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LETTER

Spatiotemporal changes in both asset value and GDP associated with seismic exposure in China in the context of rapid economic growth from 1990 to 2010

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Abstract

Accurate exposure estimation is essential for seismic risk assessment. Recent rapid urbanization and economic growth in China have led to massive spatiotemporal changes in both the asset value and GDP exposed to seismic hazards. Using available GDP data, the asset value dataset produced by Wu *et al* (2014a) and spatial disaggregation technology, gridded maps of GDP and asset value are overlaid with the latest seismic map to investigate spatiotemporal changes in economic exposure in the most seismically hazardous areas (MSHAs) in China in 1990, 2000 and 2010. We found that 15.4% of China's asset value and 14.1% of China's GDP were located in MSHAs in 2010, and the asset value and GDP exposed to MSHAs reached 15.9 trillion CNY and 6.2 trillion CNY, respectively, with average annual rates of increase of 14.4% and 11.3% over the two decades. The evidence of increased exposure provides valuable information regarding whom or what risk managers should give the most attention based on the economic exposure changes in earthquake-prone areas of China. Notably, the North China seismic belt, which is associated with the largest economic exposure to earthquakes and a rapidly increasing rate of economic exposure compared to those in other seismic belts, and the Qinghai-Tibet seismic belt, which has the highest earthquake occurrence, are two seismic belts of interest. A more detailed study is required to determine the relationship between increased economic exposure and earthquake disaster losses combined with hazard level and vulnerability.

1. Introduction

Disaster risk is a function of the hazard level, exposure and vulnerability, and it is often expressed as the probability of loss of life, injury or destruction or damage to capital stock in a given period of time (UNISDR 2013, De Bono and Mora 2014). Economic exposure can be defined in terms of the economic value of both physical assets (buildings and non-building infrastructure) and Gross Domestic Product (GDP) (Gunasekera *et al* 2015). Direct loss is significantly related to the exposure of assets to hazards, while GDP is considered an indicator that reflects the indirect economic impact (e.g. production

loss due to a business interruption) after a disaster (Hallegatte 2008, Wu *et al* 2012). Asset value and GDP value are two main measures that reflect the extent of disaster-related impacts on an economic system. Therefore, timely and accurate assessment of the exposure of asset value and GDP to seismic hazards is essential for disaster loss estimation and risk assessment, and such analyses benefit earthquake risk management.

Earthquakes are one of the most serious natural disasters in China. The 2008 great Wenchuan earthquake resulted in US$124 billion in direct losses and over 80 thousand deaths, while the indirect economic losses were estimated at 40% of direct losses

(Wu *et al* 2012). The 1976 Tangshan earthquake resulted in around US$10 billion in direct losses and over 242 thousand deaths (Grossi *et al* 2006), and post-disaster economic recovery lasted at least 11 years (Wu *et al* 2014b).

Seismic hazard estimation is generally the first step in seismic risk assessment. The Chinese Earthquake Administration provided an updated seismic ground motion parameter zonation (SGMPZ) map (GB 18306–2015) in 2015 (General Administration of Quality Supervision Inspection and Quarantine of PRC 2015). SGMPZ provides the distribution of peak ground acceleration (PGA, a measure of the maximum ground shaking) with a 10% probability of exceedance over a period of 50 years (He *et al* 2016). PGA is generally correlated with the macroseismic intensities of the earthquake, and it is commonly applied by engineers and government agencies to determine building and infrastructure codes.

Most previous studies focused on seismic hazards (e.g. Xie *et al* 2010) because of their significant effect on engineering design (Wang 2010), and limited attention has been paid to hazard exposure in China, specifically, the buildings (Wald *et al* 2008, Xu *et al* 2016) and population (e.g. He *et al* 2016). Meanwhile, the annual GDP growth rate averaged around 10.2% for China in 1990–2010 according to the World Bank's national accounts data (http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG). How such rapid economic growth and its regional differences can contribute to the seismic exposure change? However, few studies have examined the spatiotemporal changes in economic exposure due to seismic hazards in the context of rapid urbanization and economic growth in China in recent decades. Data availability is the main constraint to such analyses because of the high spatial heterogeneity of the asset values and GDP.

Improvements and updates to statistical data and the development of disaggregation technology based on Geographic Information Systems (GIS) make it is possible for such a seismic exposure assessment. Thus, the main objective of this study was to analyse the characteristics of both the asset value and GDP value based on exposure to seismic hazards in China in 1990, 2000 and 2010 in the context of rapid economic growth. Additionally, the seismic exposure change was analysed using GIS at the national, economic zone (West, Central and East China) and seismic belt levels.

2. Methods

2.1. Data sources

This study used four types of data. First, boundary data were extracted from the SGMPZ map discussed above, which provides the seismic belts and economic zones in China and the administrative divisions of all provinces, prefectures and counties in China (as shown in figure 1). The seismic belt data were obtained

from the Chinese Earthquake Administration. The three economic zones (i.e. West, Central and East China) were established based on the definition of the Chinese Ministry of Housing and Urban–Rural Construction. This division is also widely used in the China Statistical Yearbooks. Administrative boundary data were obtained from the National Geomatics Center of China[5]. Taiwan, Hong Kong and Macao were excluded from this study owing to the lack of statistical data.

