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Subject: Response letter to review of referee #1 on manuscript titled: "Split incentives in property-level flood adaptation across households, insurers and government in the Netherlands"

Dear anonymous referee,

Thank you for your constructive comments which have helped to improve our manuscript. We appreciate your time, effort and support. The referee comments are structured around seven paragraphs, we structured our reply in the same manner to address each paragraph.

Referee comment: The manuscript assumes universal insurance coverage for the sampled properties, with insurers covering 90% of structural and 80% of contents damage for precipitation and regional flooding, while the government is assigned 90% of damages from primary-defence failures. However, the authors acknowledge that approximately 10% of households have no flood coverage and that Wts compensation is discretionary; they also note that only approximately 60% of damage was covered by insurance and government compensation combined during the 2021 Limburg floods. These assumptions are especially important because the manuscript's main conclusion is that the household-only adaptation budget is approximately an order of magnitude lower than the three-stakeholder coalition budget. Since households are assigned only 10–20% of much of the damage by construction, part of this result follows directly from the allocation assumptions. The robustness analysis varies hazard and vulnerability models but keeps these institutional parameters fixed. I strongly recommend adding an institutional sensitivity analysis varying at least insurance take-up, reimbursement rates, deductibles, and Wts compensation/activation. The authors should then demonstrate whether the magnitude of the split-incentive remains similar under plausible alternative institutional configurations.

Authors' reply: The current sensitivity analysis is focused on the hazard and vulnerability method, and not so much on the institutional component. In the revised manuscript, we will extend it in two directions.

The extended sensitivity analysis will consist of two parts. In the first part, we will analyse the hazard and vulnerability components to obtain distributions of EAD. Using a Monte Carlo analysis, we will calculate variants to present the uncertainty around our EAD numbers. The second part will focus on the coalitions needed to cross the adaptation budget threshold of EUR 800 for minor adaptation. We will vary institutional parameters along the dimensions suggested by the referee: the uninsured fraction, the insurance coverage rate, and the activation of the public compensation backstop (Wts). For each configuration, we will evaluate whether the household-only budget, the insurer-household coalition, and the three-way coalition cross the adaptation threshold, and in which percentile band they do so

Referee comment: The manuscript deliberately couples the standard primary-defence method with the upper-bound precipitation interpretation and BREACH with the lower-bound interpretation, while the basis scenario combines an arithmetic average of the defence methods with the precipitation midpoint. The stated reason is to reduce the complete analysis from 27 combinations to nine. This coupling is problematic because the two uncertainty sources are conceptually independent. Pairing high-with-high and low-with-low creates constructed corner cases and prevents the reader from determining whether uncertainty originates from defence-failure probability, precipitation-depth discretisation, or their interaction. This is particularly important because the manuscript subsequently concludes that hazard uncertainty exceeds vulnerability uncertainty in 2025. I recommend evaluating the complete factorial combination. With approximately 13,000 properties, 27 combinations do not appear excessive relative to the importance of the uncertainty analysis. If the authors retain the reduced design, a much stronger statistical and conceptual justification is required, and the resulting scenarios should be described explicitly as bounding scenarios rather than alternative methods of equal standing.

Authors reply: We agree with the referee that the manuscript insufficiently justified the coupling. The two hazard uncertainty sources work via disjoint flood source pathways. The assessment approach (standard method vs. BREACH) sets failure probabilities for flood defences and thus governs EAD from breach-related flood sources only. The precipitation class interpretation (upper vs. lower bound) determines pluvial water depths and governs EAD from the precipitation source only. No single flood source is influenced by both in our modelling. The interaction term between the two factors is therefore zero by construction/design, and the nine existing coupled scenarios already span the full (factorial) range. A 27-combination table would confirm this but would not reveal additional information about the uncertainty structure. We will make this more explicit in the revised manuscript.

What the original manuscript did lack is a decomposition of the hazard uncertainty into its two constituent sources, one arising from the defence-breach probabilities, the other from the bounds of the precipitation classes. We will report this decomposition in the extended sensitivity analysis, separating the contribution from defence-breach probabilities and from the precipitation-class bounds.

