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Assessment of the Slovenian Economy's Flood Exposure Using Flood Hazard Maps

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Abstract

This paper integrates detailed flood hazard maps with the geographical locations of businesses to evaluate the exposure of the Slovenian economy to flood events. The analysis was motivated by the occurrence of devastating floods in Slovenia in August 2023, which revealed the economy's vulnerability to extreme weather events. Three distinct scenarios, categorised by severity, have been developed to estimate the share of value-added and employment at private enterprises, and the credit portfolio exposure of Slovenian banks that is exposed. The findings highlight the significant susceptibility of the Slovenian economy to flood-related risks. Furthermore, the aggregate estimate masks substantial regional heterogeneity, with the majority of exposure concentrated in specific regions, while sector-specific analysis highlights the heightened vulnerability of the manufacturing sector.

Introduction

In the early days of August 2023, after weeks of heavy rainfall, significant downpours led to major rivers overflowing. The floods that ensued caused the largest natural disaster in the history of independent Slovenia, with damage estimates reaching several billion euros, and revealed the susceptibility of the Slovenian economy to extreme weather events. Considering the anticipated increase in both the frequency and intensity of climate-change-induced events in the future, Slovenia is poised to be particularly vulnerable, as indicated by the research of Alfieri et al. (2015), which illustrates a substantial projected increase in the frequency of large floods by 2050.

While there is a limited amount of literature that employs flood hazard maps to assess the impact of climate change in the context of banking and economics, there has been a noticeable increase in such research in recent years. For example, Faiella and Natoli (2019) utilised a map of flood risk in Italy to investigate whether banks consider climate-related risks in their lending decisions. Their findings suggest that, irrespective of credit demand factors and disaster insurance coverage, banks tend to limit credit to risky firms, highlighting their awareness of climate-related catastrophe risks. Banks also consider flood risk in their lending decisions at the household level, as demonstrated by Santos and Blickle (2022), who investigated how banks respond to the presence of and changes in flood insurance requirements, as dictated by flood maps. Their study reveals that both the likelihood of loan acceptance and the size of the loan are smaller in flood-prone areas. However, it is important to note that their definition of flood exposure varies somewhat from the one applied in this paper. Santos and Blickle (2022) do not utilise the precise street address information of applicants; instead, they rely on census tract data. They determine the probability of a household being situated within a flood-prone area and requiring insurance by equating it to the percentage of the flood-prone area within the observed household's census tract. Furthermore, Sastry (2022) examines residential mortgage agreements in Florida, aiming to analyse the distribution of flood risk among banks, households, and the government flood insurer. The study reveals that lenders primarily manage flood risks by adjusting down payment requirements rather than interest rates. Specifically, banks decrease the loan-to-value ratio by 85 basis points in flood zones, while interest rates do not undergo significant adjustments.

This paper evaluates the exposure of the Slovenian economy to floods by linking the location of enterprises to flood hazard maps provided by the Slovenian Water Agency. The results shed light on the extent of vulnerability in relation to value-added, employment, and credit portfolio exposure if any of the three scenarios were to materialise. While this analysis captures the exposure at risk from both macroeconomic and financial stability perspectives, assessing the dynamic impact on GDP and the macroeconomic environment is beyond its scope.

The remainder of the paper is structured as follows: Section 1 outlines the methodology and presents the data, Section 2 delves into the results of the severe scenario, and Section 3 concludes. Note that the discussion of the moderate and catastrophic scenarios, along with a separate decomposition of exposure within the manufacturing sector, is located in the appendix.

1 Methodology and Data

The analysis of the Slovenian economy's exposure to floods involved three main steps. First, three scenarios – moderate, severe, and catastrophic – were developed. Second, it was determined whether a company's headquarters were located within the flood-prone area of the analysed scenario. Last, the share of exposed value-added, employment, and credit exposure was determined.

In the first step the identification of scenarios relied on detailed flood hazard maps obtained from the Slovenian Water Agency database. More specifically, two types of flood hazard map were used, which differ somewhat in their generation process. Initially flood warning maps are developed by analysing historical and archival data concerning flood events, and by leveraging prior studies, research, analyses, and other relevant data. Following this initial phase, these maps are employed in conjunction with modelling and analytical methods that adhere to established scientific standards, incorporating hydrological, geological, geomorphological and geodetic data, as well as land use and land cover data, to generate Integrated Flood Hazard Maps (IFHMs).[1]

The two types of flood hazard map described were used interchangeably, depending on the location of the analysed company's headquarters. IFHMs were used if they were located within their validity area; otherwise flood warning maps were used. These maps enable the separation of flood events into three categories, namely moderate, severe, and catastrophic, based on their expected frequency of occurrence. Specifically, within the validity area of the IFHM, these three scenarios emulate flood events with 10-,100-, and 500-year return periods.[2] Outside of their validity area, the moderate scenario assumes the occurrence of rare floods, while the other two assume catastrophic flood events.

Next, it was determined whether a company was located within the flood-prone area of the respective scenario based on its location. After retrieving headquarters address data for all active private Slovenian enterprises from the Slovenian Business Register provided by AJPES, their coordinates were determined. If within the risk area, it was assumed that the entire employment, value-added, and credit exposure to Slovenian banks were exposed to flood risk. However, it should be noted that this assumption might be overly restrictive, as certain companies have subsidiaries or production facilities adjacent to their headquarters, and their hazard status (i.e. whether they are located within the flood-prone area) might differ from that of the parent company. Unfortunately, it remains unfeasible to differentiate between various company locations and their specific significance within the production process, as only company-level financial data is available. Therefore, only the location data of the parent company was considered. Furthermore, due to the importance of micro-location, some of the production facilities located near the headquarters may be within the flood-prone area, while the headquarters building itself may not be, or vice-versa. In these borderline cases, the position of the headquarters building was considered. Note that several robustness tests were conducted to address these shortcomings. While the results showed some variations in magnitude, the overall conclusions remained qualitatively unchanged.

[1] Rules on methodology to define flood risk areas and erosion areas connected to floods and classification of plots into risk classes (2007). Official Gazette of the Republic of Slovenia, No. 60/07.