Second, county-level GDP data and the prefecture-level GDP proportion of the agriculture sector from 1990, 2000 and 2010 were collected from the China Statistical Yearbooks Database (CSYD)[6], which collects almost all national, provincial and prefectural statistical yearbooks published by the China Statistics Press (Wu *et al* 2014a).

Third, prefectural asset value data from 1990, 2000 and 2010 were taken from Wu *et al* (2014a), who estimated the asset values (or wealth capital stocks) of 344 prefectures in Mainland China from 1978 to 2012 using published statistical data.

Fourth, raster datasets from the LandScan Global Population Database in 2000 and 2010 were produced by Oak Ridge National Laboratory, and the global radiance calibrated nighttime lights datasets from 1995, 2000 and 2010 were obtained from the National Aeronautics and Space Administration (NASA). These data were used in the disaggregation of asset values and GDP. The spatial resolution of the two datasets is 30 arc seconds.

2.2. Gridded GDP and asset value mapping using disaggregation technology and GIS
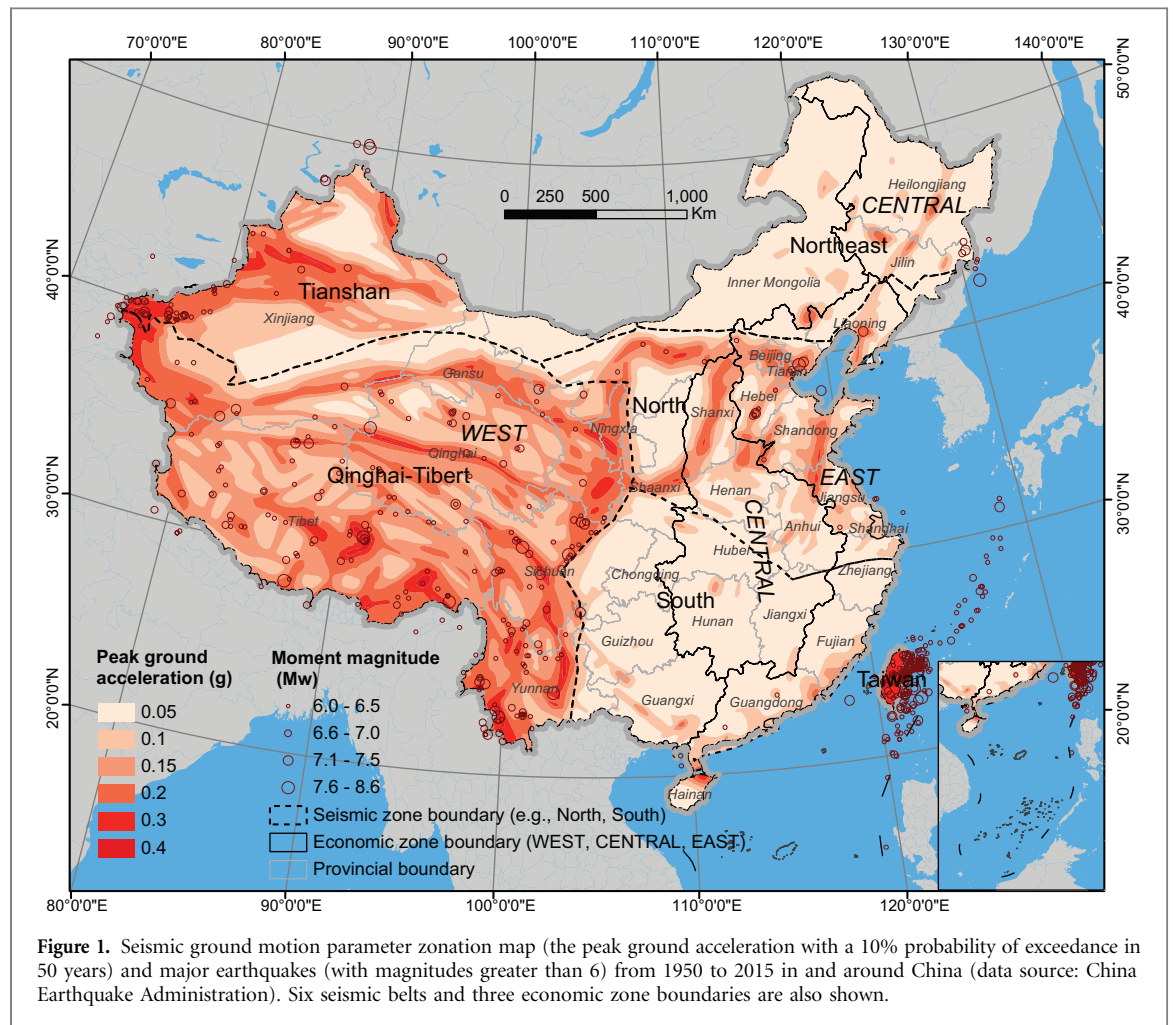
As shown in figure 1, the PGA zones are not consistent with the administrative boundaries (i.e. provincial boundaries), and the spatial heterogeneity of economic activities has been increasingly recognized as a key component in environmental exposure and risk assessment (Zhou *et al* 2014, Zagmutt *et al* 2016). To resolve the mismatch between the PGA extent and statistical economic data based on administrative boundaries, this study uses a disaggregation (or downscaling) method to disaggregate county-level GDP to the typical georeferenced grid level via the following steps.

