The use of insurance to improve flood resilience

1. Introduction ............................................................................................................. 1
   1.1 Flood risk modelling: an overview ................................................................. 3
   1.2 Managing natural disaster risk ...................................................................... 5
      1.2.1 Natural disaster risk reduction ................................................................. 5
      1.2.2 Natural disaster risk transfer ................................................................. 6
      1.2.3 Combining natural disaster risk reduction and risk transfer .............. 8
   1.3 This thesis’s research questions ................................................................... 13
   1.4 The data and methodology employed ......................................................... 14

2. Chapter 2: Impacts of flooding and flood preparedness on subjective well-being: A monetisation of the tangible and intangible impacts .......... 19
   2.1 Introduction ..................................................................................................... 20
   2.2 Data and methodology .................................................................................... 21
      2.2.1 Survey and data description ................................................................. 21
      2.2.2 Methodology .......................................................................................... 26
   2.3 Results and discussion .................................................................................... 30
      2.3.1 Results and discussion .......................................................................... 30
      2.3.2 Comparison with existing studies ......................................................... 33
      2.3.3 Policy implications ............................................................................... 36
      2.3.4 Sensitivity analysis ............................................................................... 37
   2.4 Conclusion ....................................................................................................... 39

3. Chapter 3: Evaluating the effectiveness of household level flood risk reduction measures by the application of Propensity Score Matching .......... 41
   3.1 Introduction ..................................................................................................... 42
   3.2 The propensity score matching method ......................................................... 46
   3.3 Data .................................................................................................................. 52
      3.3.1 Survey description ............................................................................... 52
<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.2</td>
</tr>
<tr>
<td>3.4</td>
</tr>
<tr>
<td>3.4.1</td>
</tr>
<tr>
<td>3.4.2</td>
</tr>
<tr>
<td>3.5</td>
</tr>
<tr>
<td>3.5.1</td>
</tr>
<tr>
<td>3.5.2</td>
</tr>
<tr>
<td>3.6</td>
</tr>
<tr>
<td>4.</td>
</tr>
<tr>
<td>4.1</td>
</tr>
<tr>
<td>4.2</td>
</tr>
<tr>
<td>4.2.1</td>
</tr>
<tr>
<td>4.2.2</td>
</tr>
<tr>
<td>4.3</td>
</tr>
<tr>
<td>4.3.1</td>
</tr>
<tr>
<td>4.3.2</td>
</tr>
<tr>
<td>4.3.3</td>
</tr>
<tr>
<td>4.4</td>
</tr>
<tr>
<td>4.4.1</td>
</tr>
<tr>
<td>4.4.2</td>
</tr>
<tr>
<td>4.4.3</td>
</tr>
<tr>
<td>4.4.4</td>
</tr>
<tr>
<td>4.4.5</td>
</tr>
<tr>
<td>4.4.6</td>
</tr>
</tbody>
</table>
4.5 Conclusion ................................................................................................................................. 109

5. Chapter 5: Incentivising flood risk adaptation through risk-based insurance premiums - Trade-offs between affordability and risk reduction. 113

5.1 Introduction .............................................................................................................................. 114

5.2 Methods: Integrated insurance, household flood preparedness and flood risk model .......................................................................................................................... 116

5.2.1 Insurance model .................................................................................................................. 116

5.2.2 Behavioural model of household flood risk adaptation investments .......................................................................................................................... 126

5.3 Results .................................................................................................................................. 131

5.3.1 Risk-based flood insurance premiums .............................................................................. 131

5.3.2 Household-level adaptation: investments in flood risk reductions ................................ 133

5.3.3 Affordability of the risk-based priced insurance and insurance vouchers ....................... 138

5.3.4 Sensitivity analysis ............................................................................................................. 139

5.4 Discussion ............................................................................................................................... 142

5.4.1 Premiums, flood risk adaptation, and insurance vouchers under the proposed insurance scheme in Germany ................................................................. 142

5.4.2 Premiums, flood risk adaptation, and insurance vouchers under the proposed insurance scheme in France ................................................................. 144

5.4.3 A comparison of changes in flood risk over time and household-level adaptation between Germany and France ........................................................................... 144

5.4.4 Practical considerations for insurance related financial incentives for risk reduction ........................................................................................................... 146

5.5 Conclusion ............................................................................................................................... 147

6. Chapter 6: Efficient and equitable flood insurance market structures under climate change ........................................................................................................... 150

Abstract ....................................................................................................................................... 150
LIST OF FIGURES

Figure 1.1 An example of a probability-exceedance curve .......................... 4
Figure 1.2 Work scheme of this thesis .................................................. 18

