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The Intensity Gap: A Global Analysis of Who Responds to the Crowdsourced "Did You Feel It?" System

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ABSTRACT

The U.S. Geological Survey's (USGS) 'Did You Feel It?' (DYFI) system is an internet tool that collects shaking intensity observations through crowdsourcing. It produces maps and provides supplementary data to ShakeMap, which offers near-real-time maps of ground motion resulting from significant earthquakes around the globe. Barriers such as technology and language make DYFI an unequally accessible tool, however, leading to a less comprehensive view of an earthquake's impact in certain regions. Here, we analyze users' global interaction with DYFI to evaluate its accessibility. We employ web analytics to quantify how users access DYFI, and perform inference modeling to predict each country's response rate to DYFI. The panel dataset built for this inference model combines physical earthquake parameters from the USGS with socioeconomic data from the World Bank and the Central Intelligence Agency for 151 countries from 2009 to 2020. Our web analytics show that users predominantly access DYFI through mobile devices and are often referred through social media. Additionally, results from the inference model reveal that socioeconomic parameters, including primary language spoken and broadband internet subscriptions, alongside physical earthquake parameters such as average shaking intensity, have a significant effect on a country's response rate to DYFI. As a result of this analysis, we establish a country priority index for improved DYFI awareness and accessibility. This index considers regions of the world lacking seismic station coverage that face barriers to DYFI access, such as language, technology, and other factors. Consequently, the USGS has made evaluating DYFI's performance on mobile devices a priority and has begun incorporating and monitoring the use of additional languages within the DYFI system. Furthermore, our analyses suggest specific nations with low response rates could benefit from targeted outreach in conjunction with partner agencies in each country.

Keywords: earthquake, citizen science, response rate, panel regression, web analysis, global, accessibility

1 INTRODUCTION

The United States Geological Survey (USGS) has been operating Did You Feel It? (DYFI) since 1999 in California, since 2000 for the rest of the United States, and since 2004 globally (Quitoriano and Wald, 2020). To date, DYFI has received more than eight million responses, covering large portions of the globe. Analogous systems around the world are typically implemented at the national level–for example, Italy's Hai Sentito Il Terremoto (HSIT) (Sbarra et al., 2010; Tosi et al., 2015) and various adaptations of the USGS DYFI software in countries such as Canada, New Zealand, and others. For a full list of analogous national systems, please see Goded et al. (2017). The European-Mediterranean Seismological Center (EMSC) provides the only other widely used global community-science method for collecting earthquake felt reports (Bossu et al., 2016). Yet, the EMSC Felt Reports system is based on users' selection of picture-based intensities, not formal macroseismic intensity values, which would require the collection of users' detailed observations for validation and reproducibility.

DYFI has led to a number of benefits for the general populace exposed to earthquakes, emergency responders, and the scientific community. DYFI benefits exposed populations–where often tens of thousands of DYFI contributors have a direct ability to engage with a federal agency and contribute to citizen science efforts (Goltz et al., 2020). This ability to engage can offer educational value where citizens are familiarized with concepts like intensity, and thus, an increased understanding of their risk (Celsi et al., 2005). Scientifically, DYFI has been shown to be an accurate measure of ground motion when a large number of DYFI responses are recorded (Atkinson and Wald, 2007). Thus, the output of DYFI is directly used as shaking constraints for USGS products like the ShakeMap (Wald et al., 2022), an important input for loss estimates provided by the PAGER (Prompt Assessment of Global Earthquakes for Response) (Quitoriano and Wald, 2020). PAGER and ShakeMap, in turn, inform stakeholders like humanitarian specialists and emergency managers responding to an earthquake and serving exposed populations (Thompson et al., 2019; Wald, 2023; Loos et al., 2026).

One key to capturing a more accurate estimate of shaking is the quantity and spatial coverage of DYFI responses (Atkinson and Wald, 2007). This is especially the case in regions where fewer seismic stations exist, such as the Central and Eastern United States (CEUS) or many countries in the developing world. Take, for example, the Haiti 2010 earthquake, an event that led to the deaths of over 200,000 people and over 8 billion USD losses, exceeding the nation's gross domestic product (Calais et al., 2010). At the time of the earthquake, no seismic stations existed–the only on-the-ground measurements of shaking were those provided by DYFI (Eberhard et al., 2010). A more accurate estimate of shaking could have aided situational awareness and better focused response. Countries, such as Haiti, that do not have an analogous DYFI system and lack seismic stations to constrain shaking estimates, stand to benefit from increased contributions to the USGS DYFI system. The goal of this study is to understand how access to DYFI can be increased in countries that would benefit from its results.

We build upon several studies that have evaluated the factors that influence DYFI contribution. Mak and Schorlemmer (2016) performed a thorough regression analysis to estimate DYFI responses per ZIP code in the United States (U.S.), while accounting for multiple factors simultaneously. This analysis was done for all earthquakes (n = 614) greater than M4 in the United States (comparing results for California and the CEUS) between 2000 and 2014. The study is rigorous and finds that DYFI responses depend on both earthquake and socioeconomic status parameters. Hough and Martin (2021b) also performed an analysis of who responds to DYFI, specifically assessing response rates (or the number of DYFI responses normalized by population) per ZIP code in California and per district in India. Compared to Mak and Schorlemmer (2016), the analysis presented by Hough and Martin (2021b) is valuable in that it is a cross-cultural comparison between India and the United States (e.g., California), and it has a greater focus on the influence of socioeconomic factors, like household income, on DYFI engagement. Hough and Martin (2021b)'s study evaluates a few widely felt earthquakes (n = 6) and analyzes the individual relationship between response rates, shaking intensity, and socioeconomic variables. Aspects of the correlation analysis in Hough and Martin (2021b) were critiqued in Wald (2021), which Hough and Martin refined in a reply (Hough and Martin, 2021a) and Hough's follow-on study (Hough, 2021). Specifically, Hough's follow-on study expanded upon their earlier work by collectively analyzing additional earthquakes (n = 21) in California and using a spatial approach, finding that economically advantaged ZIP codes were correlated with high DYFI response rates (Hough, 2021). Our study aims to build upon the strengths and concepts of these foundational analyses, including the regression analysis presented in Mak and Schorlemmer (2016) and the detailed focus on socioeconomic factors contributing to DYFI engagement presented in Hough and Martin (2021b) and Hough (2021). Here, we extend the statistical analysis to the global level and investigate between-country differences in DYFI response rates for all recorded major earthquakes from 2009 to 2020 (n = 1758).

Given that DYFI responses have been collected for over two decades around the globe (Quitoriano and Wald, 2020), an opportunity exists to conduct a global empirical analysis of the factors that contribute to DYFI response rates for all earthquakes and countries around the world to understand current limitations and potentially improve access to DYFI in places where it matters the most. Specifically, we answer the following research questions (Q).

- Q1 How do earthquake-affected populations interact with DYFI?
- Q2 What are the factors that influence the number of responses to DYFI globally?
- Q3 Which countries would benefit from increased DYFI accessibility?

To address these questions, we draw on multiple data sources and methods. We begin with a web traffic analysis, which informs a subsequent regression analysis using statistical inference techniques. This regression is applied to panel data that links DYFI responses with earthquake and population variables over a 12-year period (2009–2020), during which consistent DYFI data are available for 151 countries. By leveraging statistical inference methods, we are able to identify significant relationships between factors and DYFI responses. We also primarily focus on population variables that may explain differences in DYFI responses, such as internet access. Using the results of these analyses, we identify the countries that would benefit from increased access to DYFI through a composite priority index. Already, as a result of this analysis, the USGS is increasing access in identified countries through language translation and improved sharing.

2 QUESTION 1: HOW DO EARTHQUAKE-AFFECTED POPULATIONS INTERACT WITH DYFI?

We conduct a web traffic analysis to understand how contributors in the earthquake-affected region access and interact with DYFI. Web traffic data describes how people interact with websites, and its value for directly estimating the area where an earthquake is felt, has been studied in-depth by the EMSC through the method called "flash-sourcing" (Bossu

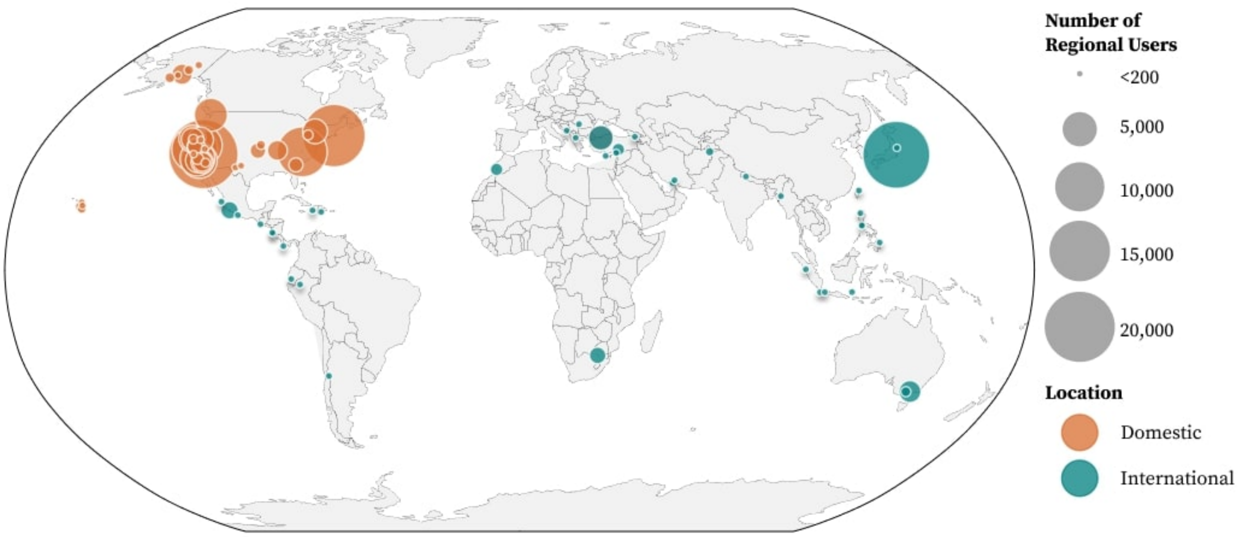

Figure 1. Web traffic data was analyzed for 80 earthquakes. Locations and number of regional users for earthquakes from 2019-2023 used in web traffic analysis.

et al., 2008, 2011, 2014). Here, we instead leverage web traffic data to gain insight into how people complete the crowdsourced DYFI questionnaire, including information about their device and the path they took to reach the form. Using these insights, we can define tangible ways to increase access to DYFI.

2.1 Question 1: Web traffic analysis

To contribute to DYFI, individuals must complete a Felt Report questionnaire, which includes a series of questions like 'Was it difficult to stand and/or walk?' and, for indoor situations, 'Did objects rattle, topple over, or fall off shelves?'. Responses to these questions are translated into a Community Decimal Intensity (CDI), which takes values between 1 (not felt) and 9+ (violent shaking). CDI is calibrated to be on the same scale as the metric used for ShakeMap, Modified Mercalli Intensity (MMI), allowing intensity estimates from DYFI to be incorporated into USGS intensity maps (Dengler and Dewey, 1998; U.S. Geological Survey, 2025).

For our analysis of interaction with the DYFI Felt Report page, we use data recorded within a week of the earthquake, since interaction with DYFI is minimal beyond this period. We source web traffic data from Google Analytics, as detailed in the Data and Resources.