[2] The return period is calculated as the inverse of the annual probability of occurrence. As a probabilistic measure, it should not be interpreted that, for example, 100-year floods can occur only once per century. On the contrary, a 100-year return period reflects a flood event that can occur each year with a probability of 1.0%.

Additionally, only directly exposed businesses were considered. Indirectly exposed entities, namely those situated outside flood-prone areas but at risk of experiencing production disruptions due to damaged infrastructure or workforce unavailability, were not taken into account. The analysis also does not encompass the implications for public infrastructure or the non-financial wealth of households. It is important to note, however, that during a flood event these factors may significantly contribute to the overall damage, as demonstrated by the devastating floods that hit Slovenia in August 2023.[3]

Once it was determined whether a company is situated within the flood-prone area, its exposure was assessed. This step relied on the detailed financial data provided by AJPES, and the credit exposure obtained from the credit register of Banka Slovenije. The exposed shares of employment, value-added by Slovenian private enterprises, and their exposure to Slovenian banks were all computed. Note that both on- and off-balance sheet exposure were considered for the latter. It should be noted that AJPES's definition of value-added varies somewhat from the definition employed by Statistical Office of the Republic of Slovenia (SORS) in the compilation of national accounts data. AJPES defines it as follows:

$$added\ value = gross\ operating\ income - COGS - other\ operating\ expenses,$$

where $COGS$ stands for cost of goods sold. Finally, the exposure data was aggregated and compared with the total value-added and employment of Slovenian private enterprises, along with their total credit exposure to Slovenian banks. This comparison aimed to assess potential exposure in the event that any of the selected scenarios were to materialise. Analysis of regional and sectoral exposure was also conducted. The first was motivated by significant heterogeneity across statistical regions, primarily stemming from their geographical characteristics, while the sectoral analysis provided insights into the vulnerability of various industries to floods.

2 Results

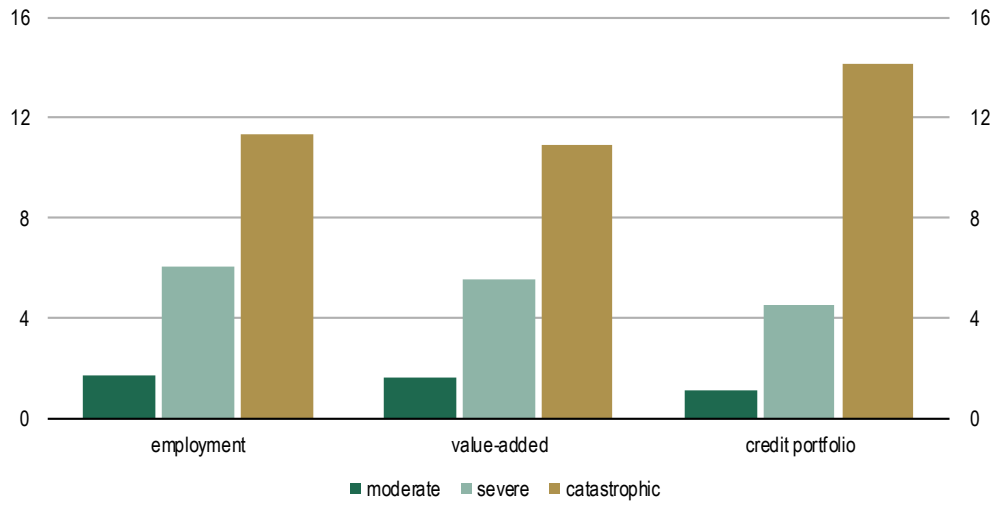
This section presents the results. First, the aggregate exposure among all active Slovenian private enterprises is shown, followed by the regional and sectoral decomposition of the severe scenario. The results of the latter are the focal point in this section, while those of the moderate and catastrophic scenarios are discussed in more detail in the appendix. The results also include a separate decomposition that focuses solely on exposure within manufacturing subsectors. This drilldown was motivated by the manufacturing sector's substantial contribution to the overall exposure.

To streamline the presentation of results, companies were classified into four groups. The "industry" group refers to companies that operate within the mining and quarrying, manufacturing, electricity and water supply, and waste management sectors. The construction sector was considered separately. "Private sector services" consist of wholesale and retail trade, accommodation and food service activities, and transportation and storage. The remaining sectors are assigned to the "other" group.

[3] The commercial sector's share of the total estimated direct damage caused by the August 2023 floods amounted to approximately 13% (Government of the Republic of Slovenia, 2023).

Focusing first on the aggregate exposure results, several patterns are evident. While the occurrence of the moderate flood scenario would potentially impact less than 2% of employment, value-added, and credit portfolio, the exposure quickly increases as the scenario intensifies. Under the severe scenario, exposure amounts to 6.1%, 5.6%, and 4.6% of all employment, value-added, and Slovenian banks' credit exposure to Slovenian private enterprises, respectively, while more than a tenth of the Slovenian economy could potentially be exposed across all metrics under the catastrophic scenario (see Figure 1).

Figure 1: **Aggregate exposure under each scenario (%)**



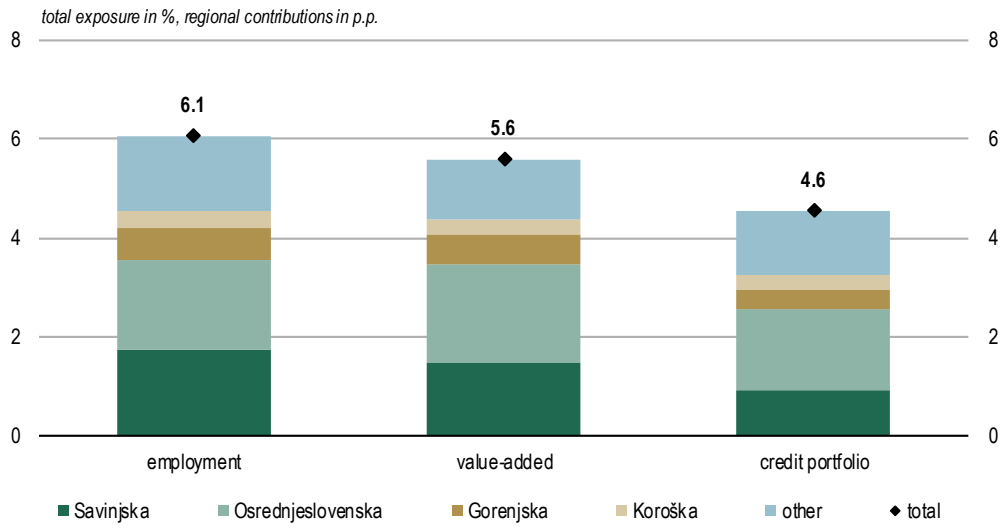
Note: The figure illustrates the share of directly exposed total value-added and employment of Slovenian private enterprises and the corresponding credit portfolio of Slovenian banks under each scenario.
Source: AJPES, Slovenian Water Agency.