First, to account for the administrative boundary changes between 1990 and 2010, 2254 county units were ultimately produced after merging more than 2800 counties in Mainland China. In total, 2254 counties can be merged into 344 prefectures for asset value estimates, as noted by Wu *et al* (2014a). Additionally, 344 prefectures can be merged into 31 provincial administrative units in Mainland China.

Second, using the CSYD database online, county-level GDP data from 1990, 2000 and 2010 were

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Figure 1. Seismic ground motion parameter zonation map (the peak ground acceleration with a 10% probability of exceedance in 50 years) and major earthquakes (with magnitudes greater than 6) from 1950 to 2015 in and around China (data source: China Earthquake Administration). Six seismic belts and three economic zone boundaries are also shown.

compiled based on the 2254 administrative county units. In some provinces (i.e. Tibet and Liaoning), county-level GDP data were not available in 1990; thus, the GDP of each county was estimated based on its proportion of GDP at the prefecture level in 2000 multiplied by the prefecture GDP in 1990.

Third, county-level GDP data were disaggregated to the georeferenced grid level using ancillary data, including the LandScan population grid and the nighttime light grid. This method was used by Ghosh *et al* (2010) to produce a worldwide map of the GDP in 2006 with a spatial resolution of 30 arc seconds. The disaggregation process was based on the following sub-steps (as shown in figure 2):
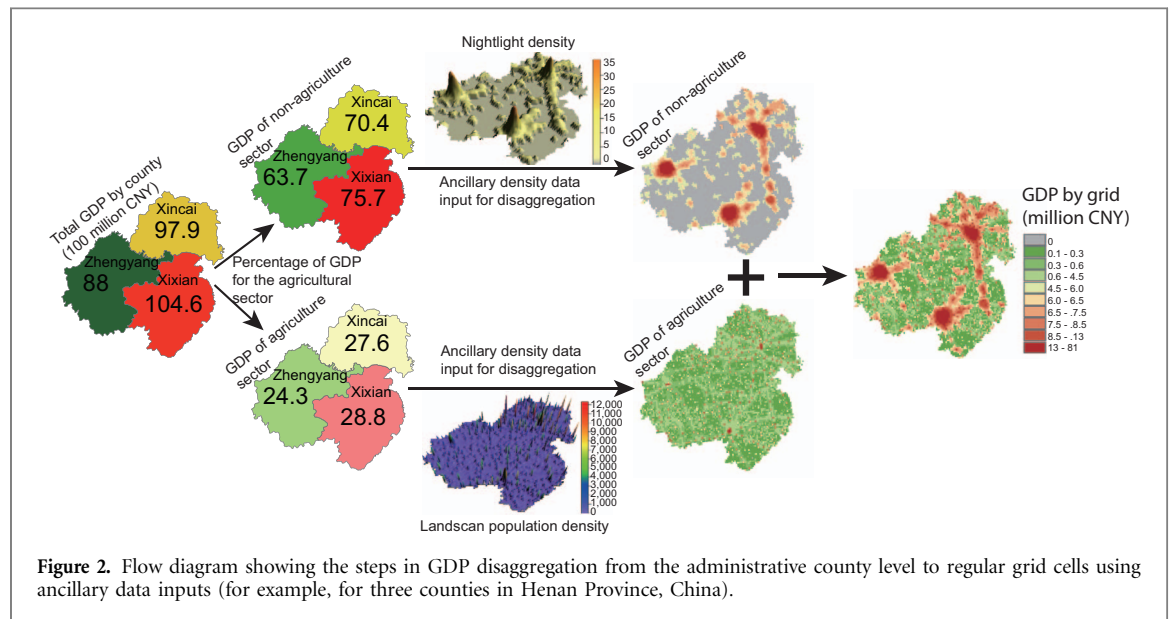
(i) Estimation of the percent contribution of the agricultural sector GDP in each county—because the county-level GDP proportion associated with the agriculture sector is not always available, this paper uses the prefecture-level percentage of GDP in the agriculture sector as a replacement, as the economic structure is similar within a prefecture.

