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Strengthening insurance partnerships in the face of climate change – Insights from an agent-based model of flood insurance in the UK

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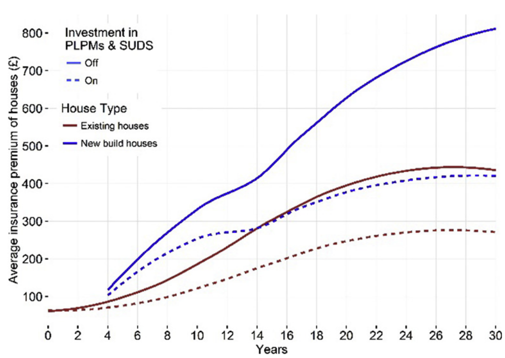
HIGHLIGHTS

- Local developer and local government actions have implications for Flood Re.
- Local government investment in SUDS and PLPMs reduces insurance premiums.
- Reducing insurance premiums and developing in flood risk areas require trade-offs.
- ABM a useful tool to investigate trade-offs in achieving aims of Flood Re.

GRAPHICAL ABSTRACT



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ABSTRACT

Multisectoral partnerships are increasingly cited as a mechanism to deliver and improve disaster risk management. Yet, partnerships are not a panacea and more research is required to understand the role that they can play in disaster risk management and particularly disaster risk reduction. This paper investigates how partnerships can incentivise flood risk reduction by focusing on the UK public-private partnership on flood insurance. Developing the right flood insurance arrangements to incentivise flood risk reduction and adaptation to climate change is a key challenge. In the face of rising flood risks due to climate change and socio-economic development insurance partnerships can no longer afford to focus only on the risk transfer function. However, while expectations of the insurance industry have traditionally been high when it comes to flood risk management, the insurance industry alone will not provide the solution to the challenge of rising risks. The case of flood insurance in the UK illustrates this: even national government and industry together cannot fully address these risks and other actors need to be involved to create strong incentives for risk reduction. Using an agent-based model focused on surface water flood risk in London we analyse how other partners could strengthen the insurance partnership by reducing flood risk and thus helping to maintain affordable insurance premiums. Our findings are relevant for wider discussions on the potential of insurance schemes to incentivise flood risk management and climate adaptation in the UK and also internationally.

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1. Introduction

The risk of climate-related disasters and associated economic losses has been increasing globally in the last few decades and will continue to

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do so as a result of climate change and socio-economic development (IPCC, 2012). To manage these risks and improve society's ability to prepare for, respond to and recover from disasters, there have been growing calls for greater collaboration and partnerships between the public, private and civil society sectors. These multisectoral partnerships (MSPs) are increasingly seen as critical for the delivery of sustainable development goals and improved disaster risk management (UNISDR (2011) and UN (2015)).

Despite the growing calls for partnerships, there has been little research examining how effectively they can help reduce the risk from disasters, the roles of public, private and civil society actors, and how they can act together. A critical issue is how to bring together those actors that can really bring about change. Furthermore, partnerships for disaster risk management are usually not static and may evolve over time, as they will be affected by a range of factors, including population growth, development trends and changing climate risks. This can have implications for the membership as new or different partners may be needed to fulfil the aims of a partnership.

In this paper, we investigate the role that partnerships can play in incentivising flood risk reduction by focusing on the arrangements between the UK government and the insurance industry. The flood insurance partnership between the Association of British Insurers (ABI) and the UK government was first established in 2000. It was modified into a new partnership in 2016 with the creation of Flood Re (outlined below), presented by industry and government as an innovative way of securing future affordability and availability of flood insurance. Yet, there are concerns about its ability to achieve its aim of providing a transition to a market with risk reflective pricing where insurance remains affordable and widely available (Hjalmarsson and Davey, 2016), especially because in its current set-up it does not provide any direct means to encourage risk reducing behaviour. Recognising its lack of potential to directly influence risk reduction, Flood Re identifies the need to build strong partnerships with a range of actors from the public, private and civil society sectors as a key strategy to ensure a successful transition phase (Flood Re, 2016).