Our analysis covers earthquake events from 2019 to 2023, with a large majority of events (96%) occurring after 2020. The dataset begins in 2019 because Google Analytics data in prior years tends to be rounded or overly aggregated. Many events in 2019 and 2020 also had this data quality issue, which resulted in there being only 3 events included prior to 2021. We used the USGS Earthquake Catalog to select events, filtering for high-impact events, identified by their PAGER alert level, and high-exposure events, indicated by the number of DYFI responses (Earle et al., 2009). We include all events with a yellow or higher PAGER alert level from 2019 to 2023, given that they had at least 100 DYFI responses. The remaining events in our sample are those with the greatest number of responses to DYFI, with the intention of having an equal number of events in the United States (domestic) and outside the United States (international) to facilitate comparison. While users can contribute to DYFI for either a specific earthquake through that earthquake's event page or a general unknown event, we only examine web traffic for users who filled out a Felt Report through an earthquake's event page, since web traffic cannot be analyzed for unknown events.

The resulting sample has 80 earthquakes, 40 domestic and 40 international. International events span 6 continents and 26 countries, and domestic events span 13 states, with magnitudes across the entire sample ranging between M_w3.6-7.8, as shown in Figure 1. All sampled events are included in Table 3 in the Appendix.

Several Google Analytics metrics measure engagement with a web page, including *users*, or the number of unique devices that interact with a given web page; *sessions*, or the number of distinct, time-separated visits to a web page; and *pageviews*, or the number of times a web page is viewed (Google Analytics, 2024). A single *user* could have multiple *sessions* in which they visit the Felt Report page, and within each *session*, they could have multiple Felt Report *pageviews*. Here, because we are interested in the characteristics of unique users of the Felt Report page, we analyze *users*. Although likely uncommon, we were unable to account for occurrences in which the same person visited a DYFI Felt Report page using multiple devices.

To only consider data for users who are most likely to be affected by the earthquake, we define *regional users* as the *users* within the region where the earthquake occurred. Location information is available for web users who grant location access to Google Analytics, where the user's IP address typically reveals their nearest city, region (state), and country. We did not have access to individual IP addresses. We filtered *users* to only include those *regional users* that are located in the states (if in the U.S.) or in the countries (if outside the U.S.) that experienced some level of shaking as reflected by that earthquake's ShakeMap. If an earthquake had shaking in multiple states or countries, *users* from each state or country with shaking would be considered *regional users*. For the 80 events, 44% of *users* could not be determined to be *regional users* and were excluded from analysis. For international earthquakes in which large, highly populated countries were impacted (such as China and India), *users* in regions without shaking (as indicated by ShakeMap) that had more *users* than regions with shaking were not counted as *regional users*. In this analysis, we are unable to account for the unlikely scenario in which a person uses a virtual private network (VPN) to alter their device's perceived location to near an earthquake event. Additionally, people that disable Google Analytics tracking permissions are not included in this analysis, resulting in available web traffic data for a total of 38% of DYFI responses in our sample, as dictated by Table 3 in the Appendix. However, trends among available user data should be consistent with the full population, given the number of users per event is still large.

To understand how DYFI is accessed both physically and digitally, we analyzed *regional users* of the Felt Report page using two main Google Analytics dimensions: *device category*, and *referral source*. We also examined browser language data, but found it to be largely influenced by the location of the earthquake. *Device category* gives the type of device (mobile device, desktop, or tablet) used to access the Felt Report. *Referral source* specifies the domain of the web page the user was on prior to entering the USGS Earthquake domain and viewing the Felt Report (Google Analytics, 2024). These chosen dimensions can be directly influenced by the USGS through their development and publicizing of the Felt Report page.

2.2 Question 1: Results and discussion

Across all 80 events, we find that a large majority of *regional users* access the DYFI Felt Report via mobile device, as shown in Figure 2a. This includes 83% of international and 78% of domestic users. The second-most used device is on desktop computers and the third-most is via tablet. There is negligible difference in device access between the international and domestic events.

Overall, users are referred to the Felt Report from numerous referral sources, including Twitter, Google, and Facebook, as shown in Figure 2b. The "None" referral source indicates that Google Analytics tracked no referral prior to the USGS Earthquake domain, which can occur if a user is directly linked to the Felt Report page from a separate application, such as an email or messaging app. Therefore, while the "None" source cannot be specifically tracked, it is likely a proxy for external messages, such as the USGS Earthquake Notification Service (ENS). For domestic events, *regional users* are somewhat evenly distributed across these referral sources. However, for international events, a large percentage (66%) of users were referred from Twitter.

The considerable number of Twitter referrals for international events is largely due to tremendous user interaction following the 2021 M 5.9 Chiba, Japan earthquake. Shortly after the earthquake, a local Japanese resident posted a tweet, encouraging others in Japan to fill out the USGS DYFI Felt Report (Figure 3). This tweet gained thousands of retweets, with some Twitter users commenting how they were using translators to fill out the form. Altogether, the tweet was largely responsible for the 17,429 *regional users* that interacted with the Chiba earthquake's Felt Report page, the second most *regional users* of all 80 events. This great citizen science response highlights the power of social media to rapidly spread information and increase engagement. While the Chiba earthquake tweet was an exceptional case, Twitter remains the most common referral source for international events overall.

3 QUESTION 2: WHAT FACTORS INFLUENCE DYFI RESPONSES?

Although the web analysis provides insight on user-specific interaction behavior, it is only available for select years and countries, and lacks detail on the characteristics that motivate global DYFI response. To determine the factors that influence global DYFI responses, we leverage statistical inference methods using a panel dataset that links country-year DYFI responses with earthquake and population variables for 151 countries over 12 years (2009-2020). Regressing on data in its panel (longitudinal) form accounts for changes in the response variable over time as well as differences between individuals (countries). This is preferable to summarizing temporal data for each country and using a generalized linear model, as it preserves time-dependent information and has a greater number of observations.

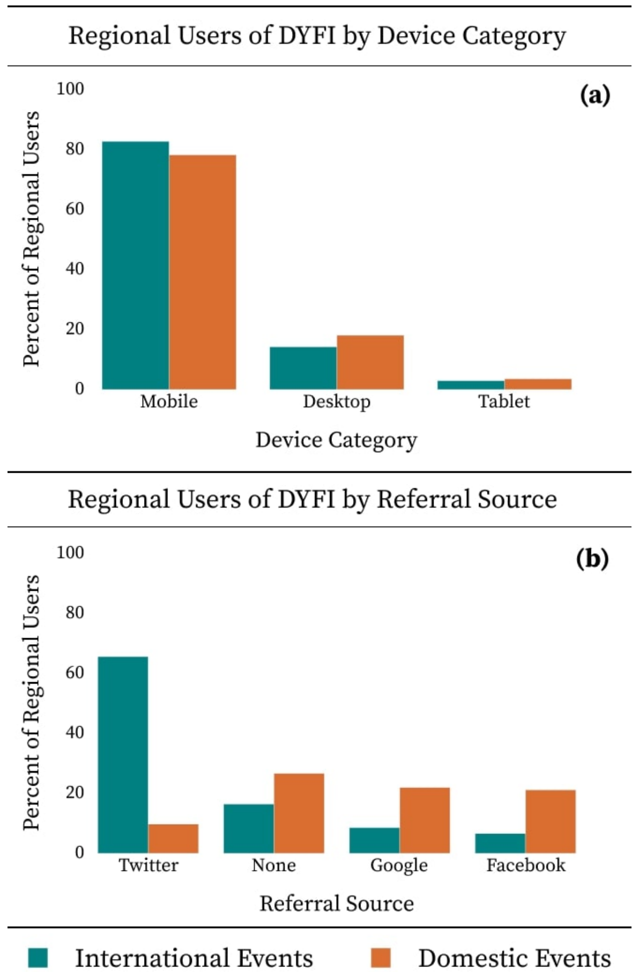

Figure 2. Earthquake-affected populations (regional users) physically and digitally access DYFI through different means. Bar charts show the number of regional users that access an event's Felt Report page by device category (a) and referral source (b) aggregated across 40 domestic events (orange) and 40 international events (teal). Only the four most common referral sources are shown (b). The 2021 M 5.9 Chiba, Japan accounts for 63% of all international regional users.

3.1 Question 2: Panel data

A panel dataset describes subjects over time. Here, we construct a country-year panel dataset by aggregating all variables annually (t), ensuring that most seismically active countries experience at least one earthquake event with DYFI responses, and aligning with the national level (c) at which most population variables are reported.

Because ShakeMap is generated at a higher magnitude threshold of $M_w 5.4$ outside of the United States compared to the domestic threshold of $M_w 3.5$, we only include events of $M_w 5.4$ and greater. DYFI responses that occurred outside of a country's boundaries and in areas with zero population or population less than the number of responses were also removed. Countries without any earthquake data and countries without data reported by the World Bank were removed from the analysis. The final panel dataset spans 151 countries between the years of 2009 and 2020. The dataset begins in 2009, one of the first years in which DYFI saw sustained and widespread global participation, with representation from 57 countries.

In our analysis, the dependent variable is DYFI response rate, y, per country per year (y_{ct}). Similar to Mak and Schorlemmer (2016) and Hough (2021), our explanatory variables (X_{ct}) are a combination of earthquake variables, largely from the USGS, and population variables, largely from the World Bank or the Central Intelligence Agency (see Data and Resources). While we aimed to include similar variables as both studies, it was not always possible due to data

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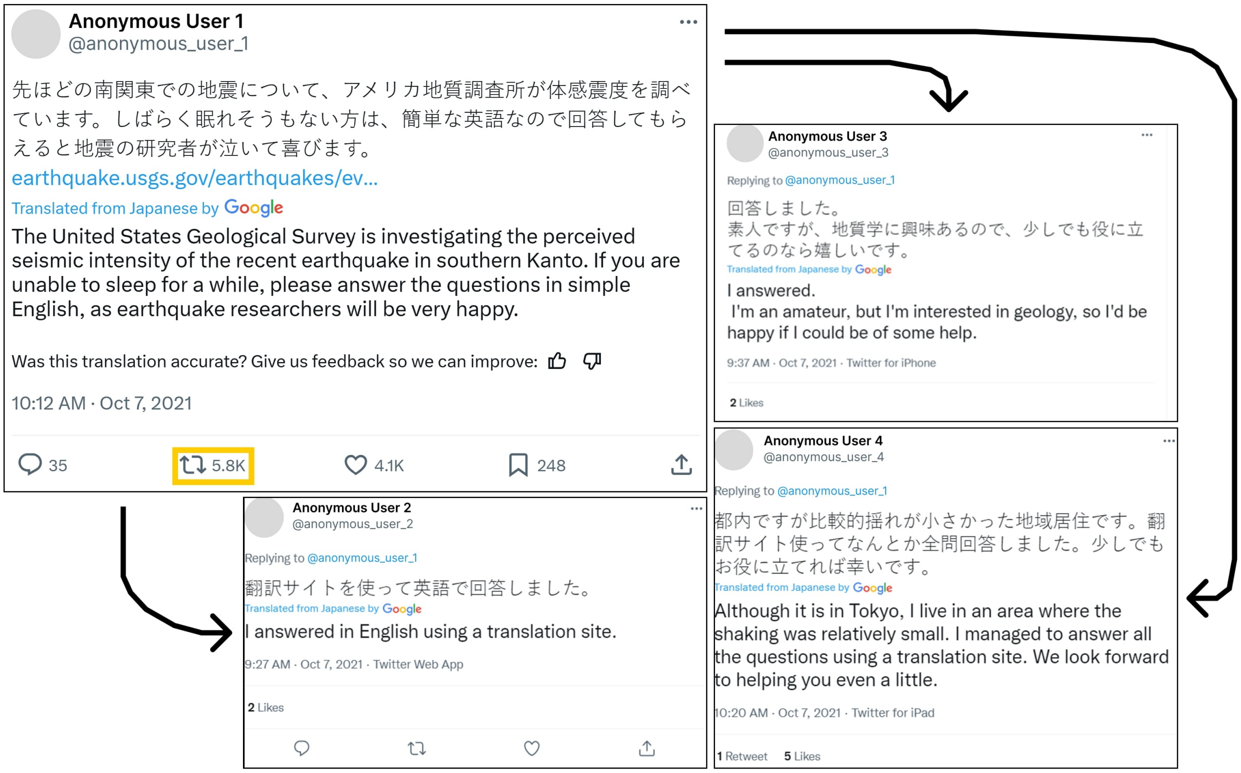

Figure 3. Social media can significantly increase DYFI interaction. Social media interactions surrounding "Did You Feel It?" and the 2021 M 5.9 Chiba, Japan earthquake. Arrows point from the original tweet to responses to that tweet.

availability. However, the regression analysis accounts for unobserved heterogeneity due to unexplained variables.

