Road Quality and Mean Speed Score

Mariano Moszoro and Mauricio Soto

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We introduce a novel measure of cross-country road quality based on the travel mean speed between large cities from Google Maps. This measure is useful to assess road infrastructure and access gaps. Our Mean Speed (MS) score is easier to estimate and update than traditional gauges of road network quality which rely on official reports, surveys (i.e., World Economic Forum’s Quality of Roads Perception survey), or satellite imaging (i.e., World Bank’s Rural Access Index). In a sample of over 160 countries, we find that MS scores range between 38 km/h (23.6 mph) and 107 km/h (66.5 mph). We show that the MS score is a strong proxy for road quality and access.


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I. Introduction

Road connectivity is key for inclusive development (Berg, Deichmann, Liu, and Selod, 2015; Asher and Novosad, 2020). Roads promote access to economic and social services, with positive effects on agricultural and non-agricultural employment and productivity in rural and urban areas (Dash and Sahoo, 2010; Calderón and Servén, 2004; Calderón and Servén, 2010; Calderón, Moral-Benito, and Servén, 2015; Asher and Novosad, 2020) and facilitate internal and external market integration (Jaworski, Kitchens, and Nigai, 2020; OECD, 2020).

Substantial work has been done on estimating country gaps in road infrastructure and access (Fay and Yepes, 2003; Roberts, KC, and Rastogi, 2006; World Bank, 2016; Iimi, Ahmed, Anderson, Diehl, Maiyo, Peralta-Quirós, and Rao, 2016; Mikou, Rozenberg, Koks, Fox, and Peralta Quirós, 2019) and quantifying the impact of roads on GDP (Jaworski, Kitchens, and Nigai, 2020). One focus has been on access under the premise that transport connectivity is supportive for development. Access to improved roads can reduce transport time and costs, increase productivity, and reduce poverty. Indicators of connectivity such as the size of the road network and the Rural Access Index (RAI)—a measure of the proportion of the rural population who live within two kilometers of an all-season road—are often used for infrastructure planning and prioritization. Recognizing the importance of connectivity, the UN 2030 Sustainable Development Goals includes the Rural Access Index (RAI) as a key indicator to track progress in infrastructure development. Originally developed by the World Bank in 2006, RAI provides an understandable and conceptually consistent indicator across countries, remaining the most widely accepted metric for tracking access to transport in rural areas. RAI, however, is costly in time and resources to collect the data, sensitive to the measuring method, and unavailable for some countries. The underlying methodology has changed from surveys to satellite imaging to leverage additional sources of data.

The quality of the road network is also regularly surveyed by the World Economic Forum (WEF) through its Quality of Road Infrastructure (QRI) score, which is used as an indicator of competitiveness across countries. QRI is based on data from a survey of business leaders in 144 countries, who are asked to rate the quality of roads on a scale from 1 (underdeveloped) to 7 (extensive and efficient by international standards). Road quality is multidimensional: from accessibility and surface condition to traffic flow and advanced engineering of tunnels and bridges—all of which factor in mean speed. QRI, however, is subjective and ambiguous by construction. It reflects a potentially biased perception by people surveyed who do not necessarily share the same reference point within countries and even less across countries. Also, the metric is not exogenous and arguably depends on several factors, including travel mean speed. While the mean speed affects the perception of road quality, the perception of road quality does not affect mean speed. Thus, the mean speed provides a conceptually robust proxy for the quality of road infrastructure.