(ii) Disaggregation of GDP using ancillary (proxy) density data (figure 2)—as proposed by Ghosh *et al* (2010) and other researchers (Nordhaus 2006, Doll *et al* 2006, Chen and Nordhaus

2011), this paper uses the LandScan population density grid and nighttime light density grid for disaggregation of the agricultural GDP and non-agricultural GDP in each year (i.e. 1990, 2000 and 2010), respectively, i.e. county-level GDP (GDPc) can be downscaled to pixel (x, y) by:

$$\mathrm{GDP}(x, y) = \mathrm{Ratio}(x, y) \times \mathrm{GDPc} \qquad (1)$$

where $\mathrm{GDP}(x, y)$ is the GDP at grid level, $\mathrm{Ratio}(x, y)$ is the ratio of the ancillary value (population for agricultural GDP or digital number of the nightlight intensity for non-agricultural GDP) at (x, y) position to its total value within a county which indicates the weighting of the GDP distribution within a county by using ancillary data. For the disaggregation of GDP in 1990, because there were no LandScan population data available in 1990; we use the LandScan population in 2000 as a substitute. Additionally, the nighttime light data from 1990 are also not available; thus, we use the nighttime light data from 1995 instead.

(iii) The disaggregated GDP values from the agriculture sector and non-agriculture sectors were summed to produce a grid-level GDP map in each year.

Figure 2. Flow diagram showing the steps in GDP disaggregation from the administrative county level to regular grid cells using ancillary data inputs (for example, for three counties in Henan Province, China).

Fourth, asset value was estimated by multiplying the capital-output ratio (COR) by the GDP. Based on the prefectural asset value estimation (Wu *et al* 2014a), prefecture-level COR was calculated by dividing the asset value by the GDP in the same prefecture and in each year. We assume that the COR is constant within a prefecture, as the industrial structure is generally similar within a prefecture. However, some spatial variations in the COR exist at the prefecture level in reality. Finally, an asset value map can be produced from the GDP map and prefecture-level COR values.

2.3. Analysis of GDP and asset value change in earthquake-prone areas

To analyse the economic exposure change associated with earthquakes in China, the national GDP and asset value of exposure to earthquakes caused by five seismic belts (North, South, Northeast, Qinghai-Tibet and Tianshan, China, as shown in figure 1) in three economic zones (West, Central and East China) were first analysed in 2010. The analysis provided a current framework of seismic exposure in China.

Then, the absolute and relative changes in both GDP and asset values exposed to the most seismically hazardous areas (MSHAs, with PGA values larger than 0.2 g in the SGMPZ map shown in figure 1) in 1990, 2000 and 2010 were analysed. To determine the MSHAs, according to the *Code for seismic design of Buildings* (GB 50011-2010) of China, the criterion of a PGA value larger than 0.2 g corresponds to areas with seismic intensities greater than degree VIII (MOHURD and AQSIQ 2010), which is commonly used to determine MSHAs (Holzer and Savage 2013, He *et al* 2016).

To compare the GDP changes in different years, GDP values in 1990 and 2000 were transformed to the price level of 2010 using China's GDP deflator, which

was obtained from the World Development Indicator database published by the World Bank.

3. Results

3.1. Total GDP and asset value in earthquake-prone areas in 2010

As shown in figure 1, China is located in an earthquake-prone area with PGA values greater than zero. At the seismic belt level, the seismic zone in North China is associated with the largest economic exposure to earthquakes, 54.3% of China's GDP (approximately 23.8 trillion CNY) and 55.7% of China's asset value (57.6 trillion CNY), as shown in figure 3(*a*); however, most of the economic exposure is concentrated in areas with PGA values below 0.2 g. Additionally, almost all of the South and Northeast seismic zones are characterized by PGA values below 0.15 g. Conversely, in both the Qinghai-Tibet and Tianshan seismic zones, the national percentages of the GDP and asset value are lower than 5%, and the PGA values in these areas are greater than or equal to 0.2 g (i.e. MSHAs).

At the economic zone level (figure 3(*b*)), 56.8% of China's GDP (approximately 24.9 trillion CNY) and 53.2% of China's asset value (approximately 54.8 trillion CNY) are located in the East economic zone. In addition, considerable proportions of both the GDP and asset value in the East and West economic zones are located in areas with PGA values larger than or equal to 0.2 g.