This paper investigates this by focusing on partnerships with local government and property developers, and for one particular flood risk category, surface water (SW). This is the least understood of the flooding risks and represents one of the biggest potential impacts of climate change on the UK (Defra, 2012). SW flood risk management has been assessed by the UK's Committee on Climate Change as a key adaptation priority where insufficient progress has been made in managing vulnerability and providing a plan of action (Committee on Climate Change, 2015). An agent-based model (ABM), designed to simulate the dynamics of SW flooding, changing levels of risk and choices made by different partners (see Dubbelboer et al., 2017 for a detailed explanation of the technical aspects of model development and design) is used to explore how the flood insurance partnership could be strengthened. In particular, we investigate how the inclusion of other partners could enhance the risk reduction potential of insurance, testing this for the new Flood Re scheme; examine whether there may be trade-offs between the goals of maintaining affordable insurance premiums and reducing SW flood risk; and highlight complexities in identifying the most appropriate balance in the role of different partners to incentivise SW flood risk reduction.

2. The role of insurance partnerships in disaster risk reduction

In general terms, partnerships can be defined as "collaborative arrangements in which actors from two or more spheres of society (state, market and civil society) are involved in a non-hierarchical process, and through which these actors strive for a sustainability goal" (Van Huijstee et al., 2007, 77). Within the context of natural disasters, the overall shared goal for partnerships would be a reduction of risks and an increase in resilience. Nevertheless, having shared goals does not ensure the smooth running of a partnership, as partners may not attach the same importance to these goals. Indeed, while an insurance company may want to reduce risks, it is ultimately driven by profits and accountability to shareholders. Maintaining shared goals and priorities between partners over time, and reconciling diverging interests and expectations to limit potential conflicts are critical challenges (Armistead et al., 2007; Chen et al., 2013; Surminski and Leck, 2016).

Flood insurance partnerships have the primary aim of providing financial risk transfer for flood risk, for example in the absence of a functioning market. However, there are indications that these partnerships could also help to achieve a move away from a narrow financial risk transfer focus towards a more holistic and joint-up flood risk management strategy (European Commission (2013)).

In the wake of recent natural disasters there has been growing interest from policy makers, practitioners and academics in the use of insurance as an economic disaster risk management tool to encourage prevention efforts and reduce physical flood risk (Crichton, 2008; Surminski, 2014; Surminski et al., 2015). This is based on the understanding that purchasing an insurance product can influence the behaviour of those at risk. This can be in a moral hazard context where insurance can lead to more risky behaviour. For example, individuals' motives and behaviour to prevent loss may be reduced if financially protected through a policy; or the existence of an insurance scheme may reduce a government's urgency to prevent and reduce risks. Alternatively, purchasing an insurance product can act as an incentive, where insurance can trigger risk reduction investments or the implementation of prevention measures (Kunreuther and Michel-Kerjan, 2009; Kunreuther, 1996).

There is wide agreement that insurance can encourage risk reduction by attaching a price tag to risk and by sending signals to agents such as policy holders, governments or insurers themselves, incentivising or even forcing them to address the underlying risk (e.g. Kunreuther, 1996, Botzen and van den Bergh, 2009, Botzen and van den Bergh, 2009, Treby et al., 2006). Indeed, there are many flood risk management options that flood insurance could incentivise, including flood proofing of buildings and property, retrofitting of houses, local flood protection measures, and building larger scale flood protection schemes (Bräuninger et al., 2011).

However, evidence highlights that this incentive role is underutilized (Botzen et al., 2009; Lamond et al., 2009; Surminski, 2014; Surminski and Hudson, 2016). A range of barriers exist, including the absence of adequate risk-based pricing, mismatch between required prevention investment by policy holders and the premium savings; the short-term nature of insurance contracts; as well as a prevailing uncertainty about the benefits of risk reduction measures (Ball et al., 2013; Bräuninger et al., 2011). In response, there is growing focus on partnerships as a way to address at least some of these barriers. The European Insurance industry, for example, views partnerships as vital for reasons of insurability, risk transfer and ensuring the use of appropriate adaptation and prevention measures (CEA, 2007).

2.1. The evolving UK flood insurance partnership

The UK flood insurance partnership between the UK government and the ABI was set up in 2000 as the "Gentleman's Agreement" in the wake of growing flood losses. From 2005 it became known as the Statement of Principles (SoP). It sets out commitments from the insurance industry to provide flood insurance, and from government to support flood risk management and improve the quality of public flood risk data. In 2008, this agreement was extended for a final five-year period until 2013 and committed the government and insurance industry to a transition to a free market for flood insurance (Penning-Rowsell et al., 2014).