1 See, also, the World Bank’s interactive “Rural Access Index Measurement Tool” available at https://rai.azavea.com/.
2 For instance, the costing of Sustainable Development Goals (SDGs) performed by the International Monetary Fund (IMF) uses RAI as an input variable for the estimating of road stock needed by 2030 (Gaspar, Amaglobeli, García-Escribano, Prady, and Soto, 2019, p. 27).
4 For example, some people take road quality literally as potholes.
We are not aware of published cross-country measures on how efficient (expeditious) the road network is in moving people and goods within countries. This is surprising, as the economic impact of road infrastructure depends on the speed at which people and goods move and travel time—i.e., the inverse of mean speed—is often used as an indicator for road quality in impact evaluation exercises (DANIDA, 2010; Mackie, Jara-Díaz, and Fowkes, 2001; Martens and Di Ciommo, 2017). In the United States, managed lanes (priced or otherwise) that fail to maintain a minimum average operating speed of 45 miles per hour (ca. 72 kilometers per hour) 90 percent of the time during peak periods are considered “degraded” (Goodin, Burris, Geiselbrecht, Wood, et al., 2013; Wood, McGee, Geiselbrecht, and Simek, 2020). Travel time can also serve as an econometric instrument. Mean speed is a means to an end to estimate economic outcomes more precisely by reducing endogeneity. For example, Karpowicz, Góes, and García-Escribano (2018) use travel time between cities to proxy the speed of price convergence.

We propose a simple alternative to compare road quality and access across countries. We develop a novel measure of cross-country road quality based on the mean speed between large cities from Google Maps. In a sample of over 160 countries, we find that the mean speeds range between 38 km/h (23.6 mph) and 107 km/h (66.5 mph). We show that the Mean Speed (MS) score is a strong proxy for road quality and access—the MS score is highly correlated with the existing World Bank’s Rural Access Index and the WEF’s Quality of Road Infrastructure score. MS score complements costly and time-consuming RAI satellite imaging and QRI surveys, produces consistent estimates, and allows for frequent replication by local authorities.

The Google Maps API yields the fastest travel times given “average traffic conditions.” These values are arguably upwardly bounded by the quality of vehicles and traffic laws. In this paper, we assume that (i) both road and vehicle quality are correlated with income per capita, i.e., vehicle quality does not bound the mean speed, and (ii) speed limits are a function of traffic fatality, which primarily is a function of road quality, i.e., road quality drives speed limits.

II. Methodology

We identify a list of major cities by country using the United Nations data on city population. We complement the dataset with cities to ensure a minimum of three cities per country. For comparability, we only include cities distant farther than 80 km (50 miles) from the largest city (i.e., travel speed between close cities is biased downwards), and exclude single-city and smaller countries (e.g., Luxembourg) and archipelagos where major cities might not be connected by road (e.g., Fiji, Maldives). We end with a rich dataset of 760 cities in 162 countries across the world, with a minimum of three and maximum of six cities per country. Appendix I presents the list of cities by country in our sample.

Using the Google Maps application program interface (API), we retrieve the geographical coordinates for each city and estimate the distance and travel time by car between the largest city and the other large cities. We estimate a measure of the speed from the largest city to each of the other cities and provide the mean speed.

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5 The World Economic Forum’s Global Competitiveness Report avouches to compute the average speed of a driving itinerary connecting the 10 or more largest cities but aggregates the results into the road connectivity index (Schwab, 2019, Appendix A: Global Competitiveness Index 4.0 Methodology and Technical Notes, p. 617).

as an indicator of road quality for each country. To validate whether the speed is a good proxy for road quality and access, we compare the MS score to traditional indicators such as road density, RAI and RQI.

A. Mean Speed Score

We compute the Mean Speed [MS] score as the sum of road distance between the largest city and other large cities by country divided by the travel time—both retrieved from Google Maps through an API as described above—between the largest city and other large cities by country:

\[
MS_i = \frac{\sum_{j=2}^{k} distance_{ij}}{\sum_{j=2}^{k} time_{ij}}
\]  

where \(i\) is the country index, \(j\) is the index of the largest cities within country excluding the largest one, \(k\) is the number of large cities within country \(i\) further than 80 km from the largest city, distance \(ij\) and time \(ij\) are the distance and fastest travel time by road between the largest city and city \(j\) in country \(i\), respectively. Note that the MS score equals the harmonic mean speed: i.e., the travel time weighted by the distance.\(^7\) In other words, the total travel time is the same as if one had traveled the whole distance at that average speed.