3.2. Economic exposure change in MSHAs between 1990 and 2010

The economic exposure change in MSHAs in 1990, 2000 and 2010 is shown in figure 4, and the related statistics are provided in table 1.
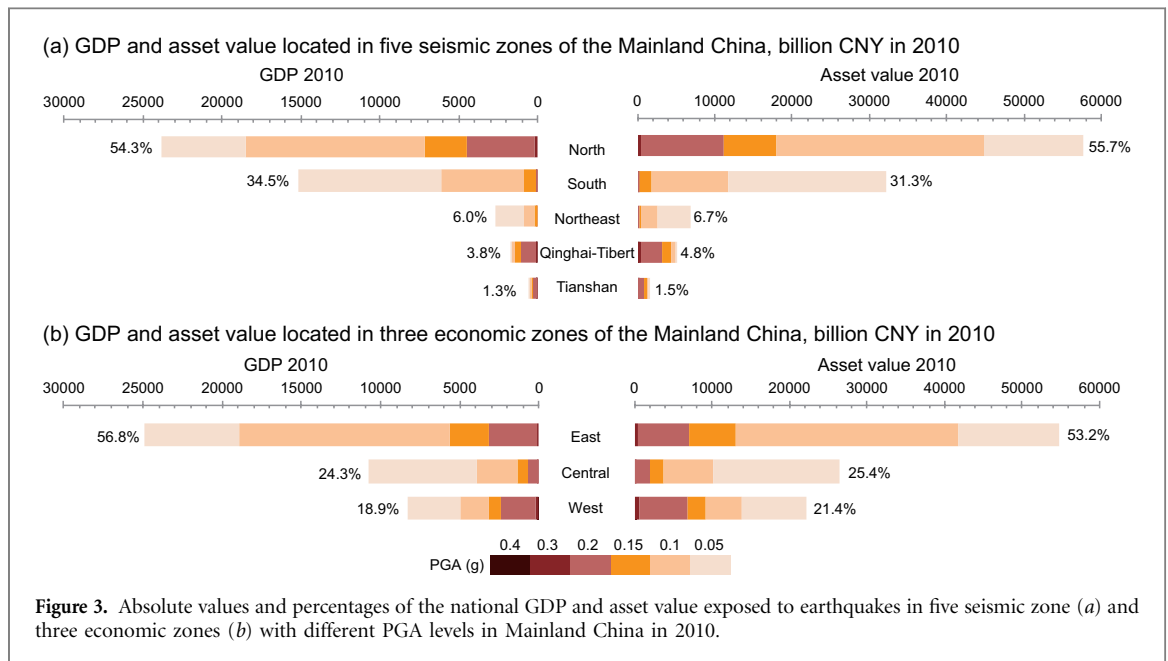
Figure 3. Absolute values and percentages of the national GDP and asset value exposed to earthquakes in five seismic zone (*a*) and three economic zones (*b*) with different PGA levels in Mainland China in 2010.
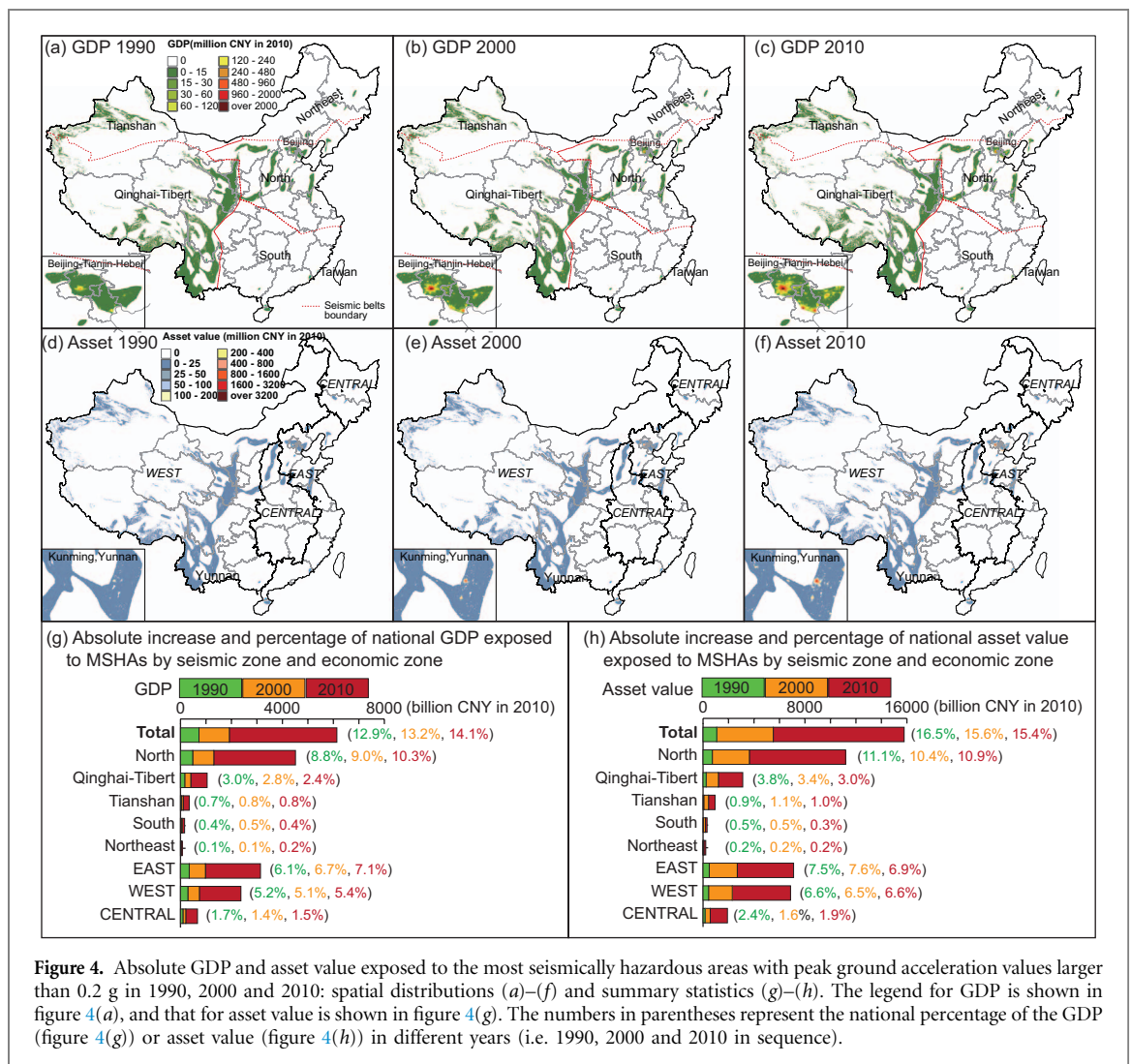