Figure 2.1 Visualization of this chapter’s methodology ................................ 30

Figure 3.1 An example of a common support ......................................... 48
Figure 3.2 A map of the survey locations and river catchment areas .......... 52

Figure 6.1 Flow chart of the Dynamic integrated flood and insurance (DIFI) model version 1.0 modelling scheme ......................................................... 154
Figure 6.2 Market structure reforms suggested by the DIFI model results for the period 2035-2055 .............................................................. 174
Figure 6.3 Example consequences of the insurance market reforms suggested by the DIFI model results for the period 2035-2055 ...................... 175

Figure 9.1 Share of total national income earned by the $n^{th}$ quantile of income (left); Income of the $n^{th}$ quantile (right) ............................................. 237
LIST OF TABLES

Table 2.1 List of variable definitions ........................................................................................................ 24
Table 2.2 Summary of descriptive statistics of key variables ................................................................. 25
Table 2.3 Estimated parameters of the regression models ....................................................................... 32
Table 2.4 Characteristics and results of other studies, which examined the impacts on subjective well-being or compensating variation of floods or other major life events ......................................................................................................................... 35
Table 2.5 The estimated compensating value required to compensate for changes in subjective well-being due to flood experiences, risk perceptions, or preparedness decisions ......................................................................................................................... 36

Table 3.1 Flood risk reduction measures ................................................................................................. 54
Table 3.2 Estimates of the effectiveness of private disaster risk reduction [in euros] .............................. 57
Table 3.3 Sensitivity analysis .................................................................................................................. 61

Table 4.1 Probit model results of the relationship between any flood risk reducing behaviour and flood insurance coverage for Germany ........................................... 91
Table 4.2 Probit model results of the relationship between any hurricane risk reducing behaviour and insurance coverage for the U.S. .............................................. 92
Table 4.3 Bivariate probit model results of the relationship between any flood risk reducing behaviour and flood insurance coverage for Germany........................................... 95
Table 4.4 Coefficient estimates of U.S. bivariate probit models ............................................................. 96
Table 4.5 Estimates of the difference in average flood damages due to having a flood insurance policy (in EUR). The average treatment effect on the treated (ATT) is estimated using Propensity Score Matching with different matching methods .............................................................................................................. 98
Table 4.6 Natural hazard summary statistics .......................................................................................... 99
Table 4.7 For those with homeowners insurance the relationship between the likelihood and number of preparation activities undertaken and deductible coverage ........................................................................................................... 104
Table 4.8 Estimates of the difference in average flood damages due to having a flood insurance policy (in EUR) for households located in the Elbe and Danube River catchment areas separately. The average treatment
effect on the treated (ATT) is estimated using Propensity Score Matching with different matching methods ................................................................. 105
Table 4.9 Difference in damage reduction measure usage between the insured and non-insured groups within the Elbe and Danube River catchment areas.................................................................................. 106
Table 4.10 Coefficient estimates of the U.S. bivariate probit models between knowing the size of the deductible and the employment of risk reducing measures .................................................................................. 108

Table 5.1 Features of a public-private flood insurance scheme .................. 120
Table 5.2 A summary of the benefits and costs of household flood risk reductions ........................................................................................................ 123
Table 5.3 Calibrated parameters of the Generalised Pareto distributions .... 129
Table 5.4 A summary of the estimated average insurance premiums (EUR/per year) for Germany and France in 2015 and 2040......................... 132
Table 5.5 Estimates of the average flood risk reduction due to household flood-proofing measures within French NUTS 2 regions, with and without financial incentives, under three risk perception scenarios ............... 136
Table 5.6 Estimates of the average flood risk reduction due to household flood-proofing measures within German NUTS 2 regions, with and without financial incentives, under three risk perception scenarios ................. 137
Table 5.7 Costs in Net Present Value (NPV) of an insurance voucher scheme to maintain insurance affordability .......................................................... 139

Table 6.1 Summary and definition of the evaluation criteria estimated by the DIFI model ................................................................................................. 153
Table 6.2 A summary of flood insurance structures to which European countries are allocated .................................................................................................. 160
Table 6.3 Estimated cost functions and cost surcharges ............................. 165
Table 6.4 Calibrated parameters of the Generalized Pareto distributions of subjective flood occurrence perceptions ............................................. 170

Table 7.1 Core implications emanating from this thesis ............................... 201
Table 9.1 Results of mean comparison tests, which examine differences between sample sub-groups in relation to key explanatory variables (in columns) ................................................................. 239

Table 9.2 Included confounders ................................................................. 240