B. Geometric Mean Speed Score

Countries with diverse economic development by region may present a high variation in the speed in different routes. Unlike the arithmetic mean, the geometric mean penalizes outliers, i.e., routes that are much faster or much slower than the country’s average.

As an alternative measure, we compute the geometric Mean Speed [gMS] score as the geo-metric average of the travel speed between these cities by country:

\[
gMS_i = \left( \prod_{j=2}^{k} \frac{distance_{ij}}{time_{ij}} \right)^{\frac{1}{k}}
\]

The geometric MS score displays appealing properties of normal distribution; however, it may be biased for mean speed of roads of different lengths within countries, since short and long routes are equally weighted.

C. Adjusted Mean Speed Score

The harmonic MS and geometric MS scores do not take into account the geography of the country which may drag down speed, like mountains, bays, swamps, and other geographic obstacles. Thus, a mountainous country with good quality roads (e.g., Switzerland) may have a lower MS score than a flat country with average quality roads (e.g., Algeria).

\(^7\) The simple arithmetic mean would overweight the speed of short distances.
To overcome this issue, we adjust the MS score by the distance “as the crow flies”—i.e., the geodesic or straight-line distance—calculated using the geographic coordinates of the city of origin to the city of destination. We divide each travel time by the ratio of actual to crow-flies distance:

\[
\text{crow-flies ratio}_{ij} = \frac{\text{distance}_{ij}}{\text{crow-flies distance}_{ij}}
\]  

(3)

I.e., a straight road would have a crow-flies ratio of 1 and a semi-circular road a crow-flies ratio of π/2. We winsorize the crow-flies ratio right tail at the 5 percent level to avoid over-adjustments. Finally, we divide the travel time by the square root of the crow-flies ratio and calculate the adjusted Mean Speed \([\text{aMS}]\) score as:

\[
\text{aMS}_i = \frac{\sum_{j=2}^{k} \text{distance}_{ij}}{\sum_{j=2}^{k} \sqrt{\text{crow-flies ratio}_{ij}}} \frac{\text{time}_{ij}}{\text{crow-flies ratio}_{ij}}
\]  

(4)

The aMS represents a theoretical construct of the MS assuming roads are perfectly flat and straight. By construction, the cumulative distribution function of aMS first-order dominates the cumulative distribution function of MS. It is important to note that high quality roads are more than the quality of the surface of the road: high quality roads overcome geographical obstacles with bridges, tunnels, and bypasses, thus aMS biases road quality upwards. Table 1 presents the summary statistics and Figure 1 plots the histograms of MS, gMS, and aMS scores.

Table 2 presents the computed MS, gMS, and aMS scores by country and Figure 2 illustrates the MS score on the world map. Despite their nuances and advantages in particular cases, MS, gMS, and aMS scores have cross-correlation coefficients above 0.96. We prefer the MS score as it has a straightforward economic interpretation, namely, the expeditiousness in moving people and goods between major agglomerations. Hereafter, we use the MS score in our analyses. In unreported tests, the results are similar with gMS and aMS.

Table 1. Summary Statistics of MS Scores

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Note: This table presents summary statistics of the mean speed scores in kilometers per hour between the largest city and other large cities located further than 80 kilometers. \([\text{MS}]\) score is the harmonic mean speed, \([\text{aMS}]\) score is the terrain-adjusted harmonic mean speed, and \([\text{gMS}]\) score is the geometric mean speed. Data are publicly available from Google Maps.
Figure 1. Histograms of Mean Speed Scores

Note: This figure presents the histograms of mean speed scores. Graph 1 (left) plots the histogram of the harmonic Mean Speed [MS] score, calculated as the sum of distances divided by the sum of travel time between the main city and other significant cities further than 80 km. Graph 2 (center) plots the histogram of the geometric Mean Speed [gMS] score, calculated as the geometric mean of the speed between the main city and other significant cities further than 80 km. Graph 3 (right) plots the histogram of the adjusted Mean Speed [aMS] score, calculated as the sum of distances divided by the sum of adjusted travel time between the main city and other significant cities further than 80 km, where the adjusted travel time is the travel time divided by the square root of the ratio of road distance divided by crow-flies distance. The blue line plots the normal distribution for reference. Countries with less than two cities distant more than 80 km by road from the main city—e.g., smaller countries and archipelagos—were dropped. Data are publicly available from Google Maps.