However, aggregate exposure masks significant regional and sectoral heterogeneity. This necessitates more detailed analysis that decomposes the exposure over these two dimensions, and is presented in the following section.

2.1 Severe scenario

As stated above, the results of the severe scenario, which represents the middle reference scenario in this analysis, are discussed in detail in this section, while those of the moderate and catastrophic scenarios are interpreted in the appendix. Under the severe scenario, floods with a 100-year return period were assumed within the IFHM validity area, along with catastrophic floods outside of it, as defined by flood warning maps. In general, the results show higher exposure than under the moderate scenario, as such floods would directly impact nearly 5% of the exposure of the Slovenian banking system to Slovenian private enterprises, as well as more than 6% of their employment and 5.6% of value-added. If such floods were to occur, the Osrednjeslovenska and Savinjska regions would contribute the most to the overall exposure (see Figure 2). It should however be noted that realisation of the severe scenario would affect the latter significantly more, as illustrated in Figure 4.

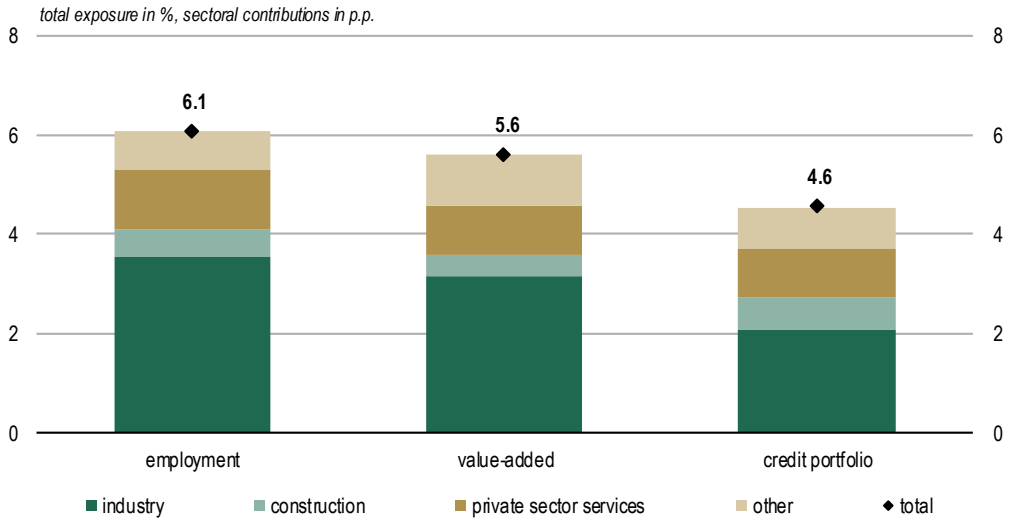
Figure 2: **Decomposition of regional exposure under the severe scenario**



Note: The figure illustrates the regional breakdown of the share of exposed employment, value-added, and credit portfolio of Slovenian banks.
Source: AJPES, Slovenian Water Agency.

The overall exposure under the severe scenario is then examined from another perspective. The decomposition depicted in Figure 3 indicates that sectors classified as industry contribute the most to the overall vulnerability of the economy, regardless of the analysed metric. For example, in the case of value-added, industry accounts for 3.2 percentage points, or nearly three-fifths of the total exposure. It is important to note, however, that the substantial contribution of industry is a consequence not only of its overall susceptibility to floods, but also of its relative importance within the structure of the Slovenian economy.

Figure 3: **Decomposition of sectoral exposure under the severe flood scenario**



Note: The figure illustrates the sectoral breakdown of the share of exposed employment, value-added, and credit portfolio.
Source: AJPES; Slovenian Water Agency.

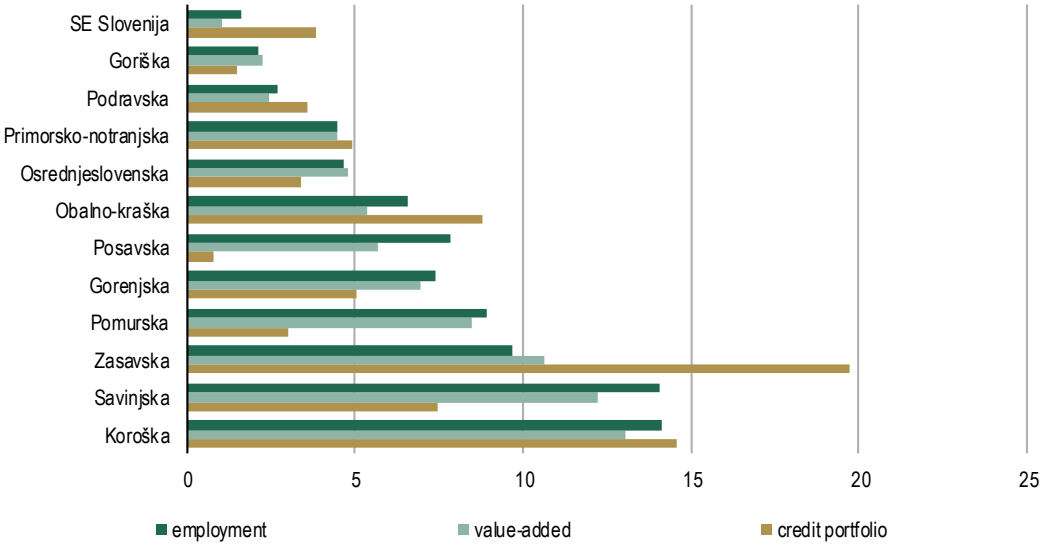
While the exposure under the severe scenario might seem limited from an aggregate perspective, more granular analysis reveals significant heterogeneity within geographical areas, as illustrated in Figure 4. Geographically, the Osrednjeslovenska region contributes the most to the overall exposure of the Slovenian economy under this scenario. For example, in terms of value-added, it adds approximately 2 percentage points. This