Overall, we evaluate a total of 52 explanatory variables, 36 from the USGS, 15 from the World Bank, and 1 from the Central Intelligence Agency (CIA). Table 4 in the Appendix provides a full list of variables and their descriptions. Figure 4 visualizes country DYFI response rates (y) over time, and Figure 5 visualizes a subset of the explanatory variables in the dataset. Those identified as most influential for DYFI response rates are explained in further detail below.

3.1.1 DYFI response rate (y_{ct})

DYFI response rate is the dependent variable in our analysis, normalizing the number of DYFI responses by the exposed population (Defined as *TotalDYFIResponseRate* in Table 4 in the Appendix). As done in other studies (Hough, 2021; Hough and Martin, 2021b) we use response rate rather than including population exposure as an explanatory variable to mitigate against the complex relationship between DYFI responses and population (Mak and Schorlemmer, 2016; Boatwright and Phillips, 2017).

The number of DYFI responses is the number of people who completed the questionnaire on the Felt Report page, introduced in the previous section for Question 1. The Felt Report requires location information for Community Decimal Intensity assignments, making location and date information available for each response. Felt Report responses were available on a 10-km grid, including the number of responses and the estimated exposed population per grid cell. Gridded population data are time-specific and originally sourced from Oak Ridge National Laboratory's (ORNL) LandScan (see Data and Resources) (Quitoriano and Wald, 2020).

To aggregate the timestamped, grid-level Felt Report data to the country-year level, we grouped the grids by country and year and, within each country-year pair, summed the number of DYFI responses and separately summed the approximate population exposed to shaking (Defined as *TotalDYFIResponses* and *TotalGriddedPopulation* in Table 4 in the Appendix). The DYFI response rate, y_{ct}, used for analysis is the ratio of total responses to total population,

$$y_{ct} = \frac{\text{Total DYFI responses per country per year}}{\text{Total exposed population per country per year}}. \tag{1}$$

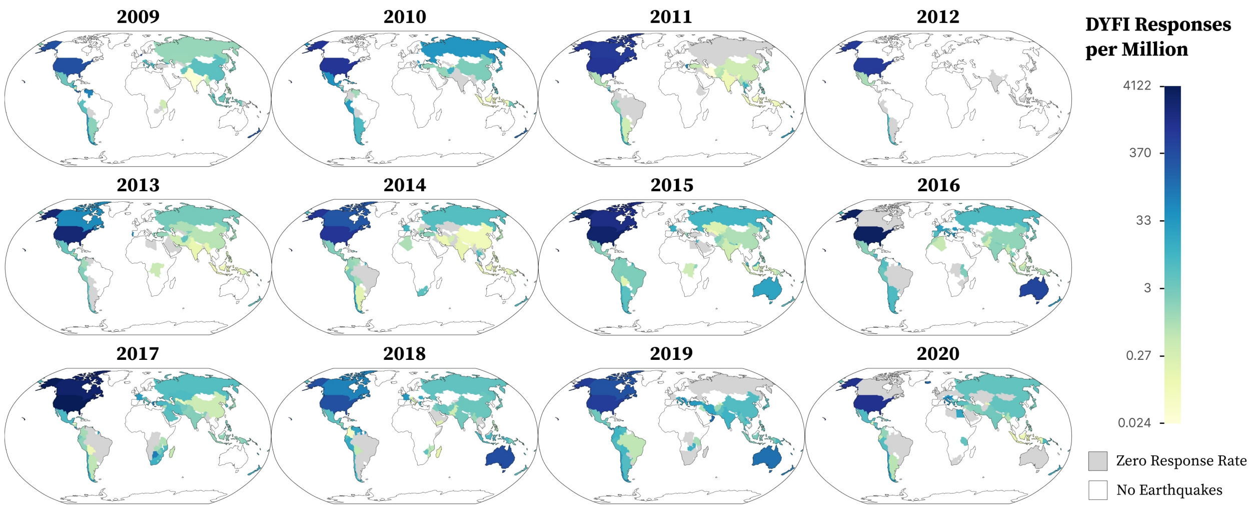

Figure 4. DYFI response rates over time. Grid of maps visualize response rate to DYFI for each year in the dataset (2009-2020). Response rates are transformed on a log scale and presented as DYFI responses per million people exposed to shaking. Countries are colored gray if they experienced earthquakes but had zero responses to DYFI for the year.

3.1.2 Earthquake variables (X_{ct})

We expect more DYFI responses in countries with frequent or large earthquakes. Therefore, we use multiple earthquake variables to capture a country's seismic hazard, which come from the USGS ShakeMap Atlas (see Data and Resources).

To represent intensity over the country, we calculate the maximum intensity across all earthquakes in that country and year ($MaxCDImedMMI_{ct}$). At the grid-level, prior to aggregation, this metric uses the CDI value if there were DYFI responses in that grid, otherwise it uses the grid's median MMI value from ShakeMap. Note that we calculated and tested alternative summary statistics to the maximum per country-year pair, such as the minimum, average, and several quantiles, which are described in Table 4 in the Appendix.

For seismically active countries, several earthquakes often occur in the same year. To account for earthquake frequency and the physical size of a country, we calculate earthquake density, $EarthquakesPerSqKm_{ct}$, as the ratio of the number of earthquakes per year to a country's land area. Some earthquake variables exhibit a data anomaly in 2012 due to potential data acquisition issues. Because this anomaly was captured by both explanatory and dependent variables, we kept the year 2012 in the dataset.

Other seismic hazard variables tested describe characteristics like magnitude and the number of grid cells exposed to shaking. These can be found in Table 4 in the Appendix.

3.1.3 Population variables (X_{ct})

As noted in other studies of DYFI, response rate is also related to characteristics of the responding population (Mak and Schorlemmer, 2016; Hough and Martin, 2021b). To describe population variables for all countries, we used data from the World Bank and the CIA World Factbook (see Data and Resources). Our initial selection of population variables was informed by the socioeconomic status variables used by Mak and Schorlemmer (2016) and Hough and Martin (2021b), the results of the web analysis, and our own intuition regarding factors that could potentially influence DYFI response rate. Given the global scale of our analysis, population variable inclusion was constrained by which variables were available for all countries.

Similar to Mak and Schorlemmer (2016), we include primary spoken language. Felt Report is a language-dependent form that only supported English and Spanish at the time of this research, thus we created a binary indicator of a country's primary spoken language, $EnglishSpanish_c$. For $EnglishSpanish_c$ to be True, a country must have English or Spanish as an official language, or at least 25% of its residents must speak English or Spanish as their first language. Language data was sourced from the CIA World Factbook (see Data and Resources), which has data that is static in time, so $EnglishSpanish_c$ is constant across all years in the dataset. We used the most recent language estimates relative to the time of data sourcing (2023), with the year of estimate varying by country. The relationship between $EnglishSpanish_c$ and y_{ct} is visualized in Figure 6. For each year, response rates in English- and Spanish-speaking countries tend to be higher than those in non-English- and non-Spanish-speaking countries.

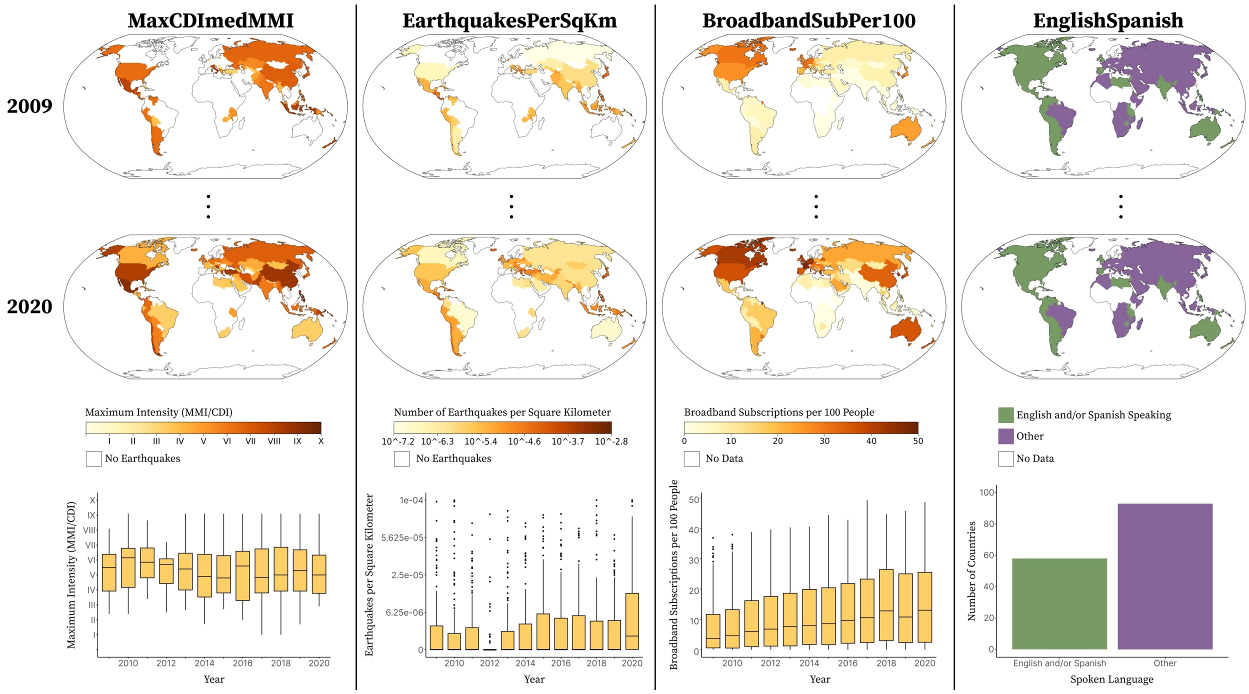

Figure 5. Explanatory variables over time. Grid of maps and charts visualize a subset of explanatory variables over time. Each column visualizes a different variable in the dataset: *MaxCDImedMMI*, *EarthquakesPerSqKm* (on a log scale), *BroadbandSubPer100*, and *EnglishSpanish*. These are the independent variables in the final statistical inference model. The first two rows show the spatial distribution of each variable for the first (2009) and last (2020) years of the compiled dataset. Intermediate years are not shown. The bottom row shows the temporal or categorical distribution of each variable. Each box in the box plot describes the variable's distribution across all 151 countries in a given year. Box plots for *EarthquakesPerSqKm* and *BroadbandSubPer100* have upper limits of 1e-04 and 50, respectively, for visualization purposes. Missing values are not visualized. A bar chart is used for *EnglishSpanish*, because it is constant over time.