Table 2. Mean Speed Scores by Country

<table>
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<th>MS</th>
<th>gMS</th>
<th>aMS</th>
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<td>United States</td>
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<td>107</td>
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</table>

Note: This table presents the mean speed scores by country. MS is the harmonic mean speed score; gMS is the geometric mean speed score; and aMS is the adjusted harmonic mean speed score. Countries are sorted by MS score. Tiny countries, archipelagos, and cities within 80 km by road from the city of reference are omitted. Data are publicly available from Google Maps.
Figure 2. MS Scores on the World Map

Note: The boundaries, colors, denominations, and any other information shown on the maps do not imply, on the part of the International Monetary Fund, any judgment on the legal status of any territory or any endorsement or acceptance of such boundaries.
III. Mean Speed Score as Informative Road Metric

A. Relationship with Other Measures

We validate the MS score against GDP per capita, road density, the QRI, and the RAI. The aim of this section is to present a simple metrics for analysis, rather than unraveling the causality channels.

GDP per capita in 2018 in US dollars comes from the World Economic Outlook Database (IMF, 2019). Road density is calculated as the road length in kilometers from the World Factbook (CIA, “Roadways,” accessed June 2020) divided by the country area in squared kilometers from the World Development Indicators (World Bank, 2019).

The World Economic Forum compiles the executives’ perception of the Quality of Road Infrastructure (QRI) score through their response to the question: “In your country, what is the quality (extensiveness and condition) of road infrastructure?,” where 1 is “extremely poor—among the worst in the world” and 7 is “extremely good—among the best in the world” (Schwab, 2019, Appendix A). Albeit quantified, it is a qualitative index in nature. The QRI score used in our analysis is the 2017–18 weighted average or latest period available, for total of 152 countries. We supplemented the data with “The 2019 Legatum Prosperity Index” for 18 countries not reported in Schwab (2019)—i.e., Afghanistan, Belarus, Central African Republic, Republic of Congo, Cuba, Djibouti, Eritrea, Guinea-Bissau, Equatorial Guinea, Iraq, Niger, Papua New Guinea, Sudan, Somalia, South Sudan, Togo, Turkmenistan, and Uzbekistan—scored on the same scale.

Rural Access Index (RAI) is the share of rural population with access to an all-weather road within two kilometers. RAI was originally survey based. The latest versions of RAI are estimated based on geographic information systems (GIS) models of the distribution of rural population, and geospatial models of rural roads, including their location and type (Mikou, Rozenberg, Koks, Fox, and Peralta Quiros, 2019). In our estimations, we use the World Bank’s RAI as the primary source (141 countries), complemented with Mikou, Rozenberg, Koks, Fox, and Peralta Quiros’s (2019) RAI estimation for primary and secondary roads (16 instances), United Nations (2015, three instances), and The 2019 Legatum Prosperity Index (11 instances) when the World Bank’s RAI was not reported, for a total of 172 countries. RAI and quality of roads are empirically and conceptually weakly correlated: a country may have a high RAI but low quality of roads and vice versa (e.g., Timor-Leste’s RAI equals 90 and QRI equals 2.2, while Namibia’s RAI equals 57 and QRI equals 5). As a result, we assembled balanced cross-sectional data for all 162 countries in our sample.