However, from 2010 onwards, sparked by concern about rising risk costs and the increasing frequency of high loss events, the insurance industry and government took steps to reach an understanding on how to replace the SoP. After a public consultation the government selected

Flood Re, a transitional arrangement designed to simultaneously support the private insurance industry and promote the affordability of flood insurance. After receiving state aid approval and securing an exemption statement from the Secretary of State, justifying the policy intervention despite not meeting cost-benefit targets, Flood Re gained parliamentary approval in 2014 (Surminski and Eldridge, 2017) and started operations in April 2016.

The scheme works by giving insurers the option of reinsuring policies with Flood Re at a highly-discounted price. The subsidy is collected as a levy from insurers, who may pass on the levy to policyholders (estimated to be £10.50 per policy (Aviva, 2016)). The discounted price for a policy is calculated based on the council tax banding of the insured property; the more affluent the council tax banding, the higher the price. As insurers can pass on their risk for a reduced price, they can charge lower premiums to high risk policyholders (Flood Re, 2016). Homes are eligible for Flood Re regardless of their flood risk. However, properties build after 2009 are excluded, as are small and medium-sized enterprises (Defra, 2013). Fig. 1 outlines the mechanics of Flood Re and the relationship between government and industry.

In the long-term, Flood Re's key objective is to provide a smooth transition to a free market that applies risk reflective pricing. However, to achieve this a combination of amending premium thresholds and reducing flood risk will be necessary to keep flood insurance affordable (Flood Re, 2016). Yet, there are already concerns that the new pool does not sufficiently consider rising flood risks due to climate change nor incentivise flood risk reduction or the improvement of the flood resilience of properties (Surminski and Eldridge, 2017; Hjalmarsson and Davey, 2016; Jenkins et al., 2017a). Indeed, the UK Committee on Climate Change find that in its current design Flood Re is likely to be counter-productive to the long-term management of flood risk as it does not provide enough incentives for high-risk households to put measures in place to avoid or reduce flood damage (Committee on Climate Change, 2015). Furthermore, a recent study by Jenkins et al. (2017a) shows that Flood Re is likely to lead to an increasing gap between subsidized premiums and risk-based prices that consumers would face outside Flood Re.

Ultimately, such studies highlight that flood insurance cannot be kept affordable without a concerted effort to address the underlying factors which drive flood risk in the first place. This requires involvement from a broad suite of stakeholders, including but not limited to the government, the insurance industry, property owners and property developers. Many of these stakeholders are indirectly benefiting from insurance but are not formally involved in the partnership.

2.2. Strengthening the insurance partnership by involving more actors?

While expectations of the insurance industry have traditionally been high when it comes to flood risk management (e.g. Kunreuther, 1996; Botzen and van den Bergh, 2009; European Environment Agency, 2013), the insurance industry alone cannot provide the solution. A wide range of private and public stakeholders have a critical role to play in incorporating flood risk reduction considerations into urban developments. This ranges from the first stage of designing the development through to the final construction: developers, local government planning officers, architects, flood risk consultants, surveyors, the Environment Agency, water companies, building contractors and mortgage providers (Bosher et al., 2009; Bosher, 2012; Surminski, 2014). Yet, many of these actors have not been actively involved in the management of flood risk, and in particular SW flood risk. Indeed, there is a lack of clarity around how to engage these different actors for SW flood risk reduction and what actions they could take independently or in collaboration with the government.

For this study we limit our investigation to property developers and local government, and explore their possible interactions with the insurance system. Both actors are of particular interest due to their role in the pre-construction phase of a development, which according to Bosher et al. (2009) is the most important stage where key stakeholders can proactively adopt flood risk reduction and prevention measures.