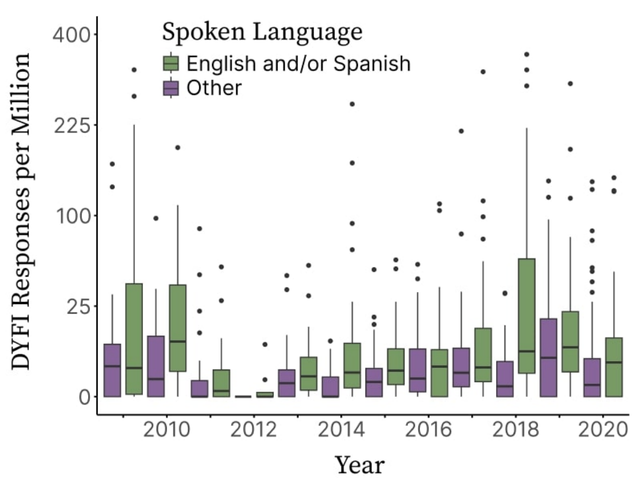

Figure 6. English- and Spanish-speaking countries tend to have higher DYFI response rates. Temporal box plots of response rate by country spoken language. For illustrative purposes, response rates are capped at 400 responses per million people exposed to shaking, and missing values are excluded from the visualization.

Similar to previous studies, we include education indicators, like the proportion of the population enrolled in tertiary education ($TertiarySchoolPct_{ct}$) and government expenditure on education ($GovExpenditureEdu_{ct}$), and wealth indicators, like gross domestic product per capita ($GDPcap_{ct}$). These variables were sourced from the World Bank (see Data and Resources).

Since DYFI is only available online and most users access DYFI via mobile devices, as found in the web analysis, we incorporate variables related to mobile phones and internet access. These variables include of cell phone subscriptions per 100 people ($CellSubPer100_{ct}$) and broadband (high-speed internet) subscriptions per 100 people ($BroadbandSubPer100_{ct}$). These variables were also sourced from the World Bank (see Data and Resources).

The subset of explanatory variables included in our selected model are visualized in Figure 5. All other initial population variables are included in Table 4 in the Appendix.

3.2 Question 2: Regression analysis

Here, we leverage panel regression methods, a class of statistical regression that allows for the evaluation of explanatory variable effects on the dependent variable while accounting for unobserved covariates through the spatial and temporal heterogeneity of the panel dataset (Angrist and Pischke, 2008). Because the dependent variable, DYFI response rate (y_{ct}), is censored and only takes values between 0 and 1, we model DYFI response rates using a Tobit regression (Colonescu, 2016) with mixed effects:

$$y^*_{ct} = \beta_{0c} + \sum_{i}^{k} \beta_i x_{ict} + \mu_c + \delta_t + \varepsilon_{ct} \tag{2}$$

where y^*_{ct} is a latent variable for the response rate, $\beta_0 c$ is the fitted intercept varying for each country c, x_{ict} is an earthquake or population variable i for country c and year t, β_i is the fitted coefficient for each variable, μ_c is the unobserved country-dependent error term, δ_t is the unobserved time-dependent error term, and ε_{ct} is a general error term. The mixed effects allows separate random intercepts and slopes to be estimated per country.

The observed response rate is derived from

$$y_{ct} = \begin{cases} {y^*_{ct}}^2 & \text{if } y^*_{ct} > 0 \\ 0 & \text{if } y^*_{ct} <= 0. \end{cases} \tag{3}$$

Equation 3 ensures predicted values are greater than 0. We square the latent variable as we actually model the square root of DYFI response rate to reduce its skew and maintain zero-values.

All continuous explanatory variables were standardized to facilitate comparison between variables and ensure variables with large variances do not dominate the model's fit. Because the maximum observed response rate is 0.005, we do not impose an upper limit on y^*_{ct}. We use the `plm` package in R to fit the Tobit model to our panel data using maximum likelihood estimation (see Data and Resources).

It is worth noting that this dataset becomes unbalanced when it is modeled, meaning each country does not have an equal number of observations. Observations are excluded from the model fit if they have a missing value for any of the model variables, and many country-year pairs are without an earthquake occurrence, causing those observations to lack a value for y_{ct} (among additional variables). Of the 1812 observations in the dataset, 1058 have a y_{ct} value that is missing.

Although a substantial part of the dataset has missing data, it does not appear to impact model results. Alternative models, which are detailed in Table 5 in the Appendix, filled missing values in y_{ct} and arrived at very similar results based on the significance and direction of the coefficients in each model.

To evaluate the impact of each explanatory variable on DYFI response rate, we estimate their marginal effects, which give the predicted change in the response variable based on a one-unit increase of the explanatory variable. In an ordinary least squares fit, the marginal effects are represented by the coefficients alone, but additional calculations are required to get these values in a Tobit regression. The marginal effect for the intercept, E_0, is

$$E_0 = \hat{\beta}_0 \Phi\left(\frac{\hat{\beta}_0}{\nu}\right) + \nu\phi\left(\frac{\hat{\beta}_0}{\nu}\right), \tag{4}$$

where $\hat{\beta}_0$ is the fitted intercept, ν is the standard deviation of the model's error term (ε), Φ is the standard normal cumulative density function, and ϕ is the standard normal probability density function (Croissant and Millo, 2018). In general, $\hat{\beta}_i$ is the fitted estimate for the i^{th} variable.

Marginal effects (E_i) for each explanatory variable, x_i, were calculated using

$$E_i = \frac{e_i}{\sigma_{x_i}} \tag{5}$$

where σ_{x_i} is the standard deviation of x_i and

$$e_i = \hat{\beta}_{0i}\Phi\left(\frac{\hat{\beta}_{0i}}{\nu}\right) + \nu\phi\left(\frac{\hat{\beta}_{0i}}{\nu}\right) - E_0, \tag{6}$$

$$\hat{\beta}_{0i} = \hat{\beta}_0 + \hat{\beta}_i. \tag{7}$$

Since we model the square root of DYFI response rate, E_i is a marginal effect in relation to $\sqrt{y}$. To obtain an untransformed marginal effect, we use the relationship $y = (\sqrt{y})^2$ and differentiate with respect to x_i. This yields an instantaneous slope that varies with y, thus we plug in the average response rate, $\bar{y}$, to arrive at our final marginal effects, $\frac{\partial y}{\partial x_i}$, which have units of responses per exposed population:

$$\frac{\partial y}{\partial x_i} = 2 \cdot \sqrt{\bar{y}} \cdot E_i \tag{8}$$

where

$$E_i = \frac{\partial \sqrt{y}}{\partial x_i}. \tag{9}$$

For variable selection, we first removed explanatory variables relating to seismic stations, since these variables describe another source of shaking intensity data, rather than earthquake or population characteristics. We also removed all variables that quantified population exposed to shaking, since this information is already present in y_{ct}. To determine the yearly summary statistic variables to consider in our model selection, we performed an exploratory data analysis that led us to keep all "maximum" variables ($MaxCDImedMMI_{ct}$, $MaxMagnitude_{ct}$, etc.) as they had the strongest correlation with DYFI response rate. This initial variable thinning reduced our pool of 52 explanatory variables to 19. We used forward selection to choose from the remaining pool, iteratively adding variables to the model based on their contribution to model fit, as evaluated by minimizing the Akaike Information Criterion (AIC) (Akaike, 1974). In this pool, we also included several variable transformations (logarithmic, square root, etc.) and interaction terms. If an interaction term between two explanatory variables is significant, this means that the relationship between an explanatory variable and the response variable is different based on the value of the other explanatory variable. We carried out the forward selection process both manually and pseudo-randomly, adding variables to the model in no particular order, which led us to select a final model with four explanatory variables and one interaction term. All model fits were recorded, compared, and evaluated for interpretability to arrive at the final model:

$$\begin{aligned} y^*_{ct} = {} & \beta_{0c} + \beta_1 MaxCDImedMMI_{ct} + \beta_2 EarthquakesPerSqKm_{ct} \\ & + \beta_3 EnglishSpanish_c + \beta_4 BroadbandSubPer100_{ct} \\ & + \beta_5 EnglishSpanish_c * BroadbandSubPer100_{ct} + \mu_c + \delta_t + \varepsilon_{ct} \end{aligned}$$

where the final response rate can be calculated using equation 3. Uncertainty in the coefficient estimates, β_i, were estimated via 100 bootstrapped samples.

Notable measures not included in this model are the country's $MaxMagnitude_{ct}$ (maximum magnitude earthquake), $TertiarySchoolPct_{ct}$, and $GDPcap_{ct}$. Unlike Mak and Schorlemmer (2016), who found magnitude to be a significant explanatory variable, $MaxMagnitude_{ct}$ did not have a strong relationship with response rate in our global analysis. This may be related to the fact that magnitude does not describe what is experienced at the Earth's surface as well as

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Table 1 **Coefficient estimates and variable marginal effects for the fitted model**. Coefficient estimates are based on standardized variables, thus they have comparable scales. The "Marginal Unit" specifies the (unstandardized) variable increase required for the estimated effect on the number of Did You Feel It? (DYFI) responses, which is given in the "Marginal Effect" column to its right. Marginal effect values were calculated using Equations 4-8.

Fitted Coefficient	x_i	**Non-Technical Name for x_i**	**Estimate ($\hat{\beta}_i$)**	**Marginal Unit**	**Marginal Effect in DYFI responses per million people exposed to shaking**†
$\hat{\beta}_0$	(Intercept)		0.0001968		
$\hat{\beta}_1$	$MaxCDImedMMI$	Shaking Intensity	0.0028222***	1 MMI	8.62
$\hat{\beta}_2$	$EarthquakesPerSqKm$	Earthquake Density	0.0012222***	1 earthquake per **1,000** km^2 per year	3.84
$\hat{\beta}_3$	$EnglishSpanish$	Spoken Language	0.0029576***	Speaking a DYFI-supported language	16.6 **greater** than countries speaking other languages.
$\hat{\beta}_4$	$BroadbandSubPer100$	Broadband Subscriptions	0.0014210**	1 broadband subscription per 100 people	0.59 in countries that speak a **language** that is **not supported** by DYFI
$\hat{\beta}_5$	$EnglishSpanish * BroadbandSubPer100$	Spoken Language, Broadband Interaction	0.0012540	1 broadband subscription per 100 people	1.10 in countries that speak a **language** that is **supported** by DYFI (0.51 greater)

† Marginal effect calculations assume an initial DYFI response rate of 0.00001981 (19.81 responses per million people exposed to shaking), which is the average global response rate.
$^{*}p < 0.05$;$^{**}p < 0.01$;$^{***}p < 0.001$.

intensity does. While *TertiarySchoolPct*$_{ct}$ had a substantial positive relationship with response rate, we excluded it from the model because 700 out of the 1812 country-year pairs lacked data for *TertiarySchoolPct*$_{ct}$, which would have significantly reduced the number of observations available for modeling. *GDPcap*$_{ct}$ also had a strong relationship with response rate, but it had high correlation with *BroadbandSubPer100*$_{ct}$ as well, introducing multicollinearity issues if both measures were included in a model (Alin, 2010). Models with *BroadbandSubPer100*$_{ct}$ resulted in better fits to the data than models with *GDPcap*$_{ct}$, justifying its inclusion.

The interaction term between *EnglishSpanish*$_c$ and *BroadbandSubPer100*$_{ct}$ was included as it yielded a model with the lowest AIC.