Figure 4. Absolute GDP and asset value exposed to the most seismically hazardous areas with peak ground acceleration values larger than 0.2 g in 1990, 2000 and 2010: spatial distributions (*a*)–(*f*) and summary statistics (*g*)–(*h*). The legend for GDP is shown in figure 4(*a*), and that for asset value is shown in figure 4(*g*). The numbers in parentheses represent the national percentage of the GDP (figure 4(*g*)) or asset value (figure 4(*h*)) in different years (i.e. 1990, 2000 and 2010 in sequence).

Overall, the total GDP increased from 730.3 billion CNY in 1990 to 6178.7 billion CNY in 2010 in the MSHAs (table 1) for a net absolute GDP increase of 5448.4 billion CNY. The GDP in 2010 was over eight times larger than the GDP in 1990, which is higher than the overall national GDP increase in China over the same period (the GDP increased at an average annual rate of 11.3% in the MSHAs over 20 years,

Table 1. GDP and asset value changes in the most seismically hazardous areas from 1990 to 2010 (in billion CNY of 2010).

Area	GDP			Asset value			GDP change ratio	Asset change ratio	GDP growth rate	Asset growth rate
	1990	2000	2010	1990	2000	2010				
North	496.67	1309.99	4525.39	728.79	3693.74	11232.07	9.1	15.4	11.7%	14.7%
Qinghai-Tibet	167.06	407.55	1054.46	249.50	1207.57	3104.78	6.3	12.4	9.6%	13.4%
Tianshan	39.51	116.44	351.49	59.09	394.24	1034.93	8.9	17.5	11.5%	15.4%
South	22.58	72.78	175.74	32.83	177.58	310.48	7.8	9.5	10.8%	11.9%
Northeast	4.52	19.50	71.62	13.13	71.03	206.99	15.9	15.8	14.8%	14.8%
East	342.99	978.25	3139.58	489.62	2685.10	7106.15	9.2	14.5	11.7%	14.3%
West	290.86	740.03	2371.33	433.43	2294.64	6866.46	8.2	15.8	11.1%	14.8%
Central	96.45	207.94	667.67	160.01	564.80	1916.58	6.9	12.0	10.2%	13.2%
Total in MSHAs	**730.30**	**1926.22**	**6178.59**	**1083.05**	**5544.54**	**15889.18**	**8.5**	**14.7**	**11.3%**	**14.4%**
Mainland China total	**5644.01**	**14555.42**	**43935.78**	**6565.69**	**35516.69**	**103492.81**	**7.8**	**15.8**	**10.8%**	**14.8%**

Note: 1) The five seismic belts include the North, Qinghai-Tibet, Tianshan, South and Northeast zones, and the three economic zones, including the East, West and Central regions. 2) The GDP change ratio is calculated as (GDP2010/GDP1990), where GDP2010 and GDP1990 refer to the GDP in 2010 and 1990, respectively. The asset change ratio is calculated as (Aseet2010/Asset1990), where Asset2010 and Asset1990 refer to the asset values in 2010 and 1990, respectively. 3) The GDP growth rate is calculated as ((GDP2010/GDP1990)^(1/20)-1)*100%, and the asset growth rate is calculated as ((Asset2010/Asset1990)^(1/20)-1)*100%, which reflects the average growth rate over the two decades.

while the overall annual increase was 10.8% in China during this period). Notably, the GDP increased by 1195.9 billion CNY before 2000 and then rapidly increased after 2000 by 4252.4 billion CNY. Thus, the growth rate in the second decade was 3.6 times that in the first decade.

During the two decades, the total asset value increased by 14806.1 billion CNY and at an average annual rate of 14.4%. Additionally, the asset value increased by a factor of 14 in 20 years, but this increase was still lower than the overall rate of increase in China (15.8%, as shown in table 1). Before 2000, the asset value increased by 4461.5 billion CNY, and this value increased by 10344.6 billion CNY after 2000. Thus, the growth rate in the second decade was 2.3 times that in the first decade.