Referee comment: The national pluvial maps contain the classes 0.05–0.10, 0.10–0.15, 0.15–0.20, 0.20–0.30, and >0.30 m. The manuscript then states that lower-bound, midpoint, and upper-bound values were evaluated for each class, while simultaneously acknowledging that the fifth class is unbounded. It is mathematically impossible to define a midpoint or upper bound for an unbounded class without an additional assumption. The exact numerical values assigned to the >0.30 m category must therefore be reported and justified. This issue may be particularly influential because precipitation dominates the upper-risk tail in the 2050 scenario.

Authors' reply: The values assigned to the >0.30 m class are: lower bound 0.30 m, midpoint 0.40 m, upper bound 0.50 m. We will report these explicitly in the revised manuscript.

The upper bound of 0.50 m is based on Deltares (2018), which reports local pluvial maxima of 0.5 to 0.6 m for the 1-in-100-year event in lowland areas. Higher values (up to 1.5 m) occur only in steeply sloping terrain such as South Limburg, which represents a small fraction of the national housing stock and of our sample. As we have a lowland-dominated sample used here, we chose 0.50 m as a defensible upper bound. Ideally, we would rely on raster maps with the actual modelled values and not classes, but this map is not available.

Referee comment: The study excludes all 5 km × 5 km cells containing fewer than 300 dwellings before sampling. This procedure could systematically underrepresent rural and low-density areas, and these areas may differ in building characteristics, elevation, flood exposure, and availability of collective drainage infrastructure. Provincial proportionality alone does not demonstrate representativeness within provinces. Please report the number and proportion of national dwellings excluded by the 300-dwelling threshold, compare the sampled and national housing stocks on relevant characteristics, and explain whether sampling weights are required. Otherwise, the wording “representative sample” should be qualified.

Authors’ reply: We will elaborate a bit more on the exclusion of dwellings in rural areas/cells. The 300-dwelling threshold removed 397 of 1,818 cells, containing 34,160 dwellings (0.4% of the national housing stock). In addition, 213 eligible cells with 300 to 655 dwellings (99,685 dwellings, 1.2%) received no sample location because of the integer allocation. The cells that contribute at least one location therefore cover 98.4% of the national housing stock, excluding 1.6% of the national building stock.

Comparing the sample with the national stock (Table below), construction year, floor area, dwelling type and local density all agree within about one percentage point. The unsampled dwellings are a distinct rural population (92% single-family, older, larger), but AHN and flood maps show they lie higher (median 4 m NAP versus 2 m) and are less flood-exposed (fluvial 42 - 43% versus 52-54%; pluvial 46 - 55% versus 77% for the T1000 ≥ 0.20 m class).

Sampling weights are not required. We verified this in two ways. First, because the sample allocates about one location per 655 dwellings in every cell, selection probabilities are nearly equal, so reweighting the sample (for example by the design probabilities or by post-stratifying to the national dwelling-density distribution) leaves the national mean baseline EAD, adaptation effectiveness and stakeholder shares essentially unchanged. Second, the excluded 1.6% of the stock cannot be reweighted because they are not included in the data. Even in the extreme cases where these dwellings had no flood risk, or twice the national average, the national mean changes by only about 1.5%.

Characteristic	National stock	Sample	Unsampled cells
Dwellings	8,602,703	13,122	133,845 (1.6%)
Median construction year	1977	1978	1962–1970
Built before 1945	17.7%	17.0%	29–34%
Built 2000 or later	22.1%	22.2%	16–18%
Median floor area (m²)	105	105	146–162
Single-family dwellings	62.2%	62.0%	92%
Median dwelling density (km⁻², within 1 km)	1,562	1,567	30–93
Median ground level (m NAP)	1.7	1.9	3.9–4.2
Ground level below NAP	26%	24%	15–17%
Non-zero LIWO max water depth, classes 1–5	54%	52%	42–43%

Referee comment: The adaptation budget is calculated using a fixed 10-year horizon and 2.8% real discount rate, producing an annuity factor of 8.62. The conclusion that adaptation becomes financially relevant only above approximately the 80th percentile depends directly on this factor. I recommend showing sensitivity to reasonable combinations of measure lifetime and discount rate, for example shorter and longer lifetimes. The comparison between adaptation budgets and engineering cost ranges should also ensure consistent price years and comparable adaptation configurations.

Authors' reply: This comment is addressed together with the next paragraph, which raises the same points and adds a related question on individual property budgets. See our reply below.