To ensure that this selection of explanatory variables yields consistent results under different choices of response variables, transformations, and handling of missing values, we fit several other models as a robustness check. Table 5 in the Appendix gives the results for these models. Additionally, diagnostic plots for the final model are available in Figures 10 and 11 in the Appendix.

3.3 Question 2: Results and discussion

From our fitted model, the earthquake and population variables most significant in explaining DYFI response rate are Shaking Intensity (*MaxCDImedMMI*$_{ct}$), Spoken Language (*EnglishSpanish*$_c$), Broadband Subscriptions (*BroadbandSubPer100*$_{ct}$), and Earthquake Density (*EarthquakesPerSqKm*$_{ct}$), as shown in Table 1 and visualized in Figure 7. All of these variables have a positive relationship (positive coefficient and marginal effect) with response rate, meaning increases in each contribute to greater DYFI response rates.

Spoken Language is the largest contributing factor overall. Countries with a population that speaks a language compatible with Felt Report have higher response rates (16.6 responses per million people higher) on average. This effect is shown in Figure 7 by the greater intercepts associated with the lines for English- and Spanish-speaking countries, compared to countries that speak other languages. Language comprehension is a fundamental prerequisite for responding

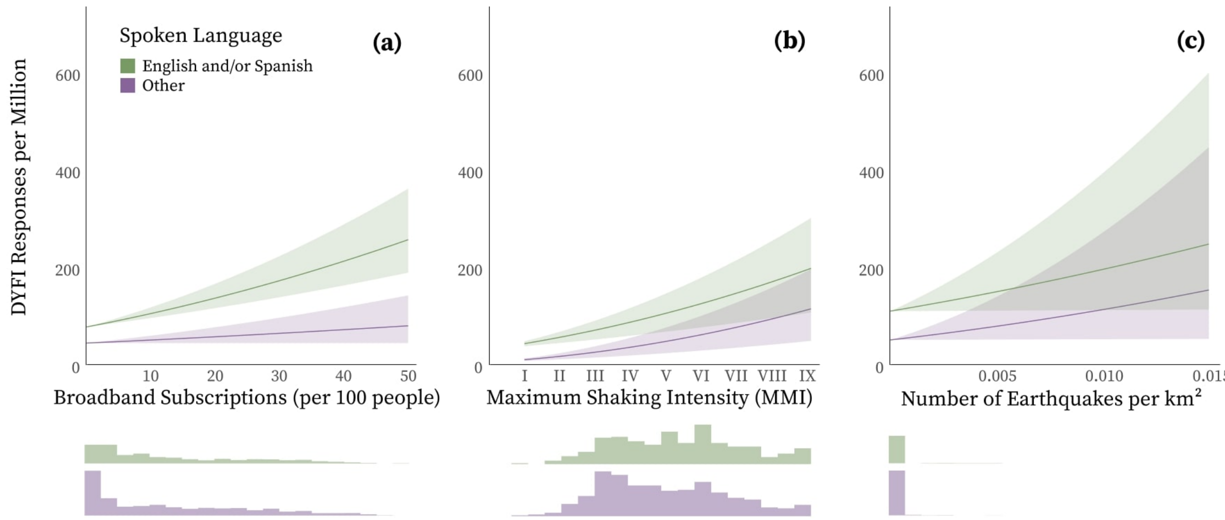

Figure 7. Individual variable impacts on DYFI response rate. Line plots with confidence bounds visualize the modeled relationship between quantitative explanatory variables and DYFI response rate, by country's spoken language, while holding all other variables constant (at their mean value). Quantitative explanatory variables plotted are Broadband Subscriptions (a), Shaking Intensity (b), and Earthquake Density (c). Based on 100 bootstrapped samples, the lines correspond to the median coefficients, and the bounds reflect a 95% confidence interval derived from the same bootstrapping process. Response rate values were calculated using Equations 3-7. Below the plots are histograms of explanatory variables by country spoken language, including data from all years (2009–2020).

to DYFI, creating a barrier for populations that do not speak English or Spanish.

Regardless of a country's spoken language, increased Broadband Subscriptions have a significant relationship with responses to DYFI. Marginal effect calculations show that an additional broadband subscription per 100 people corresponds to a higher rate of DYFI responses (0.59 responses per million people exposed) in countries that do not speak a language compatible with DYFI. In countries where a DYFI-compatible language is spoken, greater broadband internet access per capita further amplifies this increased response rate. Our model has a positive interaction term between Spoken Language and Broadband Subscriptions, meaning that an additional broadband subscription per 100 people coincides with an even greater DYFI response rate (1.10 responses per million people) in English- and Spanish-speaking countries. The compounding effect of Broadband Subscriptions and Spoken Language on DYFI response rate is illustrated by the differing slopes in Figure 7a. This effect is also likely influenced by the language barrier. While greater internet accessibility generally leads to higher DYFI engagement, countries with strong digital infrastructure and a larger proportion of English or Spanish speakers are better positioned to have high response rates, as more people are able to easily engage with the platform.

These results for Spoken Language and Broadband Subscriptions provide statistical evidence that strengthens the claims made by Hough and Martin (2021b) and Hough (2021) on a broader, global scale.

Earthquake variables, as expected, have a significant effect on DYFI response rate. Shaking Intensity has a strong relationship with response rate (Figure 7b), with an increase in maximum shaking intensity of 1 corresponding to an average increase in DYFI responses of 8.62 responses per million people. This relationship may be explained by stronger surface shaking causing greater societal impact, which in turn motivates people to share their experiences and learn more about the event. This positive relationship between intensity and DYFI responses is consistent with Mak and Schorlemmer (2016) and Hough and Martin (2021b).

Earthquake Density and DYFI response rate also have a strong relationship. Holding all other factors constant, a country that experiences an additional earthquake per 1,000 km^2 per year is expected to see an increase of 3.84 DYFI responses per million people. One possible interpretation of this relationship is that populations in seismically active countries are likely more familiar with earthquakes and related resources, such as DYFI.

In Figure 7c, the confidence bounds for the marginal effects of Earthquake Density on DYFI response rate are wider than those for Broadband Subscriptions and Shaking Intensity. Earthquake Density values are typically very low, but a few seismically active, small-area countries have high values, causing greater uncertainty in estimates for the impact of high Earthquake Density on response rate.

4 QUESTION 3: WHERE CAN DYFI RESPONSES BE INCREASED?

Based on the results from the statistical inference model, we develop a priority index to identify countries where improved DYFI access is likely to lead to increased engagement. With this priority index, we build upon the significant variables identified from Question 2, and also include an additional variable to account for the relative importance of increased access to DYFI given other sources of ground motion data in a country. For example, in a country like Japan that has a dense network of seismic stations, an additional DYFI response is valuable for earthquake perception, but is not as influential on the final estimate of shaking distribution in the ShakeMap as compared to a country that has a sparse set of stations. Our index assigns equal weight to each country's relative position across all variables to generate a composite metric for country prioritization.

4.1 Question 3: Data

For the priority index, we build upon the dataset from Question 2 to identify where DYFI access can be increased in the future. Our goal is to characterize each country by the variables identified as important for DYFI access in Question 2 and include additional information on seismic stations. Here, we include six variables: *TotalDYFIResponseRate*, *EnglishSpanish*, *BroadbandSubPer100*, *MaxCDImedMMI*, *TotalGriddedPopulation*, and *StationsPerCapita*. Each of these variables was collapsed to remove the time dimension, as described below.

For *EnglishSpanish* and *BroadbandSubPer100*, we select the countries' most recent values (from 2020). For *MaxCDImedMMI*, we use the countries' largest recorded shaking intensity between 2009-2020. Since we are identifying countries where DYFI responses could be improved, we also use the DYFI response rate variable (*TotalDYFIResponseRate*) as an input factor in the priority index, which we recalculate over 2009-2020. We use *TotalGriddedPopulation*–which represents the total population exposure to shaking each year–as our measure of earthquake density and exposure, summing its annual values from 2009 to 2020. This approach is used instead of *EarthquakesPerSqKm* because *TotalGriddedPopulation* reflects the number of people potentially able to respond to DYFI, a dimension that *EarthquakesPerSqKm* does not capture.

In addition to the variables we found in the model, we add the ratio of ShakeMap-input seismic stations and a country's population, *StationsPerCapita*. Here, we use seismic station location data from the International Federation of Digital Seismograph Networks (FDSN), selecting data from 2020 (see Data and Resources).

4.2 Question 3: Priority index

We create a composite priority index that averages the relative standing of countries across each variable to identify countries that are most likely to benefit from improved DYFI accessibility. This is similar to creating a composite index score for a country (OECD and JRC, 2008).

Figure 8 outlines the calculation of the priority index, with greater detail available in Figure 12 in the Appendix. For the quantitative variables, we create empirical cumulative distribution functions (ECDFs) to assign quantiles to each country, giving them a value ranging from 0-1 for each variable. The *EnglishSpanish* variable remains binary, with non-English- and non-Spanish-speaking countries being assigned a 1.

We use results from the inference model to determine a variable's direction of influence on the priority ranking, as specified by the vertical arrows in the quantile boxes in Figure 8. For example, while limited high-speed internet subscriptions hinder DYFI interaction, broadband infrastructure is nearly impossible to modify. Larger values of *BroadbandSubPer100* indicate that a country's population is better equipped to access the DYFI Felt Report, suggesting a high potential for increased engagement. For variables where smaller values represent higher priority, such as *StationsPerCapita*, quantiles are inverted (e.g., 0.01 becomes 0.99).

After computing variable quantiles for each country, they are averaged with equal weights to form the composite priority index. This index ranges from 0 to 1, with higher values representing greater priority for improved DYFI accessibility.

4.3 Question 3: Results and discussion

The priority index highlights that non-English-speaking Asian and Central European countries would most benefit from having improved for improved DYFI access, as shown in Figure 9 and Table 2. The top ten ranked countries have a historical DYFI response rate below the global median and seismic station coverage that places each of them in the bottom 20% globally. While they are unified in these aspects, they differ in their seismic and technological contexts.

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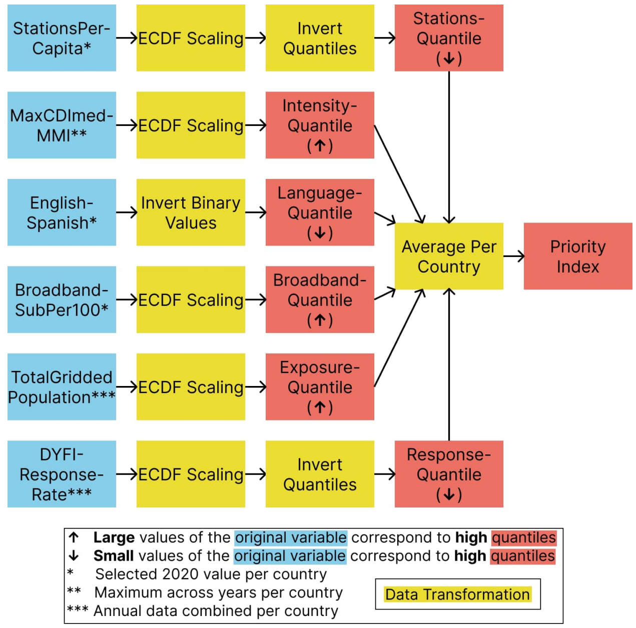

Figure 8. Calculating the country priority index. The diagram flows left to right, starting with input variables, transforming them into country quantiles, and averaging quantiles to create the priority index. ECDF scaling involves constructing an empirical cumulative distribution function to assign country quantiles for each variable. For further details on the priority index calculation, see Figure 12 in the Appendix.

