## RC1 comments and responses:

The manuscript outlines a methodology for constructing a time-dependent fixed asset model applicable to China. It establishes a model using fixed asset data at the provincial level and further refines it to a more detailed grid level with remote sensing ancillary data. The findings are validated with results from other studies. The methodology is purported to assist in quick post-earthquake loss estimations. The topic is interesting, and the manuscript is well-written. However, it can benefit from some comments I suggest below to improve its clarity and contribution to the field.

**Response:** Thank you very much for your time and efforts spent on reviewing our manuscript, which is deeply appreciated. We have read all your constructive comments and suggestions carefully and tried our best to prepare the following responses. Hopefully, they can help release the concerns you have on the prior version of the manuscript.

**General comment:**

The methodology and results seem useful for assessing economic losses due to any hazard, not only due to earthquakes. Even though the introduction includes references about the importance of earthquakes and previous earthquake loss estimations, the methodology and results do not confront loss estimations from past earthquake events. Furthermore, Fig. 2 has no input that one could identify with an earthquake hazard or risk (e.g., ground motion fields, earthquake occurrence rate, or fragility model). The methodology and results focus on modelling the observed economic and demographic growth in the study areas consistently, considering the data quality limitations in terms of spatial resolution and time-frequency. I think the paper can be stronger (and closer to the journal's scope) by adding some statements in the discussion and conclusion about how the methodology and results can help in the loss estimation due to an earthquake event or other natural hazards. It would also be interesting to add to the introduction a review of studies of other natural hazards, such as floods or extreme wind events.

**Response:** Thank you for this comment and all your suggestions. To better demonstrate the application of the developed fixed asset data to seismic loss estimation, we have added Section 4.3 and Figure 13 to the revised manuscript indicating how the fixed asset data can be overlapped with the macro-seismic intensity map for the Ms6.2 Jishishan earthquake occurred on December 18, 2023 in Gansu province, China, as given in **Lines 514-540, Pages 23-25** of **newly added Section 4.3** in the clean version of the revised manuscript.

We agree that it is also necessary to have an in-depth discussion on the applicability of the developed fixed asset data to the risk analysis of other natural hazards (e.g., flood, wind, etc.). We have added this discussion to **Lines 541-559, Page 25** in the **newly added**

**Section 4.3** of the revised manuscript.

For the suggestion to add a review of other natural hazards in the Introduction section, considering the focus of this paper is to introduce how the fixed asset model is developed and disaggregated, the application of this fixed asset data to seismic loss estimation is added and its limitation for risk analysis of other natural hazards is also discussed in-depth in the revised manuscript, we think adding an extensive review of other natural hazards (e.g., flood, wind etc.) is not that closely related to the focus of this paper.

In addition, there are already quite good review articles written by specialists focusing on risk analysis of flood and wind. Among them, De Moel et al. (2015) provided a quite comprehensive overview on the current state, development, assessment characteristics of quantitative flood risk assessments at different scales (supra-national, macro, meso, micro). They also outlined the lessons learnt from current practice and identified future research needs for flood risk assessment. Yu et al. (2023) gave a comprehensive review on the studies related to exposure roughness exposed to wind hazard as well. Therefore, we consider it is better not to give an extensive but not in-depth overview of other natural hazards in the Introduction section that is centered around the earthquake hazard.

**Specific comment:**

1. The conclusion says the methodology can be extended to more recent years once the data is available. However, considering that the methodology aims to help in quick loss assessment for future earthquake events, can the methodology with the available data today (in 2024) provide a prediction, for example, of the losses after an earthquake event in 2030?

   **Response:** Thank you for this question. The direct answer is yes if prediction accuracy is not strictly required. And the accuracy can be enhanced if the increased fixed asset values from 2024 to 2030 are available as well. Rapid seismic loss estimation after the occurrence of a damaging earthquake is based on the combination of intensity map, fixed asset in the earthquake-stricken area, and the empirically regressed vulnerability model for the earthquake-affected region. For an earthquake to occur in 2030, we would recommend the use of latest fixed asset map available to assess its seismic loss, as long as the intensity map can be reasonably modelled/predicted by using ground motion prediction equations or physics-based simulation methods, and the vulnerability curve can be rectified by considering the changing in building vulnerability from 2020 to 2030 as well, since currently the available vulnerability curve developed in our another work (Li et al., 2023) is only based on damaging information of earthquakes occurred before 2020.

2. I suggest mentioning the future availability of grid-level fixed asset data only in the section "code and data availability", as it is done and justified in this version of the manuscript, and only mentioning it in the abstract and conclusion in a later version, when the data is effectively available.