might seem somewhat unexpected, given that the regional exposure illustrated in Figure 4 seems limited. Nevertheless, the contribution under this scenario is linked to its significant weight in the structure of the Slovenian economy. In other words, while the region itself may be among the least affected (ranking fifth out of twelve), its most significant contribution under the severe scenario arises from its role as the primary engine of Slovenian economic activity. To further clarify, note that in 2022, approximately two-fifths of the total value-added of Slovenian private enterprises was generated by those headquartered in the Osrednjeslovenska region.

By contrast, the smaller regions, which play a lesser role in aggregate economic activity and contribute less to overall exposure, seem to have higher relative local exposure. For example, while the Savinjska region does not contribute most to the overall exposure under the severe scenario, as it does under the moderate and catastrophic scenarios (see appendix), the share of the region's value-added and employment exposure appears more significant.

To be more precise, the occurrence of the severe scenario in the Savinjska region would imply exposure in the amount of 12.2% and 14.1% of its value-added and employment, respectively. Furthermore, the Koroška region exhibits even higher exposure, with such floods putting 13.1% of its value-added at risk. While Koroška's regional exposure is notable, its limited aggregate contribution results from its minor role in the structure of the Slovenian economy. To phrase it differently, the realisation of the severe scenario in regions that have a limited impact on the aggregate perspective might have severe local consequences, whereas the direct impact on aggregate activity resulting from such a shock could be manageable or even negligible from a macroeconomic standpoint. This was evident in the recent August flood episode where, despite the substantial impact on activity in the most affected areas, the ramifications appeared manageable at the aggregate level.[4]

Figure 4: **Regional exposure under the severe flood scenario (%)**



Note: The figure illustrates the share of directly exposed employment, value-added, and credit portfolio at the regional level.
Source: AJPES, Slovenian Water Agency.

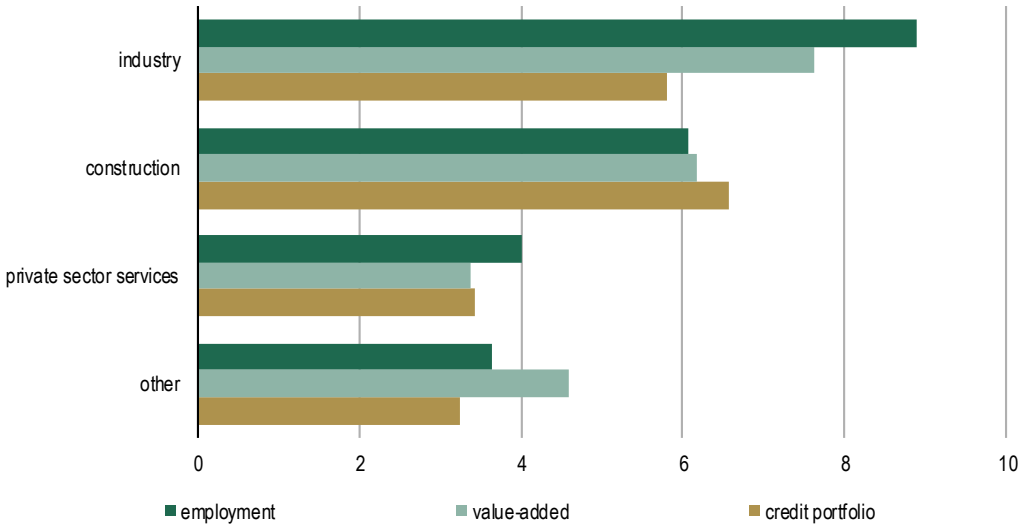
While exposure under the severe scenario is, as expected, larger than under the moderate, the sectoral heterogeneity appears somewhat smaller. In other words, while

[4] See Box 3.3 of the September 2023 issue of the Review of Macroeconomic Developments provided by Banka Slovenije, which addresses the impact of extreme weather events on macroeconomic activity in Slovenia.

companies classed as industry were both the most exposed and the largest contributors under the moderate scenario, the increase in the expected flood intensity altered this slightly. While they remained the largest contributors and the most exposed, with 8.9% and 5.8% of employment and credit exposure directly at risk of floods, respectively, the relative spread across sectors narrowed.

For example, the results show that 7.6%, 6.2%, and 3.4% of value-added would be exposed in industry, construction, and private sector services under the severe scenario, compared with 2.9%, 1.4%, and 0.5% under the moderate scenario, respectively. The latter indicates that the sectoral exposure, while lower in magnitude, exhibited larger heterogeneity under the moderate scenario. Note that the exposure across sectors narrows even further under the catastrophic scenario (see the appendix for a detailed discussion of the results from the moderate and catastrophic scenarios).

Figure 5: **Sectoral exposure under the severe scenario (%)**



Note: The figure illustrates the share of directly exposed employment, value-added, and credit portfolio at the sectoral level.
Source: AJPES, Slovenian Water Agency.

3 Conclusion

As climate change is expected to increase the frequency and intensity of extreme weather events in the future, the assessment of physical risks is becoming increasingly important for central banks to ensure the fulfilment of their price and financial stability mandates. The results of this paper represent an important milestone in understanding a country's vulnerability to floods from an economic perspective, and underscore the significance of micro-location in understanding the physical risks stemming from climate change.

They demonstrated that although the exposure may seem limited from an aggregate perspective, with approximately 6% of value-added and employment at risk under the severe scenario, a geographical drilldown reveals substantial heterogeneity. For instance, in Koroška, the most exposed region under this scenario, 14.1% of employment

is at risk, but its contribution to the overall exposure appears relatively limited at 0.3 percentage points. In other words, while local realisation of the severe scenario (i.e. in one region only) would likely cause a significant shock in the affected region, the aggregate impact would probably be limited, masking the true extent of the catastrophe at the local level. To some extent this was evident in the August flood episode in Slovenia. While the affected areas were devastated, its aggregate ramifications appeared manageable from a macroeconomic perspective.