Indonesia and several countries in the Middle East and South Asia (Iran, Iraq, and Pakistan) have high priority indices due to intense earthquake hazards. These countries are very seismically active, with large populations exposed to earthquakes, yet they have few or no seismic stations in the FDSN. Additionally, their limited high-speed internet coverage compared to other high-priority countries makes it harder for them to engage with DYFI.

Central European countries, such as Germany, Poland, and the Netherlands, also have high priority indices, though they face lower earthquake hazards. High-intensity earthquakes are less common, resulting in lower population exposure and a reduced need for a seismic station network. However, these countries have high broadband internet coverage, giving them greater potential to engage with DYFI when an earthquake does occur.

Countries with high DYFI response rates and populations that speak a DYFI-compatible language, such as Costa Rica, Venezuela, and New Zealand, tend to have low priority indices. Similarly, many African countries, with their low

Table 2 **Variable quantile breakdown for the composite priority index**. The top ten countries for improved Did You Feel It? (DYFI) accessibility are listed in descending order.

Country	Priority	Stations	Intensity	Language	Broadband	Exposure	DYFI Response Rate
China	**0.92**	0.96	1.00	1.00	0.85	0.98	0.73
Germany	**0.85**	0.83	0.62	1.00	0.96	0.67	1.00
Indonesia	**0.83**	0.97	1.00	1.00	0.28	0.99	0.76
Uzbekistan	**0.81**	1.00	0.52	1.00	0.51	0.83	0.99
Iran	**0.81**	1.00	0.89	1.00	0.47	0.93	0.56
Poland	**0.81**	1.00	0.54	1.00	0.68	0.62	1.00
Iraq	**0.81**	1.00	0.81	1.00	0.53	0.90	0.60
Netherlands	**0.80**	1.00	0.59	1.00	0.97	0.48	0.77
Pakistan	**0.80**	1.00	0.83	1.00	0.17	0.95	0.85
Russia	**0.79**	0.88	0.79	1.00	0.72	0.75	0.60

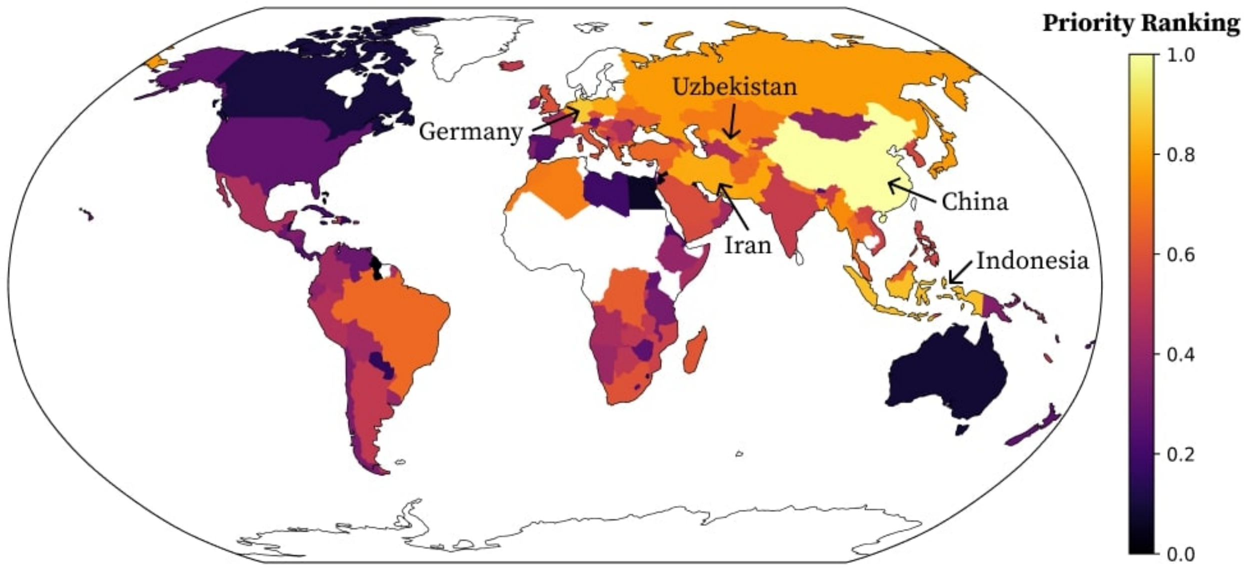

Figure 9. Mapped results of the composite priority index. Countries with the highest priority for improved DYFI accessibility are labeled. White-colored countries had no recorded earthquakes from 2009 to 2020.

seismic hazard, have low priority indices, or no priority index was calculated due to a lack of recorded earthquakes in the dataset.

Built on variables with a statistically significant relationship to DYFI response rate, the composite priority index offers an immediate application of the model results. Countries with the highest priority are those where efforts to increase interaction with DYFI are most likely to result in substantial increases in response rate. These efforts can meaningfully expand public and scientific understanding of seismic activity in countries that need it most, all without the need for costly seismic infrastructure.

5 CONCLUSION

In this first comprehensive global analysis of DYFI, we found that a large majority of DYFI respondents access the Felt Report page via mobile device, with social media being a primary driver for engagement. Additionally, we observed that socioeconomic factors, such as high-speed internet infrastructure and primary spoken languages, along with the intensity and frequency of earthquakes, significantly influence DYFI response rates globally. Our findings add to those of previous studies (Mak and Schorlemmer, 2016; Hough, 2021; Hough and Martin, 2021b) by presenting a thorough statistical analysis of 1,758 earthquakes around the world. Overall, the results of this study suggest that with improved DYFI accessibility, non-English-speaking Asian and Central European countries are most likely to see large increases in DYFI interaction.

Moving forward, efforts to improve the accessibility of DYFI can take many forms. For example, technological approaches could include building a social media presence to raise awareness of DYFI among populations exposed to shaking, as well as optimizing the questionnaire for a smoother user experience on mobile devices. Language, specifically, has been an integral factor contributing to DYFI engagement, and as a result, the USGS has already begun supporting languages beyond English and Spanish, including Chinese and German. To further enhance language accessibility, more languages could be incorporated–such as Indonesian or Persian–based on those spoken in priority countries, or reliance on language could be reduced through visual aids. When adapting DYFI to be more accessible in various parts of the world, it could be beneficial to tailor the questionnaire to the local population, considering the geographical, cultural, and structural differences that may influence their experience with the earthquake. Furthermore, collaborating with partner agencies in countries with high priority indices is not only encouraged, but required when relevant in-country partners exist, to ensure that the questionnaire is accessible and understandable to their residents.

The aim of this study is to develop the first global analysis of DYFI accessibility to support future engagement efforts by the USGS. As with any global analysis, tradeoffs exist between leveraging consistent, globally available data sources and more accurate country-specific sources. For example, the developed panel dataset leverages The World Bank and the

CIA World Factbook, which provide consistent socioeconomic variables as opposed to country-level census data, which have differences in collection methodologies and frequencies between countries. Because of this, some variables may be underestimated, like spoken language, as the CIA World Factbook only provides information for first languages spoken by country, regardless of the percentage of the population that may speak English or Spanish. Therefore, some effects may be underestimated, though the results of this study are useful for initial decision-making with which to engage. Continued engagement will of course depend on more detailed information on each country's socioeconomic makeup.

Considering data limitations, the results do capture overall trends in DYFI access between countries.

In this study, we found that interaction with DYFI–a key input into USGS rapid loss estimates used to inform humanitarian response–is influenced not only by earthquake characteristics, but also by access to resources and language comprehension. Thus, disadvantaged populations that do not speak a DYFI-compatible language are unfavorably positioned to provide on-the-ground measurements that calibrate shaking estimates influencing emergency response. For emergency managers to better serve earthquake-affected populations, it is crucial to reduce the barriers that prevent people from documenting their experiences. It is also critical to acknowledge the existence of these barriers, particularly when considering potentially marginalized populations whose impacts from the earthquake may have been underestimated. With the global reach of the USGS earthquake products, earthquake-affected populations and scientific communities around the world stand to benefit from increased spatial coverage of DYFI, making it essential that its barriers to access are reduced in the areas that need it most.

6 DATA AND RESOURCES

Google Analytics user data was acquired through the Digital Analytics Program and the Technology Transformation Services at the U.S. General Services Administration (U.S. General Services Administration, 2024). This aggregated user data is available from the authors upon request. All "Did You Feel It?" (DYFI) data for this analysis is publicly available at http://earthquake.usgs.gov/dyfi. The USGS Comprehensive Catalog (ComCat) has a web page interface, application programming interface (API), and associated command-line tool (`libcomcat`) for retrieving earthquake event information, including DYFI data. Raw, anonymized DYFI data are available upon request from the USGS. Earthquake data was sourced from the USGS ShakeMap Atlas (Marano et al., 2024). Data for population exposed to shaking comes from ORNL LandScan (Sims et al., 2023). Socioeconomic data was collected from the World Bank (2023) and language data was scraped using Python from the CIA World Factbook (Central Intelligence Agency, 2023). Seismic station location data was gathered from the FDSN (International Federation of Digital Seismograph Networks, 2023) and the station list for ShakeMap (U.S. Geological Survey, 2011). Statistical analyses were conducted in R using the plm package (Croissant et al., 2024). The Appendix includes tables describing sampled events used in the web analysis, variables in the global panel dataset, and results from alternative statistical models. It also contains model diagnostic plots and a more detailed diagram of the priority metric calculation.

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8 DECLARATION OF COMPETING INTERESTS

The authors acknowledge there are no conflicts of interest recorded.

9 AUTHOR CONTRIBUTIONS

Conceptualization, SL, EK, DW; Methodology, EK, SL; Data Collection, VQ, EK; Formal Analysis, EK, SL; Writing—Original Draft, EK; Visualization, EK; Writing—Review & Editing, SL, VQ, DW, EK; Funding acquisition, SL, DW; Project Administration, SL.

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10 APPENDIX

Table 3 **All sampled events included in the web analysis**. Data is ordered by year and number of regional users. Totals across all events are given in the final row.