Meanwhile, the relative percentage of GDP (to that of China) in MSHAs increased from 12.9% in 1990 to 14.1% in 2010 (figure 4(*g*)), while the relative percentage of the asset value (to that of China) exposed to MSHAs decreased from 16.5% in 1990 to 15.4% in 2010 (figure 4(*h*)).

Of the five seismic belts in Mainland China, the seismic belt in North China exhibited the largest economic exposure to MSHAs, as 4525.4 billion CNY of GDP and 11232.1 billion CNY of asset value were located in MSHAs in 2010, accounting for 73.2% of the MSHA GDP and 70.7% of the MSHA asset value. At the economic zone level, East China exhibited the largest economic exposure to MSHAs, as 3139.6 billion CNY of GDP and 7106.2 billion CNY of asset value were located in MSHAs. Additionally, the West China zone exhibited similar, although slightly lower, economic exposure.

Over two-thirds (4252.4 billion CNY) of the total increase in GDP from 1990 to 2010 was due to the absolute increase in total GDP between 2000 and 2010.

This increase is mainly in the North China seismic belt, which contributed to nearly 60% (3215.4 billion CNY) of the total increase in GDP (5448.4 billion CNY) from 1990 to 2010, largely due to the considerable areas of MSHAs in Beijing-Tianjin-Hebei (figure 4). Additionally, Beijing and Tianjin are two of the most developed areas in China. Furthermore, the GDP growth rates in Tianshan and the Northeast seismic belt were higher than that in the MSHAs overall (table 1).

The increasing trend of asset value exposure is similar to that of the GDP: (i) the asset value change between 2000 and 2010 contributed to the majority of the increase in asset value exposure from 1990 to 2010, and nearly 70% of the asset value increase (10344.6 billion CNY) occurred in this period; and (ii) at the seismic belt level, the majority of the increase in asset value exposure occurs in North China (figure 4(*h*)).

The differences between the GDP and asset value trends are as follows: (i) at the economic zone level, compared to the GDP change ratio in West China, the asset value increase is higher than that in MSHAs overall. Additionally, the asset value in West China (6866.5 billion CNY) is similar to that in East China (7106.2 billion CNY) in 2010; (ii) the GDP increase in East China was higher than that in MSHAs overall; however, the asset value increase was slightly lower than that in MSHAs overall (table 1); and (iii) based on the national percent change in economic exposure (figures 4(*g*) and (*h*)), the total GDP increase displayed an upward trend from 1990 to 2010 (the total GDP percentage increased from 12.9% in 1990 to 13.2% in 2000 and 14.1% in 2010), but the total asset value exhibited decreasing trend simultaneously (the total asset value percentage decreased from 16.5% in 1990 to 15.6% in 2000 and 15.4% in 2010).

4. Discussion

4.1. Prominent increases in economic exposure and urbanization in MSHAs

Rapid urbanization and economic development in China provide important reasons for studying the increased economic exposure to earthquakes. First, driven by China's national reform and policies, including foreign investment beginning in the 1990s and the national implementation of a series of regional development plans in the 21st century, such as the Western Development plan and the Revitalization of Old Industrial Bases in Northeast China, fixed asset investments and the construction of large-scale urban development zones (e.g. Beijing-Tianjin-Hebei in the North China seismic belt) have promoted an increase in economic exposure in MSHAs. Notably, the increases observed in the Northeast seismic belt, Tianshan seismic belt and West economic zone were greater than or equal to that of Mainland China overall (table 1).

Second, along with urbanization, the population increased by 32.53 million, and the rate of population change reached 33.6% in MSHAs from 1990 to 2010. Additionally, one-tenth of the Chinese population lived in MSHAs in 2010 (He *et al* 2016). Based on China's multi-temporal land use/cover datasets (1 km^2 grids) provided by Liu *et al* (2014) and an overlay analysis based on the extents of MSHAs, within two decades, the area of built-up land increased by over 5285 km^2, and the rate of increase reached 24.5%. Meanwhile, the national GDP and asset value exposed to MSHAs increased by factors of 8 and 14 (table 1), respectively.

4.2. Serious seismic risk in MSHAs

Seismic risk is a function of the hazard level, exposure and vulnerability. The economic value located in MSHAs is subject to seismic risk. First, from 1950 to 2015, of the 274 earthquakes with *Ms* values greater than or equal to 6 in Mainland China (figure 1), 64.6% of the earthquakes occurred in MSHAs. Of these earthquakes in the MSHAS, 66.1% occurred in the Qinghai-Tibet seismic belt, 24.9% occurred in the Tianshan seismic belt and the remaining 9.0% occurred in the North China seismic belt. Thus, the Qinghai-Tibet seismic belt had the highest frequency of earthquake occurrence in Mainland China, and the costly 1920 Haiyuan earthquake (in Ninxia Province), the 2008 great Wenchuan earthquake and the 2015 Nepal earthquake, all with *Ms* values greater than or equal to 8, occurred in this area. By economic zone, 91.5% of the earthquakes in the MSHAs occurred in the West economic zone, and 8.5% occurred in the East economic zone.