Finally, an established database that incorporates flood hazard maps, corporate headquarters location data, corporate financial information, and credit exposure to Slovenian banks presents a unique opportunity for future research. This entails the ability to evaluate the repercussions of physical risks associated with climate change, extending beyond exposure assessment, encompassing both macroeconomic and financial stability perspectives. While the analysis in this paper does not venture into this domain, the results can nonetheless serve as a valuable foundation for such future research initiatives.

4 References

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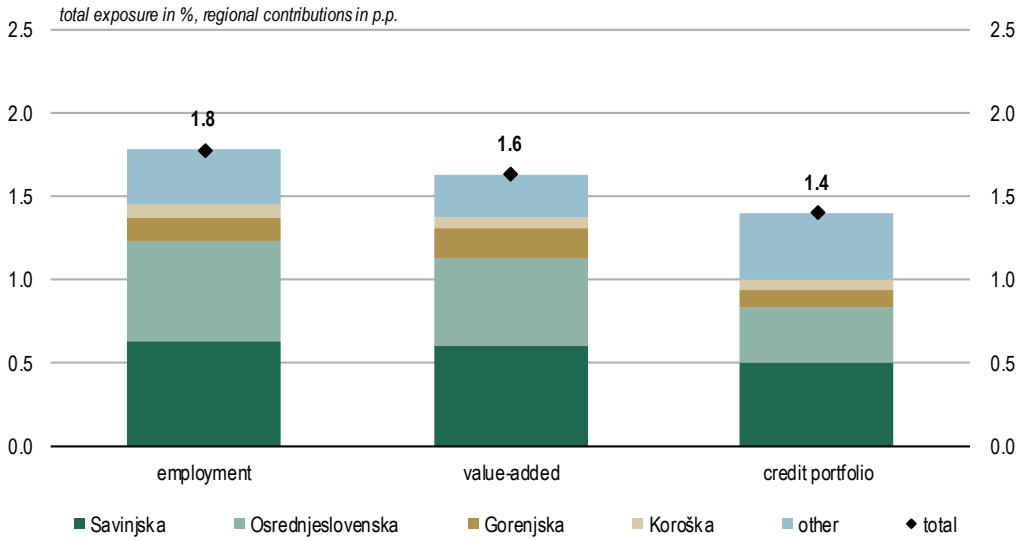
5 Appendix

The appendix opens with a discussion of the moderate scenario, followed by the catastrophic scenario, before discussing a separate decomposition that analyses the contributions of manufacturing subsectors to overall flood exposure.

5.1 Moderate scenario

The regional breakdown of the moderate scenario as illustrated in Figure 6 is presented first. The results indicate that its realisation should be manageable from a macroeconomic perspective, given the limited exposure. Approximately 1.8% and 1.6% of the employment and value-added of Slovenian private enterprises, respectively, and 1.4% of credit exposure may potentially be directly exposed to floods under this scenario. It is worth noting that the majority of this exposure is concentrated in the Savinjska and Osrednjeslovenska regions, with each contributing approximately 0.6 percentage points to the overall exposure of value-added and employment.

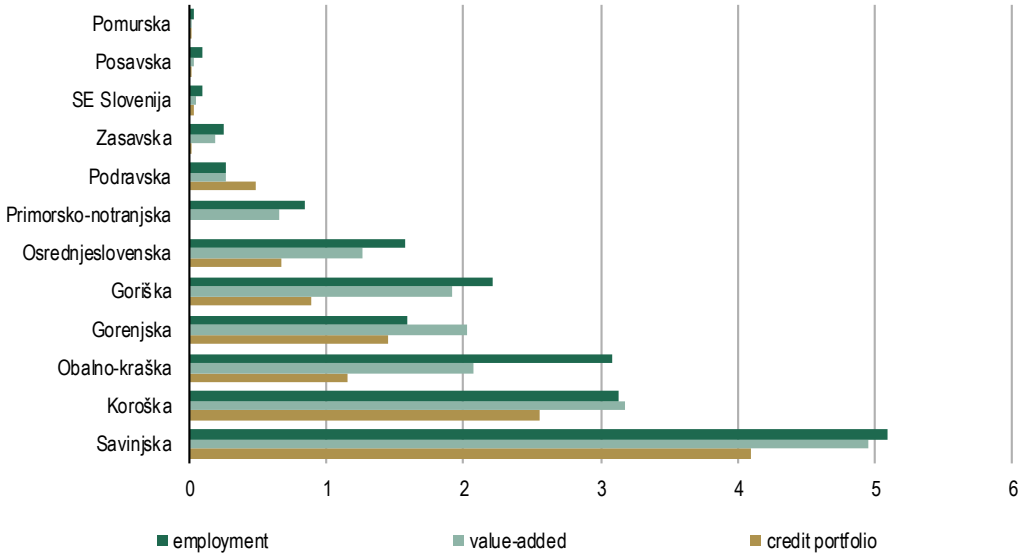
Figure 6: **Decomposition of regional exposure under the moderate scenario**



Note: The figure illustrates the regional breakdown of the share of exposed employment, value-added, and credit portfolio of Slovenian banks.
Source: AJPES, Slovenian Water Agency.

Figure 7 provides further confirmation of the low vulnerability under the moderate scenario by presenting the exposed share of each analysed variable at the regional level. The results show that relative regional exposure is largely limited below 2% for all three analysed variables, with the exception of the Savinjska and Koroška regions, where it reaches 4.9% and 3.2% of total value-added, respectively.