---

9 These countries are at the low spectrum of the score. Therefore, omitting them would have made our estimates from the matched countries upwardly biased. Unfortunately, there is no official data for Kosovo.
11 Mikou, Rozenberg, Koks, Fox, and Peralta Quiros (2019) estimated the RAI using open data. The correlation of their and the World Bank’s RAI is low, though: 0.40 for primary and secondary roads, and 0.31 and 0.30 when tertiary and tracks are included, correspondingly.
12 In a few cases where variables were not available for specific countries (e.g., GDP or road network length for Cuba, Kosovo, and Syria), we procured them from various alternative sources and then cross-checked them with other data and similar counties.
Table 3 presents the summary statistics of QRI, RAI, GDP per capita, and road density.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>Min.</th>
<th>Max.</th>
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<tr>
<td>GDP per capita 2018 (USD)</td>
<td>13,572.59</td>
<td>18,873.62</td>
<td>1,539.90</td>
<td>5,268.20</td>
<td>16,415.19</td>
<td>307.46</td>
<td>82,756.02</td>
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<td>Road density</td>
<td>0.42</td>
<td>0.71</td>
<td>0.03</td>
<td>0.13</td>
<td>0.38</td>
<td>0</td>
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<tr>
<td>Quality of road infrastructure</td>
<td>3.86</td>
<td>1.05</td>
<td>3.04</td>
<td>3.8</td>
<td>4.53</td>
<td>2.01</td>
<td>6.37</td>
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<tr>
<td>Rural Access Index</td>
<td>64.36</td>
<td>25.47</td>
<td>43</td>
<td>69</td>
<td>84</td>
<td>5</td>
<td>100</td>
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<td></td>
<td></td>
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</table>

Note: This table presents summary statistics of key variables. **GDP per capita** is the GDP in 2018 in US dollars divided by the population in 2018. **Road density** is calculated as the road length in kilometers divided by the area in square kilometers. **Quality of road infrastructure** is the World Economic Forum compilation of executives’ perception of the quality of road infrastructure, ranging from 1–bad to 7–excellent. **RAI** is the share of rural population with an all-weather road within two kilometers.

Alternative measures highlight distinct interpretive road network features. The RAI speaks to the extent to which rural households can reach local markets and other facilities and services, while MS score focuses on the road expeditiousness between major urban centers. While these measures partially overlap and correlate, it is conceivable that a country can undertake infrastructure investments that dramatically increase one measure without changing the others. Furthermore, these variables are endogenous, simultaneous, and autocorrelated. For example, rural access, road density, and road quality contribute to higher GDP per capita, while higher GDP per capita allows for investment in road network extension and quality.

Figure 3 presents the results of OLS and quantile regressions of the natural logarithms of GDP per capita, road density, quality of road infrastructure survey score, and the Rural Access Index on the MS score. There is a strong and positive relationship between GDP per capita and road density and the MS score. This relationship rises exponentially for wealthier countries and countries with more dense road networks. Put differently, a marginal improvement in the MS score is associated with a higher GDP per capita and higher road density for advanced economies than for low-income developing countries.\(^{13}\) There is also a strong and positive relationship between the quality of roads and RAI, on the one hand, and the MS score, on the other hand. This relationship is stronger for the countries with low RAI.

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\(^{13}\) Jaworski, Kitchens, and Nigai (2020) estimate that the US interstate highway system contributes to ca. 4 percent of GDP, a quarter of which through foreign trade.
Figure 3. OLS and Quantile Best Fit Lines of MS Score and GDP per Capita, Road Density, Quality of Road Infrastructure, and Rural Access Index

In GDP per Capita 2018

In Road Density

Quality of Road Infrastructure

Rural Access Index

Note: This figure presents the OLS and quantile regression best fit lines of Mean Speed [MS] score on the natural logarithm of the GDP per capita in 2018 in US dollars (top-left graph), the natural logarithm of road density defined as road length in kilometers divided by country area in squared kilometers (top-right graph), the quality of road infrastructure survey score ranging from 1-poor to 7-excellent (bottom-left), and the Rural Access Index, which measures the share of rural population which have access to an all-weather road within two kilometers (bottom-right graph). The top and bottom solid blue lines represent the 90th and 10th quantile fit lines, correspondingly; the dashed middle blue line represents the OLS fit line. Round red squares represent low-income developing countries (LIDC), yellow circles represent emerging market economies (EME), and green triangles represent advanced economies (AE). Countries with less than two cities distant more than 80 km by road from the main city—e.g., smaller countries and archipelagos—were dropped.