   **Response:** Thank you for this suggestion. The expression related to data availability in the abstract and conclusion has been removed in the revised manuscript.

**Technical corrections**

1. Tables 2 and 3, as well as Figs. 5, 7-9: Consider changing the monetary units to billion Chinese yuans, as done in Figs. 11-12

   **Response:** Thank you for this suggestion. In Tables 2 and 3 of the revised manuscript, the monetary units of numbers (representing the sum of fixed asset value in multiple cities and provinces) have been changed to billion Chinese yuan. However, in Figs. 5.,7-9, the value represents the fixed asset in each 1km×1km grid, not like that in city agglomerations or provinces in Tables 2 and 3. Therefore, to better demonstrate the spatial location of high fixed asset clusters, the upper threshold of fixed asset value in the color bar of Fig. 5, Fig. 7, Fig. 8, and Fig. 9 is automatically set as 243801864, 74247334, 61145222, and 88179937 in QGIS, respectively, which corresponds to the 98% quantile of the grid-level fixed asset value in each figure. These upper threshold values are all smaller than 1 billion since these values only represent fixed asset in those 1km×1km grids. If the unit in these figures is expressed in billion Chinese yuan, the numbers at grid level will be too small to differentiate the spatial clusters of high fixed assets (since the upper threshold values in Figs. 5-8 and Figure 9 will be 0.244, 0.074, 0.061, and 0.088 billion Chinese yuan respectively). Therefore, for better visualization effect and the comparison among different urban agglomerations, using the monetary unit of yuan for the automatically determined thresholds corresponding to 98% quantile of grid-level fixed asset in each figure is a relatively better choice.

2. Fig. 2: There is a typo in one of the charts: "Harmonized" instead of "Harmanized".

   **Response:** Thank you so much for your careful check! This error has been rectified in Figure 2 of the revised manuscript (in **Line 155, Page 6**).

3. Although described in the text, the delta in Eq. 3 has a different meaning than the delta in Eq. 4. I suggest using a different symbol for one of them.

   **Response:** Thank you so much for this suggestion! We has used $\kappa$ to replace $\delta$ in Eq. (3) and in related context of the revised manuscript (in **Lines 229-230, Page 9**).

4. Table 1: There is a typo in the 2nd column, 8th row: “Population density data” instead of “Population dentsity data”.

**Response:** Thank you again for your so careful check! This typo has been rectified in the revised manuscript (in **Line 156, Page 6**).

## RC2 comments and responses

**The overall quality of the preprint (general comments)**

The overall quality of the paper is high. The topic of developing a novel fixed asset model to improve seismic loss estimation is significant for the science community. By mapping fixed assets at a 1 km × 1 km grid level, the model better serves rapid seismic loss assessments and informs emergency response plans. The research is well structured and explained. The authors made an effort to combine various data sources and techniques.

While the model represents a significant advancement, several limitations could impact its effectiveness, particularly in high-stakes applications like earthquake response. The paper's scientific contributions justify publication with minor revisions to handle specific data assumptions better and further validate the model's application. These adjustments would help ensure the model's broader applicability and robustness.

**Response:** We deeply appreciate the time and efforts you have devoted to improving the quality of this manuscript and thank you so much for all the constructive comments! Our detailed responses are given as follows. Hopefully they can help release your concern on the earlier version of the manuscript.

**Individual scientific questions/issues (specific comments)**

Here are some topics which the authors could discuss in more detail:

**Reliance on Historical Investment Data and Simplified Depreciation Rates**. The model bases its estimates on historical investment data and applies a uniform 5% depreciation rate across all provinces, regardless of variations in asset type, economic condition, or regional maintenance practices. The uniform deprecation rate can introduce inaccuracies, especially for assets with different service lives or conditions. The simplified approach to depreciation may lead to skewed asset values, particularly in provinces with unique economic trajectories or asset compositions. For instance, in industrialized regions, assets may have a shorter useful life than in less industrialized provinces, affecting the accuracy of economic loss projections. Can the model be refined by including a variable depreciation rate based on more detailed asset-specific and regional data, if available?

**Response:** Thank you very much for this pertinent suggestion! We totally agree that it is quite necessary to integrate the temporal and spatial change in depreciation rate when modelling the net value of depreciated fixed asset, should the statistical data required to differentiate such rates be accessible for the period 1951-2020 considered in this study. As a matter of fact, in a prior prefecture-level fixed asset modeling work of Wu et al. (2014) for China during 1978-2012, they did develop varying depreciation rates for different provinces.