Event Name	Event ID	DYFI Responses	Total Users	Regional Users	Year
M 7.1 - Ridgecrest, California	ci38457511	24382	23721	18581	2019
M 3.6 - Bliss Corner, Massachusetts	us7000cc4d	19612	16284	15148	2020
M 5.1 - Sparta, North Carolina	se60324281	66710	44083	9662	2020
M 5.9 - Chiba, Japan	us6000fsl6	5679	21703	17429	2021
M 6.0 - Antelope Valley, CA	nc73584926	25976	8459	6174	2021
M 4.3 - Carson, CA	ci39812319	10294	5672	4996	2021
M 6.2 - Petrolia, CA	nc73666231	4401	3639	1978	2021
M 5.9 - Mount Buller, Australia	us7000fd9v	5839	2126	1846	2021
M 4.0 - Williamsville, Missouri	nm60363582	5442	3791	1533	2021
M 5.9 - Port Alsworth, Alaska	us6000geb1	1886	735	391	2021
M 4.3 - Gypsum, Kansas	us6000gaga	811	576	318	2021
M 5.3 - Calipatria, CA	ci39919392	1173	490	313	2021
M 6.2 - Naalehu, Hawaii	hv72748782	3485	717	282	2021
M 4.9 - Harding-Birch Lakes, Alaska	ak021bt4ffvw	1085	421	232	2021
M 5.2 - Kukuihaele, Hawaii	hv72565662	1335	261	149	2021
M 4.7 - San Simeon, CA	nc73644630	619	251	129	2021
M 7.0 - Acapulco, Mexico	us7000f93v	654	510	113	2021
M 5.7 - Chile-Argentina border region	us7000fr0v	450	96	75	2021
M 6.2 - Falam, Myanmar	us7000fx45	333	130	73	2021
M 5.7 - Talisay, Philippines	us7000fen1	211	82	70	2021
M 6.7 - Hukay, Philippines	us6000eyfk	317	116	60	2021
M 7.2 - Nippes, Haiti	us6000f65h	362	436	52	2021
M 6.4 - Bandar Abbas, Iran	us7000fu12	207	152	50	2021
M 7.5 - Barranca, Peru	us7000fxq2	274	263	23	2021
M 6.2 - Yilan, Taiwan	us6000fx56	113	160	21	2021
M 6.7 - Burica, Panama	us6000exs5	225	106	17	2021
M 6.3 - Masachapa, Nicaragua	us7000fskw	110	97	16	2021
M 5.6 - Corral del Risco, Mexico	us7000eik4	110	47	15	2021
M 5.1 - Alum Rock, CA	nc73799091	24216	22163	8098	2022
M 6.4 - Ferndale, CA	nc73821036	5950	6287	2864	2022
M 6.1 - Duzce, Turkey	us7000irp8	1686	4045	2355	2022
M 4.0 - Palomar Observatory, CA	ci39928087	5793	2393	1955	2022
M 7.6 - Aguililla, Mexico	us7000i9bw	1171	2344	1172	2022
M 4.5 - Medford, Oklahoma	ok2022cedc	4766	1879	933	2022
M 4.1 - Bay Point, CA	nc73740051	5796	1736	861	2022

M 3.9 - Stillmore, Georgia	se60400186	2352	1754	762	2022
M 4.0 - Santa Paula, CA	ci40194736	2096	660	526	2022
M 4.7 - H?lualoa, Hawaii	hv73019747	1600	1017	490	2022
M 5.2 - Cantwell, Alaska	ak0221pb6nv5	1362	514	350	2022
M 4.7 - Wailua, Hawaii	hv72889347	847	211	148	2022
M 4.8 - Deep Springs, CA	nc73674211	526	353	139	2022
M 6.0 - Bandar-e Lengeh, Iran	us6000hz8x	488	315	136	2022
M 4.5 - Waimea, Hawaii	hv72956917	754	166	113	2022
M 5.2 - Range Hill, Texas	tx2022yplg	2405	237	95	2022
M 6.2 - Nueva Concepción, Guatemala	us7000gl8w	431	215	95	2022
M 7.3 - Namie, Japan	us6000h519	452	299	73	2022
M 6.6 - Pólis, Cyprus	us7000gaqu	486	247	70	2022
M 4.7 - Tyonek, Alaska	ak0228vb1a7q	1400	186	64	2022
M 5.7 - Ljubinje, Bosnia and Herzegovina	us6000hfqj	464	188	60	2022
M 6.6 - Labuan, Indonesia	us7000gbu4	140	97	45	2022
M 6.1 - Bukittinggi, Indonesia	us6000gzyg	212	112	31	2022
M 5.3 - Metsavan, Armenia	us7000gkl5	117	40	26	2022
M 5.5 - Flórina, Greece	us7000gaex	154	93	23	2022
M 5.6 - Sukabumi, Indonesia	us7000ir9t	161	60	23	2022
M 7.0 - Dolores, Philippines	us6000i5rd	664	332	15	2022
M 6.6 - Masachapa, Nicaragua	us6000hf75	159	63	13	2022
M 5.1 - Ojai, CA	ci39645386	14126	7510	4693	2023
M 4.3 - Port Townsend, WA	uw61965081	10892	6323	4253	2023
M 5.5 - Lake Almanor, CA	nc73886731	7025	3419	2539	2023
M 4.2 - Malibu Beach, CA	ci40161279	11376	6234	2429	2023
M 3.8 - West Seneca, New York	us6000jlqv	5920	4556	2389	2023
M 4.5 - Eagle River, Alaska	ak0238gji26s	2191	2097	1597	2023
M 4.2 - Palomar Observatory, CA	ci39508378	7603	2176	1392	2023
M 4.2 - Isleton, CA	nc73948665	7895	1724	1254	2023
M 4.9 - Gauteng, South Africa	us7000k7q8	1377	1193	1048	2023
M 6.8 - Al Haouz, Morocco	us7000kufc	1294	1365	607	2023
M 7.8 - Turkey earthquake sequence	us6000jllz	2035	2125	583	2023
M 3.8 - Mickleham, Australia	us7000k4me	1588	409	389	2023
M 3.6 - Madison, Ohio	us7000krer	1403	611	385	2023
M 5.4 - Rio Dell, CA	nc73827571	976	747	351	2023
M 6.5 - Jurm, Afghanistan	us7000jln7	1084	445	286	2023
M 5.6 - Lelesti, Romania	us6000jnqz	646	262	201	2023
M 5.2 - Canyondam, CA	nc73887046	1350	250	160	2023
M 5.2 - Coalson Draw, Texas	tx2023vxae	1241	314	133	2023
M 5.0 - Matanzas, Dominican Republic	us6000jkqk	629	169	128	2023
M 5.7 - Dailekh, Nepal	us7000l8p5	372	147	97	2023

M 7.1 - Gili Air, Indonesia	us7000krjx	628	213	72	2023
M 6.3 - Uzunbag, Turkey	us6000jqcn	546	479	67	2023
M 7.6 - Mindanao, Philippines	us7000lff4	351	366	59	2023
M 6.8 - Balao, Ecuador	us7000jl3s	194	162	38	2023
Total		**331485**	**226426**	**126431**	

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Table 4 **Variable descriptions and sources for the global inference model**. The Category column defines the type of variable as one of the following: identifier, time, population, stations, earthquake, exposure, or responses. Data sources for these variables are the World Bank, Central Intelligence Agency, International Federation of Digital Seismograph Networks, U.S. Geological Survey, and LandScan (see Data and Resources).

Variable	**Category**	**Description**	**Source**
CountryName	Identifier	Name of the country.	
CountryCode	Identifier	Country's ISO 3166-1 alpha-3 code.	ISO
CountryNumber	Identifier	World Bank Official Boundaries country code.	World Bank
EnglishSpanish_CIA	Population	Binary variable indicating if the country has an official or major language of English or Spanish, or if English or Spanish is the first language for more than 25% of the population. This variable is assigned a 1 if true, 0 otherwise.	CIA World Factbook
Year	Time	Year corresponding to the data.	
Population_WB	Population	Population of a country during a given year, including all residents regardless of legal status or citizenship.	World Bank
LandAreaSqKm_WB	Population	Country's total area in square kilometers.	World Bank
UrbanPopPct_WB	Population	Percentage of a country's population living in urban areas (the same as 100 – RuralPopPct_WB).	World Bank
RuralPopPct_WB	Population	Percentage of a country's population living in rural areas (the same as 100 – UrbanPopPct_WB).	World Bank
InternetPct_WB	Population	Percentage of a country's population that has used the Internet in the last 3 months, using any sort of device.	World Bank
CellSubPer100_WB	Population	Number of subscriptions to a public mobile telephone service per 100 people in a country.	World Bank
ElectAccessPct_WB	Population	Percentage of a country's population that has access to electricity.	World Bank
ElectAccessUrbanPct_WB	Population	Percentage of a country's population living in urban areas that has access to electricity.	World Bank
ElectAccessRuralPct_WB	Population	Percentage of a country's population living in rural areas that has access to electricity.	World Bank
BroadbandSubPer100_WB	Population	Number of fixed subscriptions to high-speed access to public Internet per 100 people in a country.	World Bank
GDPcap_WB	Population	Gross domestic product (GDP) per capita based on purchase power parity (PPP) in constant 2017 international dollars.	World Bank
JournalArtNo_WB	Population	Number of scientific and engineering articles published per country per year.	World Bank
PrimarySchoolPct_WB	Population	Percentage of total individuals enrolled in primary education of the population of the age group eligible for primary education.	World Bank
TertiarySchoolPct_WB	Population	Percentage of total individuals enrolled in tertiary education of the population of the age group eligible for tertiary education.	World Bank

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GovExpenditureEdu_WB	Population	Total government expenditure on education expressed as a percentage of the country's GDP.	World Bank
NumStations_USGS	Stations	Number of ShakeMap stations within the country's boundaries.	FDSN
StationsPerSqKm_USGS	Stations	Number of ShakeMap stations divided by the total land area of the country (NumStations_USGS / LandAreaSqKm_WB).	FDSN, World Bank
StationsPerCapita_USGS	Stations	Number of ShakeMap stations divided by the country's population (NumStations_USGS / Population_WB).	FDSN, World Bank
CDImedMMI_USGS (Mean, Sd, Min, Q1, Median, Q3, Max)	Earthquake	CDI (Community Decimal Intensity) is a metric resulting from DYFI and is an aggregate of the weighted sums of the various indices of the DYFI questionnaires. The metric, medMMI, is the median Modified Mercalli Intensity (MMI) of the grid cell, which is a shaking intensity measure that results from ShakeMap. CDI and MMI are on the same scale. So, CDImedMMI is equal to the CDI value when there are DYFI responses, otherwise it is equal to the medMMI value. These summary statistics describe the shaking intensity of all grids that experienced shaking.	USGS
Magnitude_USGS (Mean, Sd, Min, Q1, Median, Q3, Max)	Earthquake	Summary statistics of the magnitude of earthquakes (event-based rather than grid-based).	USGS
GriddedPopulation_USGS (Mean, Sd, Min, Q1, Median, Q3, Max)	Exposure	Summary statistics of the estimated population per grid that experienced shaking.	USGS, LandScan
GridsNo_USGS (Mean, Sd, Min, Q1, Median, Q3, Max)	Exposure	Summary statistics of the number of grid cells associated with each earthquake.	USGS
DYFIResponsesNo_USGS (Mean, Sd, Min, Q1, Median, Q3, Max)	Responses	Summary statistics of the number of DYFI responses in each grid that experienced shaking.	USGS
DYFIResponseRate_USGS (Mean, Sd, Min, Q1, Median, Q3, Max)	Responses	Summary statistics of the DYFI response rate per grid that experienced shaking. The response rates are the number of responses divided by the approximate population within the grid. If there were responses in a grid with a population of 0, no response rate for that grid is calculated.	USGS, LandScan
GridResponseRate_USGS (Mean, Sd, Min, Q1, Median, Q3, Max)	Responses	Summary statistics of the grid response rate for each earthquake. The grid response rate is the number of grid cells with at least one DYFI response divided by the number of grid cells exposed to shaking for that earthquake.	USGS
NumEarthquakes_USGS	Earthquake	Number of earthquakes that led to USGS ShakeMap and/or DYFI responses.	USGS
EarthquakesPerSqKm_USGS	Earthquake	Number of earthquakes divided by the total land area of the country (NumEarthquakes_USGS / LandAreaSqKm_USGS).	USGS, World Bank