B. Contest between Road Network Measures

As argued previously, road quality is multidimensional. The perception of the quality of road infrastructure is foremost a function of road access, road density, and mean speed. Which of these variables has the highest predictive power regarding the QRI? To answer to this question, we run single and simultaneous horse races of road network variables.

Since the RQI survey score is a continuous variable, we encode it as “1–low” if the quality of roads survey score is below 3; “2–medium” if it ranges between 3 and 5; and “3–high” if it is above 5. To complete the
sample, we classified Kosovo—which does not have a QRI score—as “2–medium” along with neighboring countries: Albania, Montenegro, North Macedonia, and Serbia. Table 4 presents the results of ordered logistic regressions of encoded RQI on RAI, road density, and MS score.

Table 4. Ordered Logistic Regressions of Road Quality on Road Network Characteristics

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<th>(4)</th>
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<td>RAI</td>
<td>0.0494***</td>
<td>0.0227**</td>
<td>-0.0099</td>
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<tr>
<td></td>
<td>-0.00781</td>
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<tr>
<td>Road density</td>
<td>0.609***</td>
<td>0.315**</td>
<td>-0.104</td>
<td>-0.129</td>
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<td></td>
<td>-0.104</td>
<td>-0.129</td>
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<tr>
<td>MS score</td>
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<td>0.0727***</td>
<td>0.0547***</td>
<td>-0.0118</td>
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<td>162</td>
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<tr>
<td>Pseudo R²</td>
<td>0.162</td>
<td>0.135</td>
<td>0.151</td>
<td>0.246</td>
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</table>

Note: This table presents the results of ordered logistic regressions of road quality on road network characteristics. The dependent variable is the quality of road infrastructure encoded as “1–low” if the survey value is below 3; “2–medium” if it ranges between 3 and 5; and “3–high” if it is above five. RAI is the share of rural population with an all-weather road within two kilometers in percentage points. Road density is the natural logarithm of road length in kilometers divided by the area in square kilometers. MS score is the harmonic mean speed between the major city and other large cities. Data are from the UN, IMF, World Bank, and World Economic Forum. The sample contains balanced data for 162 countries. Heteroskedasticity-robust standard errors are reported in parenthesis; * denotes significance at 10%, ** significance at 5%, and *** significance at 1%.

The results accentuate that the MS score is economically meaningful and statistically significant, and more resilient than other covariates to explain the quality of roads perception. While the coefficients associated with RAI and road density fall by 54 and 48 percent from univariate to multivariate regressions (cf. models 1–2 versus model 4), correspondingly, the coefficient for MS score fall only by 25 percent (cf. model 3 versus model 4).

Similarly, a country’s road network characteristics—access, density, and speed—contributes to its income level. Which road network variable is most strongly correlated with income? In a similar fashion as with QRI, we encode the three income levels according to the IMF’s World Economic Outlook: “1” for LIDC, “2” for EME, and “3” for AE.14

Table 5 presents the results of ordered logistic regressions of income levels on RAI, road density, and MS score. The MS score outperforms other road network variables in their explanatory power of country

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14 The classification of countries by income levels used by the IMF follows a waterfall process. The main criteria to sort countries into advanced economies and emerging market and developing economies are: (i) income per capita, (ii) export diversification, and (iii) degree of integration into the global financial system. Further, within the emerging market and developing economies the LIDCs are countries that have per capita income levels below a certain threshold (currently set at US$2,700 in 2016 as measured by the World Bank’s Atlas method), structural features consistent with limited development and structural transformation, and insufficiently close external financial linkages to be widely seen as emerging market economies. See https://www.imf.org/external/pubs/ft/weo/2019/02/weodata/groups.htm. For this exercise, we also classified Cuba and Kosovo to the group of Emerging Market Economies on the basis of their GDP per capita.
development. While RAI and road density coefficients fall by 35 and 40 percent, respectively, the MS score coefficient only adjusts downwards by 8 percent.