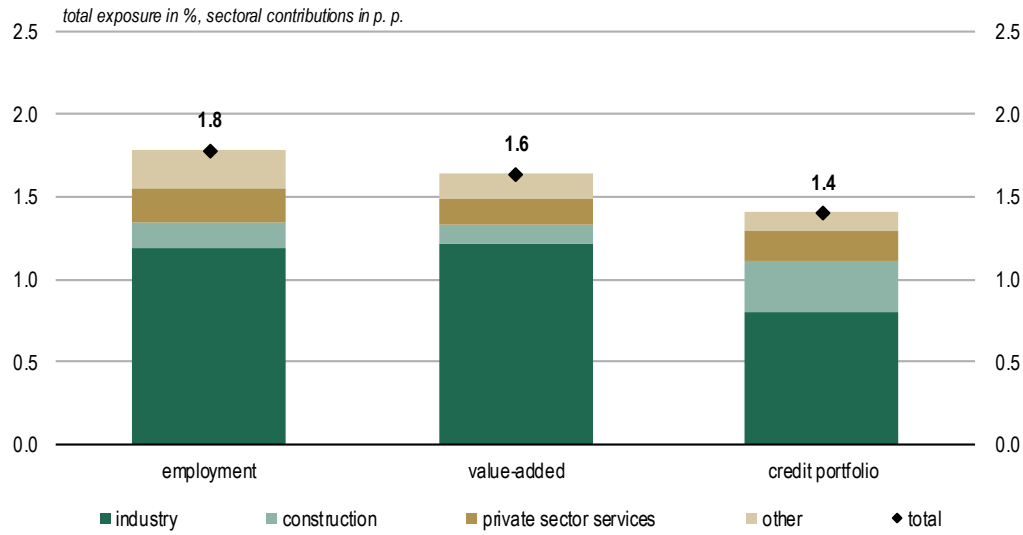
Figure 7: **Regional exposure under the moderate scenario (%)**



Note: The figure illustrates the share of directly exposed employment, value-added, and credit portfolio at the regional level.
Source: AJPES, Slovenian Water Agency.

Figure 8 displays the sectoral decomposition, and highlights the heterogeneity under the moderate scenario. While the overall exposure appears limited from a macroeconomic standpoint, the contribution of industry stands out. It accounts for over half of the total value-added and employment of Slovenian private enterprises exposed under this scenario.

Figure 8: **Decomposition of sectoral exposure under the moderate scenario**

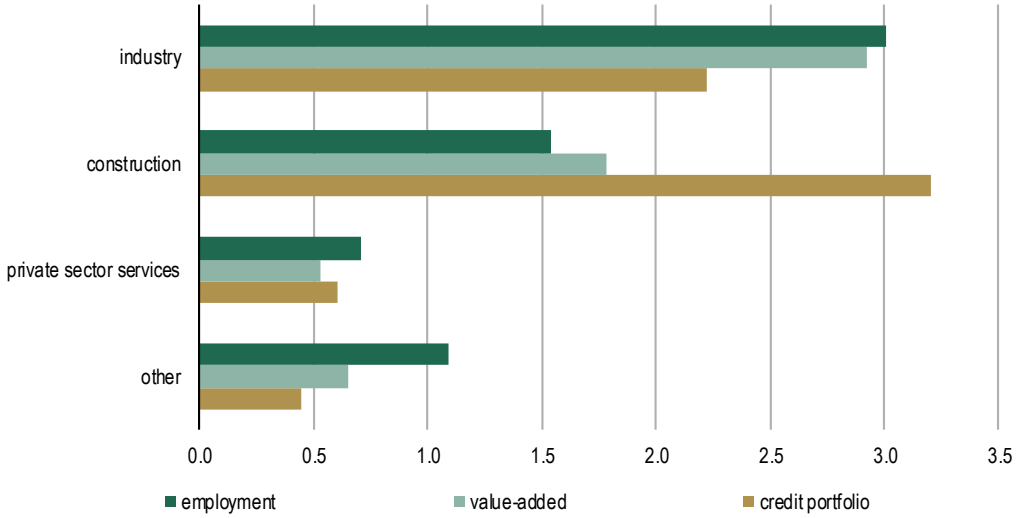


Note: The figure illustrates the sectoral breakdown of the share of exposed employment, value-added, and credit portfolio.
Source: AJPES, Slovenian Water Agency.

Figure 9 further confirms that under the moderate scenario, it is industry's exposure that stands out. Specifically, almost 3% of its employment and value-added could be affected. By contrast, exposure in construction – the second most exposed sector as measured by these two metrics – tops out at less than 1.5%. A closer examination reveals that manufacturing is particularly exposed within industry. Note that the results of the severe scenario, as presented in the main body of the paper, and the results of the catastrophic scenario, which will be discussed next, indicate that more intensive

scenarios increase the overall sectoral exposure while reducing exposure heterogeneity across sectors.

Figure 9: **Sectoral exposure under the moderate scenario (%)**

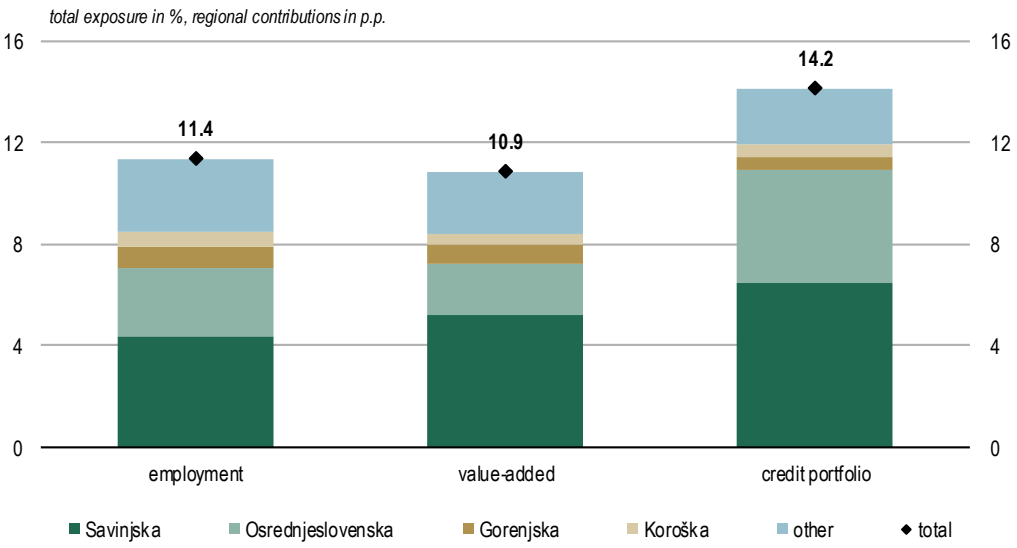


Note: The figure illustrates the share of directly exposed employment, value-added, and credit portfolio at the sectoral level.
Source: AJPES, Slovenian Water Agency.