Second, regarding the economic exposure described above, the North China seismic belt is associated with the largest GDP and asset value

exposure to earthquakes, and the average annual growth rates of economic exposure (asset value and GDP) are higher than those in MSHAs overall. The Chinese capital, Beijing, the municipality of Tianjin and parts of Hebei Province are located in MSHAs in the North China seismic belt. This seismic belt has been affected by several devastating earthquakes, including the 1679 Sanhe-Pinggu earthquake (Ms = 8.0) in Sanhe county, Beijing (Huang and Zhao 2004), and the 1976 great Tangshan earthquake (Ms = 7.8) in Tangshan, Hebei Province, which caused more than 240,000 fatalities, immeasurable economic losses (Peng *et al* 2011) and a more than eleven-year economic recovery process (Wu *et al* 2014b). Karakostas *et al* (2013) found that positive stress changes caused by the largest events of the 1976 Tangshan sequence provided the framework for potential future seismogenesis in Hebei Province. Risk Management Solutions estimated that over US $100 billion of economic losses could be expected if the Sanhe-Pinggu earthquake in Beijing were to reoccur (Grossi 2007). With rapid urbanization and the implementation of the Beijing-Tianjin-Hebei Coordinated Development Strategy in 2015, the economic exposure to hazards is expected to increase in the North China seismic belt.

Third, vulnerability is one of the major components of risk. Increased economic exposure does not reflect an increase in economic losses due to an earthquake or a seismic risk increase in MSHAs. However, as one of the major drivers of historic earthquake losses, how increased economic exposure contributes to earthquake losses in space and time requires further study in the future.

4.3. Limitations

Several limitations exist in this study. First, although the most available county-level GDP data were collected, the GDP data from 1990 in some counties of both Tibet and Qinghai were unavailable, and we had to estimate these values based on the proportion at the prefecture level in 2000 and the prefecture GDP in 1990. Such an estimation for missing value may not accurately represent the true GDP of the county, as the statistical GDP of the higher administrative level (i.e. prefecture) is exist, the benchmark GDP value (used in this study) for GDP downscaling is still superior to that of Ghosh *et al* (2010), who used provincial GDP as a start point for GDP disaggregation. Second, although there are uncertainties in asset value estimation, the database constructed by Wu *et al* (2014a) provides a foundation for more precise seismic exposure estimation of China. Meanwhile, uncertainties are inevitable in the disaggregation of both GDP and asset value from the administrative level to the grid level. However, this study intends to analyse changes in the economic exposure landscape at the macro-level (i.e. the seismic belt or economic zone

levels) rather than exact risk assessment in the study area. Therefore, the main findings would not be affected by using such estimations or disaggregation methods. The disaggregation of the GDP and asset value allowed us to perform an overlay analysis of seismic hazards and economic exposure. The resulting disaggregated economic exposure dataset could also be used in estimates involving other natural disasters.

5. Conclusion

Rapid urbanization and economic growth in China led to large increases in both the GDP and asset value in Chinese MSHAs between 1990 and 2010. The total MSHA GDP increased from 730.3 billion CNY in 1990 to 6178.7 billion CNY in 2010, an average annual increase rate of 11.3%, which is higher than that of the nation (10.8%) over the two decades. Compared to the GDP growth, the total asset value increased by 14806.1 billion CNY over the same period at an average annual rate of 14.4% and reached 15889.2 billion CNY in 2010. The rate of the asset value increase in MSHAs is lower than that in China overall, but the rate of GDP increase rate in MSHAs is higher than that of the nation.

Furthermore, the most notable economic exposure increases are located in three seismic belts: the North, Northeast and Tianshan seismic belts. In these areas, both the GDP and asset value growth rates are higher than the overall rates in MSHAs. The North seismic belt, which includes the capital of China, Beijing, has the largest economic exposure in a seismic belt, as 73.2% of the MSHA GDP and 70.7% of the MSHA asset value were located in this area in 2010. Additionally, the Qinghai-Tibet seismic belt accounted for 17.1% of the MSHA GDP and 19.6% of the MSHA asset value in 2010.

Historical records indicate the vulnerability of asset values to earthquakes in China. Assuming that the current rates of urbanization and economic growth in China continue, both the percentages of GDP and asset value exposed to seismic risk in MSHAs will continue to expand, especially in the North seismic belt and the Qinghai-Tibet seismic belt. The former currently has the highest economic exposure, while the latter exhibited the highest seismic frequency over the last 55 years. Meanwhile, devastating earthquakes with *Ms* values of 8.0 have occurred in these seismic belts. Thus, the Chinese government should pay more attention to the economic exposure changes in MSHAs, especially in the two seismic belts mentioned here.

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