Table 5. Ordered Logistic Regressions of Income Levels on RAI, Road Density, and MS Score

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<tr>
<td>RAI</td>
<td>0.0891***</td>
<td>0.0575***</td>
<td>-0.011</td>
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<td>Road density</td>
<td>0.928***</td>
<td>0.554***</td>
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<td>MS score</td>
<td>0.103***</td>
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<td>Pseudo ( R^2 )</td>
<td>0.342</td>
<td>0.244</td>
<td>0.25</td>
<td>0.506</td>
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Note: This table presents the results of ordered logistic regressions of income levels on road network characteristics. The dependent variable is the IMF’s World Economic Outlook country classification by income encoded as “1–Low-Income Developing Countries,” “2–Emerging Market Economies,” and “3–Advanced Economies.” RAI is the share of rural population with an all-weather road within two kilometers in percentage points. Road density is the natural logarithm of road length in kilometers divided by the area in square kilometers. MS score is the harmonic mean speed between the major city and other large cities. Data are from the UN, IMF, and World Bank. The sample contains balanced data for 162 countries. Heteroskedasticity-robust standard errors are reported in parenthesis; \* denotes significance at 10%, \*\* significance at 5%, and \*\*\* significance at 1%.

Taken together, these results suggest that MS score is a relevant independent dimension which is less collinear, more stable, and more strongly correlated with road quality and income than other road network variables.

IV. Mean Speed Score for Welfare Calculations

The MS score can be used to enhance the cost-benefit analysis of a road investment (cf. OECD, 2020). Assuming arguendo that a public administration in an emerging economy is considering building a bypass or alternative road to alleviate traffic that would increase the MS score in the network from the median MS score of 73 by one standard deviation to 90 (Table 1).

For simplicity, let us assume that the bypass is 100 km long and that the cost of paving two lanes, in line with the World Bank’s estimates, is US$1,000,000 per km (Mikou, Rozenberg, Koks, Fox, and Peralta Quiros, 2019).\(^{15}\) Further, the bypass would shorten the average 50-km commuting time by ca. 8 minutes each way (i.e.,

\[^{15}\text{Mikou, Rozenberg, Koks, Fox, and Peralta Quiros (2019) estimate that the cost of paving two lanes ranges between US$843,000 in South Asia to US$1,588,000 in Eastern Europe and Central Asia.}\]
from 41 minutes to 33 minutes)\(^\text{16}\) for 100,000 commuters. At an hourly GDP per capita of US$3.30,\(^\text{17}\) the road investment would pay back in ca. five years.\(^\text{18}\)

Cost-benefit calculations become simpler for ex-post evaluations using pre- and post-investment MS scores for a defined area. For specific purposes, the MS score can be calibrated to local and regional networks, and to ranges of distances (e.g., 20–50 km).

V. Public Investment Management

The MS score is an output variable of a complex public investment and management process. But what goes into its \textit{production function}?\(^\text{19}\)

The Public Investment Management Assessment (PIMA) database (IMF, 2015 and 2018)\(^\text{19}\) surveys over 60 countries and evaluates 15 institutions involved in the three key stages of the public investment cycle: (i) planning of sustainable investment across the public sector, (ii) allocation of investment to the right sectors and projects, and (iii) implementation of investments projects to deliver productive and durable public assets—for a total of 45 variables. Each institution is assessed on institutional strength (the organization, policies, rules and procedures on paper) and effectiveness (the degree to which the intended purpose is being achieved in practice or there is a clear useful impact).