5.2 Catastrophic scenario

The next section focuses on the findings concerning the catastrophic scenario. As the name suggests, its occurrence would carry significant implications for both Slovenian society and the economy, given the extensive exposure. Overall, the occurrence of floods with a 500-year return period, combined with catastrophic floods outside the IFHM area of application, would impact more than a tenth of the employment and value-added of Slovenian private enterprises. The results also suggest that approximately 14% of credit exposure of Slovenian banks to Slovenian private enterprises would be at risk. Regional heterogeneity is particularly evident in this case, as the majority of exposure is concentrated in two regions, namely Osrednjeslovenska and Savinjska, with the latter accounting for almost half of the total exposed value-added (see Figure 10).

Figure 10: **Decomposition of regional exposure under the catastrophic scenario**

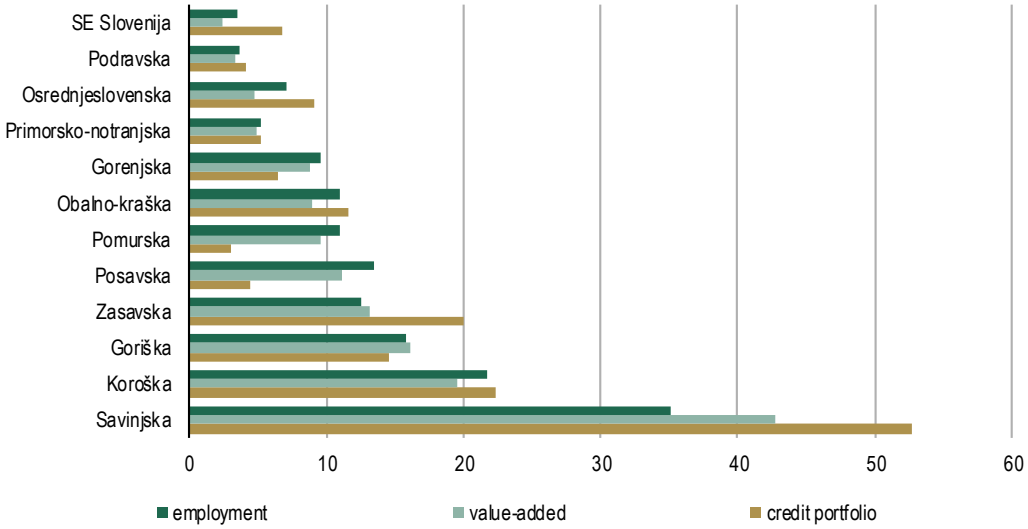


Note: The figure illustrates the regional breakdown of the share of exposed employment, value-added, and credit portfolio of Slovenian banks.
Source: AJPES, Slovenian Water Agency.

Figure 11 delves further into the challenge of regional heterogeneity. It shows that the Savinjska region is particularly exposed to flood risk, with more than two-fifths of value-added and 35% of employment at private enterprises at risk in the region should the catastrophic scenario materialise. Similarly, approximately one-fifth of employment and value-added would be exposed to flood risk in the Koroška region.

By contrast, exposure in other regions is more limited. The results show that the realisation of a catastrophic scenario would affect less than a tenth of value-added in seven out of the twelve Slovenian statistical regions, with exposure in the Podravska and South-East Slovenia regions being less than 4%. In other words, the substantial exposure under the catastrophic scenario stems from a small number of regions, emphasising the crucial role of micro-location and regional heterogeneity in assessing the vulnerability of the Slovenian economy to floods (see Figure 11).

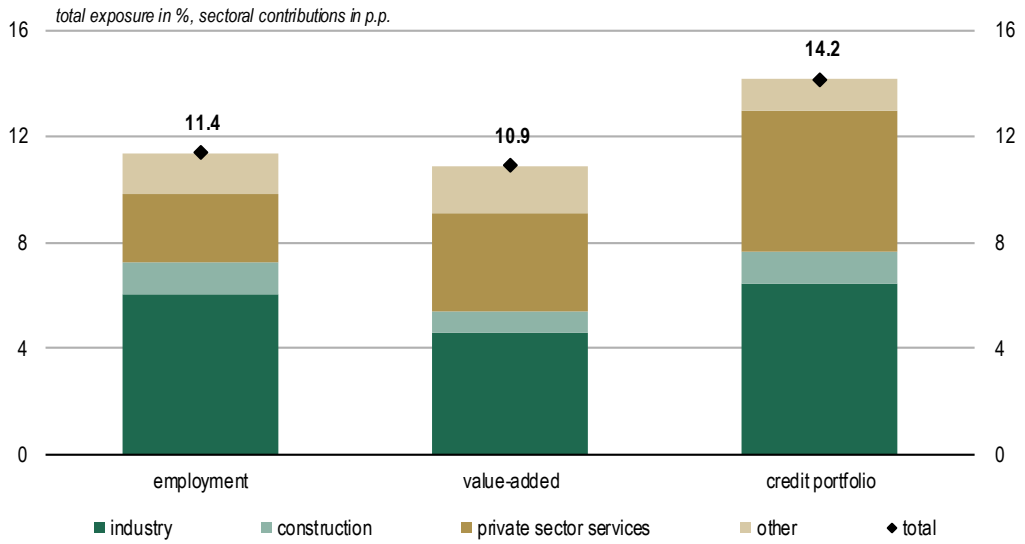
Figure 11: **Regional exposure under the catastrophic scenario (%)**



Note: The figure illustrates the share of directly exposed employment, value-added, and credit portfolio at the regional level.
Source: AJPES, Slovenian Water Agency.

The sectoral decomposition of the catastrophic scenario reveals that once again industry contributes the most to the overall exposure, accounting for 6.0 and 4.6 percentage points of the total exposed employment and value-added, respectively. Just as under the severe and moderate scenarios, manufacturing accounts for the majority of the exposure within industry. It should however be noted that the share of total exposure accounted for by private sector services is larger than under the previous two less-intensive scenarios (see Figure 12).