In England, local governments have lead responsibility for managing local flood risk, including SW runoff, are the approving body for sustainable drainage systems (SUDS), and approve local developments as well as investing in flood defences. Likewise, developing in a flood-resilient way and in the correct location can minimise current and future risks to both the development itself and the surrounding area. In the UK, planning guidelines have been tightened under the National Planning Policy Framework (DCLG, 2012) with subsequent amendments in

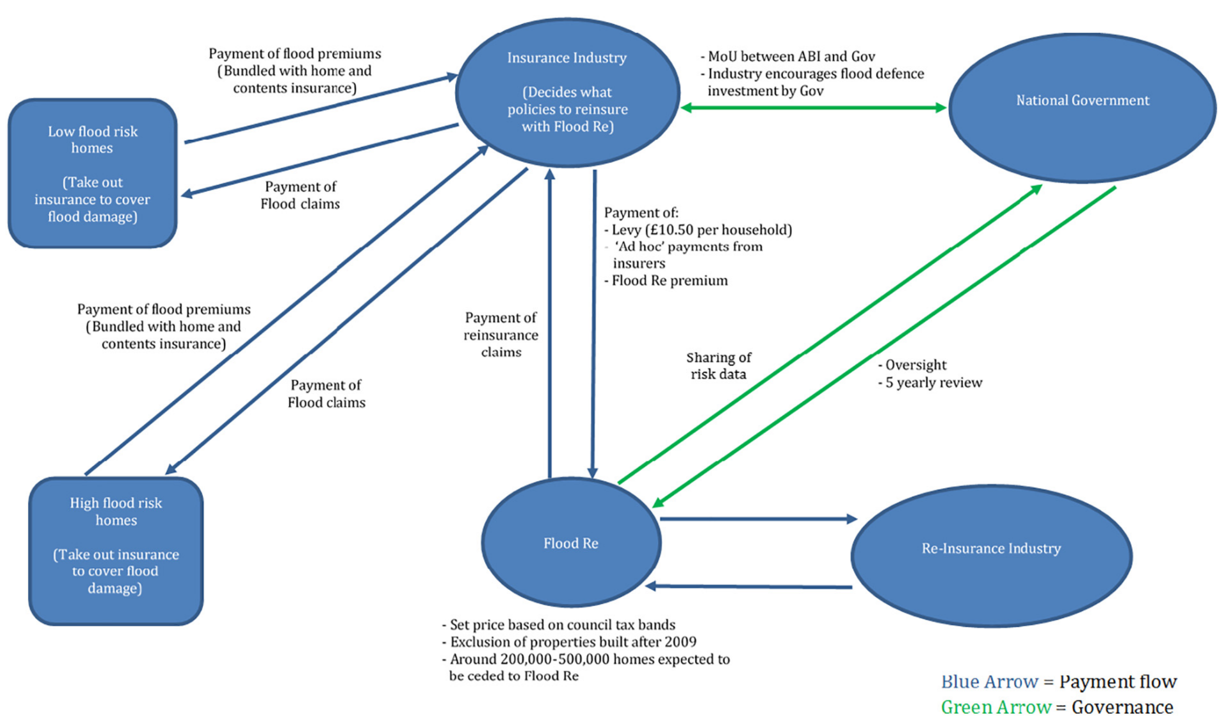

Fig. 1. The new insurance partnership – Flood Re.

2015 for the inclusion of SUDS in developments of 10 or more properties (DCLG, 2014). However, the economic benefits of developments and demand for housing provide a case for developers to continue to build on high flood risk land, and for local authorities to approve such developments. Yet, the role of property developers in reducing flood risk has to date received little attention with the exception of a few case studies (e.g. Taylor et al., 2012; Taylor and Harman, 2016; Handmer, 2008). Interestingly for our investigation is that the burden of flood risk does not remain with developers but rests with home-owners, who then use flood insurance to transfer this risk, either voluntarily or as required through their mortgage provider.

Currently, Flood Re is not available for properties built after 2009. This is in line with earlier practices, when insurers in 2008 decided that new buildings would no longer require the flood insurance guarantee given through the SoP based on the assumption that a strengthened planning system, as well as increased awareness of developers, should deliver and prevent new high risk properties from being built (Alexander et al., 2016). At that time the ABI also issued guidance to assist developers with building flood resilient properties through practical steps such as raising floor levels of properties (ABI, 2009). However, it is unclear how successful these measures were, as there is evidence that costs of risks are becoming less of a concern, overridden by the growing concern about lack of housing, which has led to an easing of planning rules (Committee on Climate Change, 2015). Overall the effectiveness of the planning system remains a cause of debate, with around 12% of all new residential development in England between 2001 and 2014 taking place in floodplains, and around 25% of that floodplain development occurring in areas at medium or high levels of flood risk (ibid.).