For the matched countries in the MS and PIMA datasets, the MS score is strongly correlated with good public investment management practices along 14 dimensions; only investment protection during budget implementation is orthogonal to MS. These correlations are only indicative as there is a selection bias into the PIMA dataset. Future work can focus on the principal components of that go into the \textit{production function} of the MS score.

VI. Discussion and Conclusion

The quality of roads is a function of various factors and difficult to encapsulate in a single statistic. We develop a computationally-efficient method to proxy countries’ road quality based on the harmonic mean speed between the major cities. We argue that the mean speed [MS] score captures a quintessential economic characteristic of road network quality: the ability to move people and goods expeditiously between cities. The MS score covers 162 countries worldwide—excepting only small countries and archipelagos with short road networks—more than any other comprehensive measure of road quality.

We show that there is a strong and positive relationship between the MS score and both GDP per capita and road density. Quantile regressions provide evidence that these relationships rise exponentially for wealthier

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\(^{16}\) The one-way commute times before and after the road upgrade are: (i) 60 minutes × 50 km ÷ average speed 73 km/h = 41.1 minutes versus (ii) 60 minutes × 50 km ÷ 90 km/h = 33.3 minutes.

\(^{17}\) I.e., at the median annual GDP per capita in our sample of US$5,268 (Table 2) and assuming 1,600 working hours per year.

\(^{18}\) The undiscounted payback period equals US$100 million investment in the bypass ÷ (US$3.30 median hour rate × 16 minutes two-way shorter commute ÷ 60 minutes × 250 working days × 100,000 commuters).

\(^{19}\) Cf. IMF’s web page on PIMA: [https://infrastructuregovern.imf.org/content/PIMA/Home/PimaTool/What-is-PIMA.html](https://infrastructuregovern.imf.org/content/PIMA/Home/PimaTool/What-is-PIMA.html) (accessed February 2021).
countries. Furthermore, the MS score outperforms other variables describing road network characteristics in predicting the perception of road quality and correlates more strongly with country income level than road access and road density.

We acknowledge two caveats of the MS score. First, the MS score reflects the fastest times in a day (usually at night), thus it may not necessarily correlate with mean speed during high economic activity for locations with high congestion variation (i.e., two countries with similar MS score may have different mean speeds during commute times). Future work will be guided towards collecting the high-low and variance MS scores.

Second, the MS score draws on speed between a minimum of three and a maximum of six cities. Since small countries have fewer large cities than large countries and large cities tend to be better connected, the city count truncation may bias upwards the MS estimate towards large countries. Thus, countries should be compared with peers by size and population rather than unconditionally across the board.

The MS score can be used as an instrument of road investment efficiency and for cost-benefit analysis of road investments. The MS score provides a robust instrumental variable for the quality of road infrastructure: (i) it strongly affects the perception of road quality (cf. Figure 3 and Table 4) and (ii) it is unlikely to suffer from the same measurement problems as the other connectivity indicators. The MS score is easy to replicate locally and can be run periodically to create rich panel data. Further applications and extensions include the quantification of different transport policies, sub-national and regional rankings, travel time between major cities in different countries, determinants of efficient investment in infrastructure, and event studies (e.g., the effects of natural disasters).

20 E.g., as a compliment to the accessibility framework presented by (Dijkstra, Poelman, and Ackermans 2019).
Appendix I. List of Countries and Cities

The table below lists the cities by country in our sample used to compute the Mean Speed [MS] score. The first city by country in the list is the city of reference (start), usually the largest metropolitan area; the remaining cities are the destinations in alphabetical order. Distance is the distance between the city of reference and the destination. Cities in all capital letters are state capitals. Tiny countries, archipelagos, and cities within 80 km by road from the city of reference are omitted. Data are publicly available from Google Maps.

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