We have added a **new section 4.4** "Limitations of the modelled fixed asset data" in the clean version of the revised manuscript (see **Lines 560-604, Pages 25-27**). In this section, a more detailed introduction on how the provincial level depreciation rates in Wu et al. (2014) are derived is given. In addition, a new figure (**Figure 14** in **Lines 591-593** of the revised manuscript) comparing the fixed asset change ratio at provincial level by using the depreciation rates in Wu et al. (2014) and by using a fixed rate of 5% and related discussion is also given.

**Inconsistencies in the Data Sources for Ancillary Datasets.** The model relies on ancillary datasets (e.g., nighttime lights, population, built-up areas) which are not consistently available across all years. This results in the use of alternative data types to approximate missing data. For instance, population data alone is used in the early years when nighttime light data is unavailable. These proxies may not accurately represent economic activity, especially in rural areas or less-developed regions, leading to potential over- or under-estimations in asset distribution. Could the model be strengthened by incorporating more recent, high-resolution satellite data or by exploring alternative disaggregation methods that do not depend solely on proxies like nighttime lights?

**Response:** Thank you for this comment. A big effort made in this paper is to find reasonable combination of different ancillary data to disaggregate provincial level fixed asset into grid level. For periods (1991-2020) when nighttime light data are available, the combination of nighttime light and population are used to create the lit-pop index, which is exactly to better avoid the over- or under-estimation problems in asset distribution by using nighttime light or population data alone. For years before 1991 (1971-1990), when nighttime data are unavailable, the built-up surface area data and population data are used to create the area-pop index. And for earlier periods (1951-1970) when only grid level population density data are available, we choose to apply the pop-pop index (derived from the squared value of population in each 1km×1km grid) to further disaggregate the asset value of years before 1970. And the correlation analysis in Figure 10 between each pair of three disaggregation indexes (lit-pop, area-pop, pop-pop) further validates the consistency among these indexes.

But for earlier periods (1951-1970) when only population density data are used to disaggregate the provincial level fixed asset, we consider it is not appropriate to incorporate the high-resolution satellite data in recent years with population data to disaggregate the asse data. The reason is that China has experienced quite different economic development stages before 1970 and nowadays. While before 1970, the economy development in China was very slow due to natural disaster, political movement and the planned economic system, thus the fixed asset distribution pattern cannot be projected by using recent remote-sensing data.

**Lack of Structural Detail in Asset Composition.** The model's focus on fixed capital should differentiate between asset types (e.g., residential vs. industrial buildings) in disaggregation. This lack of structural specificity reduces the model's utility for applications that require asset type differentiation, such as insurance underwriting or infrastructure resilience planning. Different asset types respond differently to seismic events; for instance, infrastructure like bridges and roads may sustain different levels of damage compared to residential buildings. This generalization could lead to misaligned resource allocations during emergency responses. Introducing asset type categorization, possibly by incorporating land use or building inventory data, would enhance the model's accuracy for specific asset loss estimations.

**Response:** We totally agree with this comment. If the research focus is to model the fixed asset value for specific years only, it is possible to use more detailed census or even in-site investigated data to estimate the value of different asset types and disaggregate each asset type into grid level by using different remote sensing ancillary data as proxy (e.g., Gunasekera et al., 2015; Wu et al., 2018; Xin et al., 2021).

However, when accumulated fixed asset data series for a long period dating back to 1951 are needed, as modelled in this paper, detailed statistics to differentiate the building types (residential/industrial/commercial) and even the quota of different fixed assets (buildings, infrastructures, instruments) exposed to past years are typically missing. In this case, the fixed asset model developed in this paper has to be based on the Level 1 data. Based on this level information, the estimated seismic loss is relatively a rough estimation since the input data mainly include demographic data and capital stock investment data extracted from the yearbooks or national census. And when seismic loss is rapidly estimated after the occurrence of a damaging earthquake, the vulnerability curve to be used is also a quite empirical one, similar to those developed in Jaiswal and Wald (2011) in the PAGER (Prompt Assessment of Global Earthquakes for Response) project. Such empirical vulnerability curve only describes the relation between the mean loss ratio and the macro intensity, which is regressed from damaging statistics (intensity map, total loss, exposed asset value) of historical earthquakes for specific countries and regions. And such loss estimation process is quite different from the one based on the structure type and apply the corresponding vulnerability curves for specific buildings.

Although in the fixed asset data developed in this paper, there is no differentiation of building types, when compared the modelled asset with our previous work focusing on developing the replacement value of residential buildings and structures (Xin et al., 2021), as shown in Figure 12, we find the correlation ratio at prefecture level between these two asset models are relatively high (with $R^2$=0.91). It is noteworthy that asset models with detailed building attributes for specific year only is not sufficient to develop the empirical vulnerability curve, which entails the fixed asset for past years as well. Considering the completeness and availability of input data for period 1951-2020, the perpetual inventory method (PIM) is the best practice to follow to develop such asset data series.