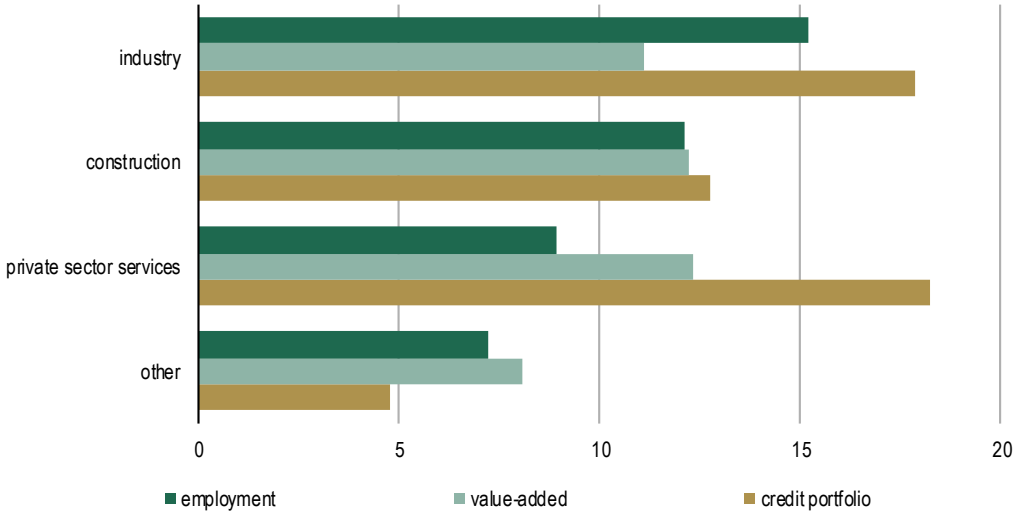
Figure 12: **Decomposition of sectoral exposure under the catastrophic scenario**



Note: The figure illustrates the sectoral breakdown of the share of exposed employment, value-added, and credit portfolio.
Source: AJPES, Slovenian Water Agency.

While Figure 13 shows that the share of exposed employment remains highest within industry, the same cannot be said for value-added. The exposure of the latter is highest within private sector services and construction, where the catastrophic flood scenario could impact approximately 12.3% of value-added, compared with approximately 11.1% of value-added in industry. Overall the exposure appears more homogeneous across sectors under this scenario. Industry's largest contribution to the overall exposure can therefore once again be attributed to its relative importance in the structure of the Slovenian economy.

Figure 13: **Sectoral exposure under the catastrophic scenario (%)**



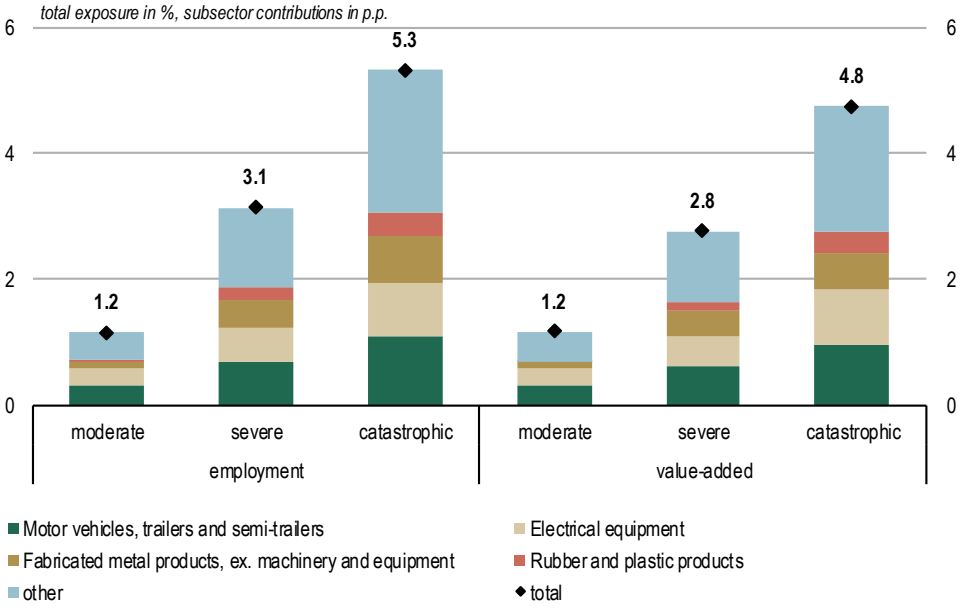
Note: The figure illustrates the share of directly exposed employment, value-added, and credit portfolio at the sectoral level.
Source: AJPES, Slovenian Water Agency.

5.3 Manufacturing-specific exposure assessment

Finally, the substantial vulnerability of the manufacturing sector to flood risk calls for a more in-depth examination to understand the distribution of exposure within the sector. As depicted in Figure 14, a significant portion of its exposure can be attributed to a few specific subsectors. Under the catastrophic scenario, the top four most-exposed collectively account for nearly 60% of the total exposed value-added within manufacturing.

The exposure of the rest of the manufacturing sector, represented by the category of "other", is distributed more evenly across the remaining subsectors. Overall, the results indicate a similar distribution of exposed employment and value-added across scenarios in the manufacturing sector. Approximately 1% would be impacted under the moderate scenario, while exposure would increase to approximately 3% and 5%, respectively, under the severe and catastrophic scenarios.

Figure 14: **Manufacturing subsectors' contributions to exposed employment and value-added**



Note: The figure illustrates how individual manufacturing subsectors contribute to the overall exposed employment and value-added.
Source: AJPES, Slovenian Water Agency.

Analysis of the contributions by individual manufacturing subsectors reveals that under the catastrophic scenario the manufacture of motor vehicles, trailers, and semi-trailers (C29) adds the most (1 percentage point) to the overall exposed value-added. This is followed by respective contributions of 0.9, 0.6, and 0.3 percentage points by the manufacture of electrical equipment (C27), the fabrication of metal products, except machinery and equipment (C25), and the manufacture of rubber and plastic products (C22).