Referee comment: The adaptation budget is calculated using a fixed 10-year horizon and 2.8% real discount rate, producing an annuity factor of 8.62. The conclusion that adaptation becomes financially relevant only above approximately the 80th percentile depends directly on this factor. I recommend showing sensitivity to reasonable combinations of measure lifetime and discount rate, for example shorter and longer lifetimes. The comparison between adaptation budgets and engineering cost ranges should also ensure consistent price years and comparable adaptation configurations. Relatedly, because the manuscript studies property-level decision-making, reporting only mean budgets within broad percentile bands may obscure considerable heterogeneity. The authors should consider reporting the percentage of individual properties for which the coalition budget exceeds representative cost thresholds, rather than relying primarily on band means. This would provide a more policy-relevant measure of adaptation viability.

Authors' reply: We will include this in the extended sensitivity analysis. We varied the effective measure lifetime over 5, 10 and 15 years and the discount rate over 1.5%, 2.8% and 4.5%, bracketing the central values of 10 years and 2.8%. Because the budget is linear in the annuity factor, varying these parameters rescales every budget proportionally. The annuity factor spans 4.4 to 13.3 across this range, against a central value of 8.6.

The central conclusion holds. In no combination does any individual or coalition budget exceed the adaptation budget threshold below P80. The three-way coalition first crosses EUR 800 in the P80-P90 band, and only for lifetimes of ten years or more; at a five-year lifetime the crossing shifts to P90-P95. The insurer-only budget, the largest single-stakeholder budget, first crosses EUR 800 in the P90-P95 band and only at a 15-year lifetime. At the central 10-year lifetime it requires the top 1%.

In response to the referee's suggestion on within-band heterogeneity, we now report the percentage of individual properties for which the coalition budget exceeds the EUR 800 cost floor, rather than relying on band means alone.

Referee comment: The EAD formulation integrates damage only from zero probability to the probability of the most frequent modelled flooding scenario. For precipitation, the most frequent mapped design event has a 10-year return period. The analysis therefore appears to assume zero relevant property damage from events more frequent than the most frequent modelled scenario. This assumption should be stated explicitly and justified. If more frequent pluvial events can produce non-zero property damage, excluding this portion of the probability curve could underestimate EAD, particularly for insurer-covered precipitation losses. Table 3 defines the maximum adaptation configuration as 0.8 m dry-proofing with a 50% wet-proof reduction, and the results and Table 5 also refer to an 80 cm barrier with 50% residual damage reduction. However,

the Figure 2 caption describes the maximum configuration as 50 cm dry-proofing with 50% contents protection. The authors need to confirm exactly which configuration was implemented in the calculations and make the method, figures, captions, and tables consistent. The distinction between reducing "contents damage" and reducing "residual damage" is also substantive rather than merely editorial. A related inconsistency concerns the 0.20 m floor-height correction. The methods state that all simulated water depths were reduced by 0.20 m, whereas the Results refer to a "0.20 m precipitation height correction." Please clarify whether the correction applies to every hazard source or only precipitation. There are also several smaller presentation issues. For example, the hazard-method section states that the API combines "three flood sources" but then lists precipitation, regional water-system overflow, regional-defence breaches, primary-defence breaches, and high water in unembanked areas. The terminology and number of flood sources should be made consistent throughout the paper. In the abstract, "with the top 5% of properties carry more than half" should be corrected to "with the top 5% of properties carrying more than half."

Authors' reply:

About the EAD integration range. The referee is correct that events more frequent than T10 (the most frequent modelled precipitation scenario) are excluded. This truncation has a negligible effect on the EAD: at T10, precipitation-driven inundation is either absent or generally shallower than 20 cm, so after the 0.20 m floor-height correction these events contribute little or no property damage. We now state this explicitly in the methods and note the implication for insurer-covered pluvial losses.

Maximum adaptation configuration. We thank the referee for spotting the inconsistency. The implemented maximum configuration is 80 cm threshold and 50% residual. We will make the methods, Figure 2 caption, Table 3, Table 5, and the results text consistent. We will correct the Figure 2 caption to refer to residual-damage reduction rather than contents-damage reduction.

About the water depth floor-height correction. The 0.20 m correction applies to all flood sources, not precipitation alone. We will correct the wording in the results (previously "precipitation height correction") and will make this explicit in the methods. We will consistently describe three sources: precipitation; flooding from the primary water system (breaches in primary defences and high water in unembanked areas); and flooding from the regional water system (breaches in regional defences and regional water-system overflow).

We will correct the abstract to "with the top 5% of properties accounting for more than half."