The above discussion and part of your comments have been further briefly summarized and added to the **new section 4.4** "Limitations of the modelled fixed asset data" in **Lines 606-621, Pages 27-28** of the revised manuscript.

**Technical corrections**

The article's language quality is overall sound, with a few areas where readability and formality can be improved. Here are specific suggestions regarding grammar, spelling, and phrasing.

- Maintain past tense in descriptions of the completed study. For example, in the sentence, "The fixed asset model to be developed in this paper is also based on the Level 1 data."

  **Response:** Thank you for pointing this out. We have thoroughly checked the use of verb tenses when revising the manuscript. However, we have to confess that sometimes it is kind of confusing to decide which tense should be used. For example, the expression "*The fixed asset model to be developed in this paper is also based on the Level 1 data*" can also be regarded as a description of the fact. In this case, it seems the present tense should be used, as suggested by the book "*Science Research Writing ---- For Non-Native Speakers of English*" (Glasman-Deal, 2010).

- Remove redundant phrases. For example, "To summarize, the nighttime light data and GHS-POP data are used to generate the lit-pop disaggregation indexes from 1991 to 2020, while the GHS-BUILT-S data and GHS-POP data are used to construct area-pop disaggregation indexes from 1971 to 1990..."

  **Response:** Thank you very much for your careful check. The initial consideration to give such summarization in the Results section is mainly to help readers who only roughly scan this paper to quickly understand the difference in ancillary data used for different periods when disaggregating the provincial fixed asset value. Therefore, we consider it might be better to keep such a reminder.

- Avoid Informal Language. For example, replacing "Luckily" with "Fortunately" is more formal.

**Response:** Thank you very much for this suggestion! We have reread the manuscript carefully and replaced the expression like “Luckily” to “Fortunately” accordingly. In addition, we also used the software Grammarly to check the whole revised manuscript, to help make sure that all the expressions are correctly organized. For example, “greatly” has been replaced by “significantly”, “next” has been replaced by “following”, and “huge” has been replaced by “considerable”, etc.

- Revise for Consistency In Abbreviations and Acronyms. Introduce abbreviations consistently upon first mention, ensuring they are used uniformly throughout.

  **Response:** Thank you for this reminding! With the help of Grammarly and self-crosscheck, we have tried our best to avoid such inconsistencies when revising the manuscript. For example, the expressions like “fixed capital stock, fixed asset” have been uniformly expressed as “fixed asset” in the revised manuscript.

## References mentioned in the responses:

De Moel, H., Jongman, B., Kreibich, H., Merz, B., Penning-Rowsell, E., and Ward, P. J.: Flood risk assessments at different spatial scales, Mitig Adapt Strateg Glob Change, 20, 865–890, https://doi.org/10.1007/s11027-015-9654-z, 2015.

Glasman-Deal, H.: Science research writing for non-native speakers of English, World Scientific, 2010.

Gunasekera, R., Ishizawa, O., Aubrecht, C., Blankespoor, B., Murray, S., Pomonis, A., and Daniell, J.: Developing an adaptive global exposure model to support the generation of country disaster risk profiles, Earth-Science Reviews, 150, 594–608, 2015.

Jaiswal, K. and Wald, D. J.: Rapid estimation of the economic consequences of global earthquakes, US Department of the Interior, US Geological Survey Reston, VA, 2011.

Li, Y., Xin, D., and Zhang, Z.: Estimating the economic loss caused by earthquake in Mainland China, International Journal of Disaster Risk Reduction, 95, 103708, https://doi.org/10.1016/j.ijdrr.2023.103708, 2023.

Wu, J., Li, N., and SHI, P.: Benchmark wealth capital stock estimations across China's 344 prefectures: 1978 to 2012, China Economic Review, 31, 288–302, https://doi.org/10.1016/j.chieco.2014.10.008, 2014.

Wu, J., Li, Y., Li, N., and Shi, P.: Development of an asset value map for disaster risk assessment in China by spatial disaggregation using ancillary remote sensing data, Risk analysis, 38, 17–30, 2018.

Xin, D., Daniell, J. E., Tsang, H.-H., and Wenzel, F.: Residential building stock modelling for mainland China targeted for seismic risk assessment, Nat. Hazards Earth Syst. Sci., 21, 3031–3056, https://doi.org/10.5194/nhess-21-3031-2021, 2021.

Yu, J., Stathopoulos, T., and Li, M.: Exposure factors and their specifications in current wind codes and standards, Journal of Building Engineering, 76, 107207, https://doi.org/10.1016/j.jobe.2023.107207, 2023.