TotalGriddedPopulation_USGS	Exposure	Total (approximate) population exposed to shaking due to earthquakes over the year. Population within the same grid can be counted multiple times if that grid experienced multiple earthquakes.	USGS, LandScan
AvgGriddedPopulationPerQuake_USGS	Exposure	Average population exposed to shaking per earthquake (TotalGriddedPopulation_USGS / NumEarthquakes_USGS).	USGS, LandScan
TotalGrids_USGS	Exposure	Total number of grid cells exposed to shaking across all earthquakes. Grids can be counted multiple times if they experienced multiple earthquakes.	USGS
NumEarthquakesWithResponses_USGS	Responses	Count of the number of earthquakes that led to at least one DYFI response.	USGS
EarthquakeResponseRate_USGS	Responses	Proportion of earthquakes with at least one DYFI response (NumEarthquakesWithResponses_USGS / NumEarthquakes_USGS).	USGS
TotalDYFIResponses_USGS	Responses	Total number of DYFI responses across all earthquakes.	USGS
TotalDYFIResponseRate_USGS (y_{ct})	Responses	Total number of DYFI responses divided by the total population exposed to shaking (TotalDYFIResponses_USGS / TotalGriddedPopulation_USGS).	USGS, LandScan
DYFIResponsesPerQuake_USGS	Responses	Total number of DYFI responses divided by the number of earthquakes (TotalDYFIResponses_USGS / NumEarthquakes_USGS).	USGS
TotalGridsWithResponses_USGS	Responses	Total number of grid cells with at least one DYFI response across all earthquakes.	USGS
TotalGridResponseRate_USGS	Responses	Number of grid cells with at least one DYFI response divided by the total number of grid cells (TotalGridsWithResponses_USGS / TotalGrids_USGS).	USGS

Table 5 Alternative Models. **Bold** variables indicate that the missing values for that variable are filled with zero. Underlined variables indicate that the missing values for that variable are filled with 0.0000001 (for applying a log transformation)

Model	**Estimate**	**Response Variable**	**Observations**
Chosen Model	MaxCDImedMMI: 0.0028222*** EarthquakesPerSqKm: 0.0012222*** EnglishSpanish: 0.0029576*** BroadbandSubPer100: 0.001421** EnglishSpanish * BroadbandSubPer100: 0.001254	sqrt(TotalDYFIResponseRate)	Total: 705 Left Censored: 202 Uncensored: 503
Alternate Response Variable 1	MaxCDImedMMI: 0.085098*** EarthquakesPerSqKm: 0.038722*** EnglishSpanish: 0.092905*** BroadbandSubPer100: 0.064442*** EnglishSpanish * BroadbandSubPer100: -0.013019	sqrt(TotalGridResponseRate)	Total: 705 Left Censored: 202 Uncensored: 503
Alternate Response Variable 2	MaxCDImedMMI: 0.18705*** EarthquakesPerSqKm: 0.01177 EnglishSpanish: 0.11156** BroadbandSubPer100: 0.031 EnglishSpanish * BroadbandSubPer100: 0.10336*	sqrt(MaxDYFIResponseRate)	Total: 705 Left Censored: 202 Uncensored: 503
Alternate Response Variable 3	MaxCDImedMMI: 0.108156*** EarthquakesPerSqKm: 0.069687*** EnglishSpanish: 0.084631** BroadbandSubPer100: 0.086638*** EnglishSpanish * BroadbandSubPer100: -0.022803	sqrt(MaxGridResponseRate)	Total: 705 Left Censored: 202 Uncensored: 503
Untransformed Response Variable	MaxCDImedMMI: 1.007E-04*** EarthquakesPerSqKm: 4.326E-05** EnglishSpanish: 1.080E-04** BroadbandSubPer100: 2.92E-05 EnglishSpanish * BroadbandSubPer100: 9.640E-05**	TotalDYFIRepsonseRate	Total: 705 Left Censored: 202 Uncensored: 503
Missing Values Filled with 0	**MaxCDImedMMI**: 0.0074988*** EarthquakesPerSqKm: 0.0020336*** EnglishSpanish: 0.0025756** BroadbandSubPer100: 0.0011937* EnglishSpanish * BroadbandSubPer100: 0.0009085	sqrt(**TotalDYFIResponseRate**)	Total: 1683 Left Censored: 1180 Uncensored: 503
Log Model	**MaxCDImedMMI**: 60.9305*** EarthquakesPerSqKm: 9.4740*** EnglishSpanish: 5.9427** BroadbandSubPer100: 2.5003 EnglishSpanish * BroadbandSubPer100: -3.1631	log(TotalDYFIResponseRate)	Total: 1683 Left Censored: NA Uncensored: NA

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

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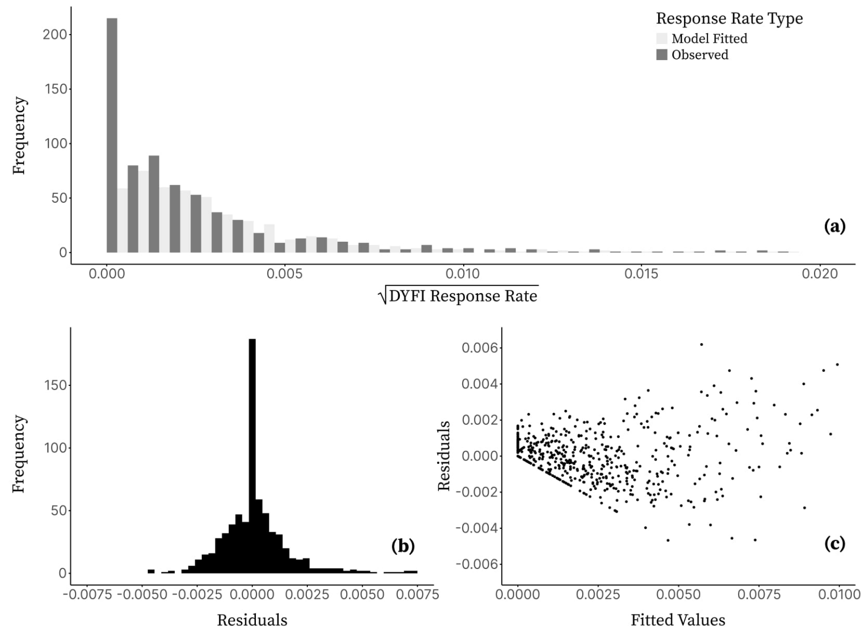

Figure 10. Detailed view of model diagnostic plots. Each plot focuses on an x-value range that captures the densest portion of the data. For the full plots, see Figure 11. The side-by-side histogram (a) compares the fitted and observed y^*_{ct} values. The distribution of residuals is given in the single histogram (b). The scatterplot (c) compares the fitted values to their residuals.

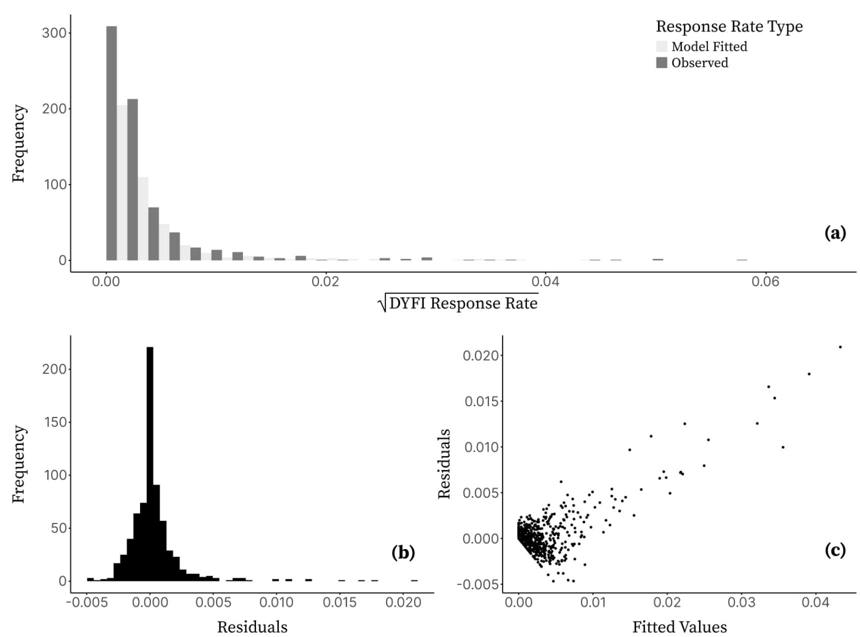

Figure 11. Complete view of model diagnostic plots. Same as Figure 10 but zoomed out.

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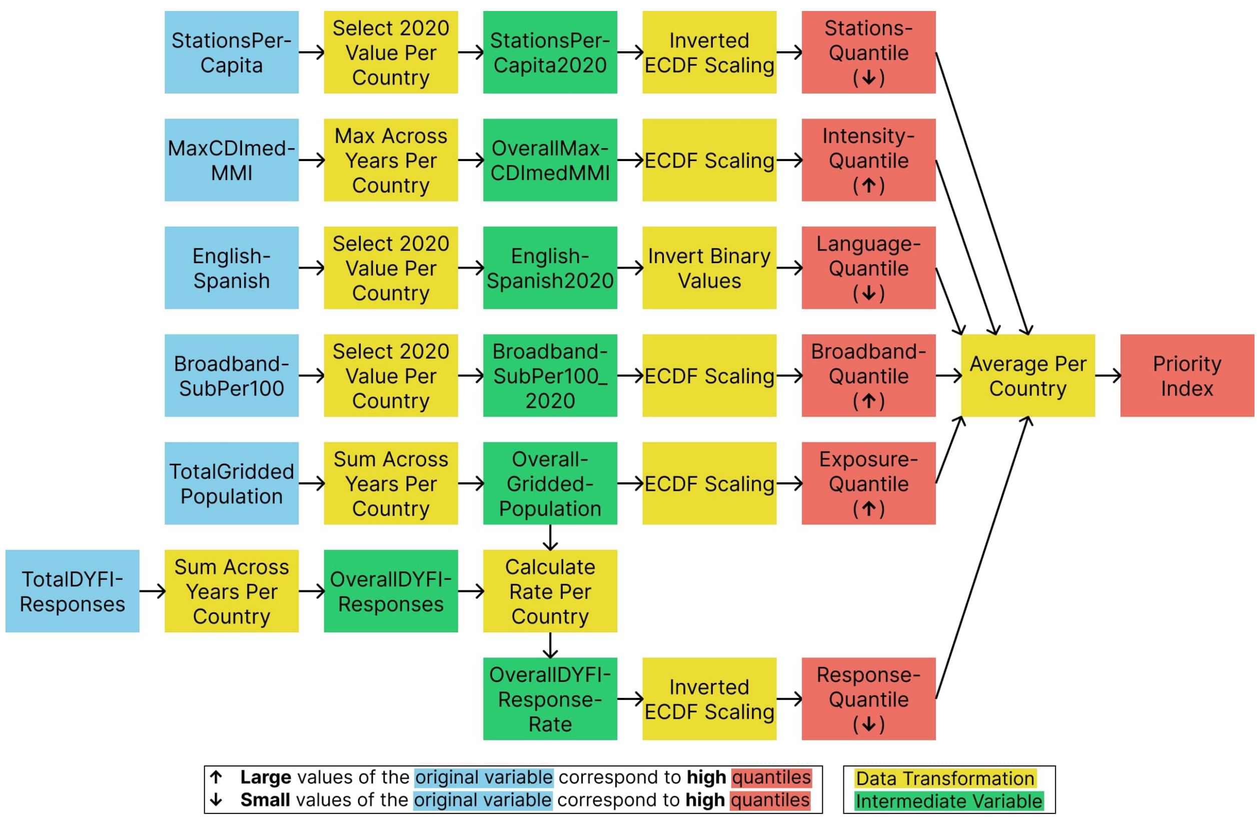

Figure 12. Detailed diagram showing the calculation of the country priority index. Same as Figure 8 but expanded to show all steps taken.