3. An agent based model to investigate the UK flood insurance partnership

An agent-based approach considers the simple and complex phenomena that may result from interactions between different agents in a shared environment. ABMs provide a bottom-up approach for understanding such dynamic interactions in complex systems, and can provide an improved understanding of systems by simulating these systems and their evolution (Bandini et al., 2009). In addition, by adjusting certain model parameters ABMs can be used to investigate key drivers, scope, and limits for future evolution of these systems, and visualise possible strategies and evolutionary pathways. As such they have a number of advantages as support tools for policy making, including their accessibility and flexibility for testing different conditions and behavioural rules (van Dam et al., 2012).

Despite a growing interest in ABMs across different fields there is limited application of this method to flood risk management. Examples include Haer et al. (2016) who use an ABM to explore the effectiveness of flood risk communication and influence of social networks in the Netherlands, and Dawson et al. (2011) who use the method to investigate flood incident management related to storm surge in the UK. As highlighted by Dubbelboer et al. (2017), ABMs have had limited application in the insurance sector to date, with no direct focus on SW flood risk management or the role of insurance in addressing rising risks.

In this paper, we use a novel ABM developed for London (ibid.), and applied here to the London Borough of Camden which is considered to be at high risk of SW flooding (Drain London, 2011). The ABM has been parameterised based on a large array of data sources and developed around GIS data. A key data input to the ABM is a probabilistic SW flood event set (Jenkins et al., 2017b) that provides a set of synthetic flood events with spatially heterogeneous return periods and estimated household flood damages. A probability-damage curve is estimated annually for every house in the model based on this data, and SW flood risk calculated as the area under the curve (see Dubbelboer et al. (2017) or Appendix A for further details).

To represent the role that the partnership could play in incentivising SW flood risk reduction the ABM includes three main agents: i) local government, which has a key role in managing local flood risk and approving new developments; ii) an insurer, which is committed to the provision of flood risk insurance and the running of Flood Re; and iii) a private property developer building new properties in the local area. In addition, the ABM represents i) people who can own, buy and sell houses in the model and require flood risk insurance; ii) a bank agent that can repossess properties if homeowners default on mortgage payments; and iii) the housing market.

Fig. 2 provides an overview of the ABM with its key processes and interactions, and Table 1 provides a summary of the main agent behaviours which underlie the model. Further details of the underlying SW flood event set, estimation of SW flood risk, and the behaviour and procedure of each agent is available in Appendix A and Dubbelboer et al. (2017).

Using the ABM we investigate the impact that different hypothetical public policy measures (Table 2) could have on reducing SW flood risk; maintaining the affordability of insurance; and whether trade-offs or counter-active effects occur on SW flood risk reduction and insurance affordability when constraints on both sets of actors are combined.

Each experiment setting was run using the set of synthetic flood events with their associated residential building flood damage, for a baseline (1961–1990) and future high emission climate change scenario for the 2030s (2030H) and 2050s (2050H) (comparable to Representative Concentration Pathways 4.5 and 8.5 respectively). The experiments were run at a yearly time-step for 100 simulations of the 30-year time series data corresponding to the baseline, 2030s and 2050s. These repeated simulations are each driven by a new resampling of the uncertainties in the climate scenarios, so the statistical results reflect these uncertainties as well as representation of the variability of behaviours in the ABM. While Flood Re is intended to be a transitional scheme to be phased out over a 25-year period, in the interests of simplicity we have tested a steady state version of Flood Re over a 30-year simulation period. For simplicity, the line graphs presented below represent results averaged across each of the 300 model repetitions.

4. Results: strengthening the partnership

4.1. Role of property developers

The ABM highlights that SW flood risk increases from the baseline when no developer restrictions are in place (experiment 1) (Fig. 3a), and is reduced when the developer is required to build all properties with SUDS (experiment 2) or where this is imposed in combination with other restrictions (experiment 3). This reflects the assumption that SUDS will homogenously reduce flood damage for properties protected by a set percentage in the model, regardless of the location or scale of flooding. Given the limited availability of more detailed quantitative data on the benefits of SUDS for flood damage reduction the value used in the ABM was assumed to be 35% (Defra, 2011), and as such will lower but not totally remove SW flood risk for protected properties. Whilst this reflects a simplified assumption to represent the role of SUDS, sensitivity analysis highlighted that the model outputs were not overly sensitive to the parameters related to the implementation and benefits of SUDS and Property Level Protection Measures (PLPMs). Similar trends were seen for the 2030H and 2050H climate scenarios, albeit at a higher level of flood risk (Appendix B, Fig. B1).

