ford** ***is the Chief Economist of the Phoenix Center for Advanced Legal and Economic Public Policy Studies. The views expressed in this* PERSPECTIVE *do not represent the views of the Phoenix Center or its staff. Dr. Ford may be contacted at*** ford@phoenix-center.org.

1 The debate over whether 25/3 Mbps is the correct definition is beyond the scope of this paper. *See generally*, G.S. Ford, *Is Faster Better? Quantifying the Relationship Between Broadband Speed and Economic Growth*, 42 TELECOMMUNICATIONS POLICY 766-777 (2018) (available at: https://www.sciencedirect.com/science/article/abs/pii/S0308596118300831).

2 *In the Matter of Inquiry Concerning Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion,* FCC 21-18, FOURTEENTH BROADBAND DEPLOYMENT REPORT, __ FCC Rcd. __ (rel. January 19, 2021) at p. 20 (available at: https://docs.fcc.gov/public/attachments/FCC-21-18A1.pdf).

3 *See, e.g.*, G.S. Ford, *Quantifying the Overstatement in Broadband Availability from the Form 477 Data: An Econometric Approach*, PHOENIX CENTER POLICY PERSPECTIVE No. 19-03 (July 11, 2019) (available at: https://www.phoenix-center.org/perspectives/Perspective19-03Final.pdf).

4 *See, e.g.*, B. Miller, *Microsoft Speeds Show Broadband Use is Far Lower than Access*, GOVERNMENT TECHNOLOGY (March 4, 2019) (available at: https://www.govtech.com/biz/Microsoft-Speeds-Show-Broadband-Use-Is-Far-Lower-than-Access.html); *Truth in Broadband: Access and Connectivity in New York City*, NYC Connected (April 2018) (available at: https://tech.cityofnewyork.us/wp-content/uploads/2018/04/NYC-Connected-Broadband-Report-2018.pdf); R. Gallardo and B. Whitacre, *The Real Digital Divide? Advertised vs. Actual Internet Speeds*, Purdue Center for Regional Development (October 7, 2020) (available at: https://pcrd.purdue.edu/the-real-digital-divide-advertised-vs-actual-internet-speeds); E. Hardison, *Pennsylvania's Rural Broadband Problem is Bigger than Anyone Thought*, PENNSYLVANIA CAPITOL STAR (June 4, 2019) (available at: https://www.penncapital-star.com/blog/pas-rural-broadband-problem-is-bigger-than-anyone-thought); R. Johnston, *Form 477 Data Undermines Conclusions in the 2020 Broadband Deployment Report*, Next Century Cities (May 8, 2020) (available at: https://nextcenturycities.org/form-477-data-undermines-conclusions-in-the-2020-broadband-deployment-report); K.Bode, *How Bad Maps Are Ruining American Broadband*, THE VERGE (September 24, 2018) (available at: https://www.theverge.com/2018/9/24/17882842/us-internet-broadband-map-isp-fcc-wireless-competition);

5 N. Feamster and J. Livingood, *Measuring Internet Speed: Current Challenges and Future Recommendations*, White Paper (2020) (available at: https://arxiv.org/abs/1905.02334); *see also Will Different Ethernet Cable Speed Affect My Network?*, FIBER OPTIC COMPONENTS BLOG (December 14, 2018) (available at: http://www.fiber-optic-components.com/will-different-ethernet-cable-speed-affect-network.html).

6 B. Darr, *Make Better Funding Decisions with Accurate Broadband Network Data: A Guide for Federal, State and Local Governments*, Speedtest.net (November 10, 2020) (available at: https://www.speedtest.net/insights/blog/better-funding-decisions-accurate-broadband-network-data); R. Bennett, *OTI United States of Broadband Map is Fake News*, HighTechForum (July 25, 2019) (available at: https://hightechforum.org/oti-united-states-of-broadband-map-is-fake-news); S. Wallsten, *OTI's Broadband Map Could Be Useful If They Understood Their Data*, Technology Policy Institute (July 23, 2019) (available at: https://techpolicyinstitute.org/2019/07/23/otis-broadband-map-could-be-useful-if-they-understood-their-data).

7 *See, e.g., Measuring Fixed Broadband - Tenth Report*, Federal Communications Commission (January 4, 2021) (available at: https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-fixed-broadband-tenth-report).

8 The FCC's report on broadband speeds (*id.*, at p. 14) shows median speeds above subscription levels for some broadband providers, but a review of the underlying data suggests the speed levels are set above the nominal subscription level.

9 Test results may be impacted by the browser or application used, another source of bias.

10 Darr, *supra* n. 6.

11 Data available at: https://registry.opendata.aws/speedtest-global-performance.

12 The linkage is made in Stata 16 using the *geoinpoly* command by Robert Picard.

13 There are 217,740 block groups across the U.S. and its territories. The population of the included groups is 283 million, or about 92% of the U.S. population in 2010.

14 Data available at: https://www.fcc.gov/general/broadband-deployment-data-fcc-form-477.

NOTES CONTINUED:

[15] Ignoring population, the test-weighted mean speeds are 138.3 Mbps and 44.4 Mbps.

[16] While the reasons for test results to fall below the maximum available speed are apparent, some commentators find this concept difficult to grasp and claim there is something is amiss when speed-tests fall below the maximum speeds ISPs report to the FCC on Form 477. *See, e.g.*, The United States of Broadband Map (available at: https://datastudio.google.com/u/0/reporting/1djtGEuqV4Qwrj26GQTN_xzp3rsMYYcmv/page/YW8NB?s=rzD5rHYkLT4) and the discussion of that map by Bennett, *supra* n. 6, and Wallsten, *supra* n. 6.

[17] Y.H. Liu, J. Prince and S. Wallsten, *Distinguishing Bandwidth and Latency in Households' Willingness-to-Pay for Broadband Internet Speed*, 45 INFORMATION ECONOMICS AND POLICY 1-15 (available at: https://doi.org/10.1016/j.infoecopol.2018.07.001); Ford, *Is Faster Better? Quantifying the Relationship Between Broadband Speed and Economic Growth*, *supra* n. 1.

[18] The relationship appears to hold at higher levels of aggregation.

[19] The regression is weighted by population.