The greatest reductions in average household flood insurance premiums occur under experiment 3 (Fig. 3b). Average flood insurance premiums begin to increase slightly from the baseline from around year 15 under experiment 1, where there are no developer restrictions, as these new builds are excluded from the Flood Re scheme. When development is not regulated and does not follow the local boroughs proposed housing trajectory around 5000 more homes are built by year 30 in the model, with a higher number of properties built in flood risk.

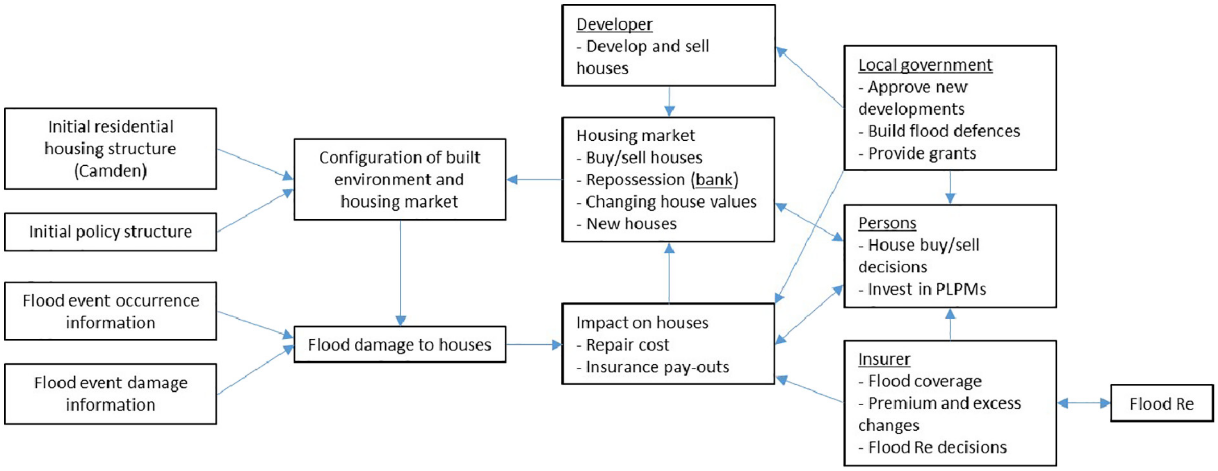

Fig. 2. An overview of the key processes and interactions in the agent based model for Greater London. The agents in the model are underlined.

Similar trends in average household flood insurance premiums are seen under the climate change scenarios (Appendix B, Fig. B1). However, there is greater divergence in the results between experiments 1–3, and greater impacts on average premiums of the different experiments.

The model also allows us to examine the effects of hypothetical increased investment in flood defences by the developer. Under experiments 2 and 3 (which both require all new developments to have SUDS installed) a larger proportion of homes are protected from SW flooding by SUDS over the 30-year period (Fig. 4). These results underlie the trends highlighted in Fig. 3.

Table 1
Summary table of main agent behaviours.

Agent	Main behaviours
Homeowner	Decide to buy or sell properties Required to renew flood insurance annually Pay household fees Decide whether to invest in PLPMs (assumed that 1% of homeowners invest proactively per year, while 34% invest reactively following a flood) May consider flood risk when considering to purchase a new property
Insurer	Estimates household SW flood risk for every property in model (it is assumed that where in place they account for PLPMs and SUDs in these estimates) Sets insurance premiums and excess levels for every property in model Provides all households with flood insurance Decide whether it is cost effective to place high risk properties into Flood Re Provide compensation, minus the excess, to properties following a flood event
Local government	Invest up to 80% of their local flood defence budget (or more in the year of a flood event) in SUDS projects which protect houses at highest risk of flooding and provide a cost-benefit ratio of ≥1:5 Invest ~20% of their local flood defence budget through £5000 grants to households investing in PLPMs Evaluate and approve/reject property development plans based on their financial benefits and flood risk Sell land to developers for approved property developments
Developer	If demand for new properties outstrips available properties on the market propose to build new properties to meet demand Identify optimal land to maximise profits from developments, within allocated development areas and the local governments planned development trajectory Submit development proposal to be approved by the local government Build new houses (initially assumed that 50% of all houses built will have SUDS) and sell on the market
Bank	Reposes houses if the owners are unable to afford household fees for three consecutive years Sell houses on market

4.2. Role of local government - investing in flood protection measures (PLPMs and SUDS) and approving new developments

Secondly, the ABM is used to examine the impact that local government investment in flood protection measures would have on the affordability of insurance and SW flood risk reduction. Fig. 5 presents the effect of local government investment in PLPMs and SUDS on the average SW flood risk and levels of premiums of both existing houses and new developments. While the average SW flood risk of existing and new build properties are similar, the benefits of government investment in flood protection measures are larger for the new build houses, as these include properties in some of the higher flood risk areas, which are targeted for SUDS projects based on their favourable cost-benefit ratio. In contrast, for existing houses in the model, the benefits are smaller and increase gradually as households mainly invest in government funded PLPMs in a reactive way after floods. Fig. 5b highlights the positive impact that flood protection measures can have for homeowners as the government reduces risk in the area, the insurer's risk portfolio is reduced, and consequently households benefit from lower premiums. In contrast, premiums remain much higher for new build houses excluded from Flood Re.

When looking at the role of the local government (experiments 4–8) in approving new developments, and consequences for flood risk and insurance premiums, the analysis highlights that the average SW flood risk of new builds does decline by around 8% by year 30 under experiment 4 where the level of profit to flood risk required if a development is to be approved is increased (Fig. 6). More substantial benefits in terms of SW flood risk reduction are seen under experiment 5 (halving the average SW flood risk of new buildings from the baseline by year 30). This assumes that the level of profit to flood risk required if a development is to be approved is increased in combination with the government also setting a lower maximum flood risk threshold and fully assessing all proposals based on flood risk and profitability.

4.3. Placing joint restrictions on property developer and local government – evidence of trade-offs

Fig. 6 also shows results for experiments 6–8 which assess a combination of restrictions placed on both the property developer and local government. Similar results to experiment 5 are seen under experiment 7, where some financial conditions and restrictions on new developments are placed on the developer in parallel. A more favourable result

Table 2
Sub-set of experiments developed to test the role of the developer and local government in strengthening the insurance partnership.

Experiment number	Developer contributes 10% to government Flood Defence Investment	Developer pays flood risk insurance for first 5 years of new property[a]	Developer must build all new properties with SUDS in place	Limited number of houses developer can build[b]	No Developer Restrictions – (i.e. no government approval needed to build)	Local Government sets a more stringent development approval ratio[c]	Local Government sets lower maximum acceptable flood risk level	Local Government must look at flood risk and approval ratio for every proposal[d]
Baseline	NO	NO	NO	NO	NO	NO	NO	NO
1	NO	NO	NO	NO	YES	NO	NO	NO
2	NO	NO	YES	NO	NO	NO	NO	NO
3	YES	YES	YES	YES	NO	NO	NO	NO
4	NO	NO	NO	NO	NO	YES	NO	NO
5	NO	NO	NO	NO	NO	YES	YES	YES
6	YES	YES	YES	YES	NO	YES	YES	YES
7	YES	YES	NO	YES	NO	YES	YES	YES
8	NO	NO	YES	NO	NO	NO	YES	YES

[a] This is used to test decision making of the developer based on profitability if they had to cover the insurance for 5 years.
[b] The number of developments allowed reflects the annual Camden development trajectories. In this scenario, the number of properties which can be built is reduced by 50% annually as a first example.
[c] The development approval ratio is increased from 1 (i.e. profits from selling land must be ≥ to the additional level of flood risk added to the local area by the development) to 1.25 (i.e. the profit made from selling land for development will need to be ≥25% higher than the additional level of flood risk added to the local area for the development to be approved). This initial assumption is based on the premise that demand for housing as well as potential economic benefits can provide a case for developers to continue to build on high flood risk land, and for local authorities to approve such developments;
[d] In comparison to the baseline where 75% of proposals are randomly approved by the local government straightaway.

in terms of the average SW flood risk of new build properties is seen under experiment 6. The average level of SW flood risk to new build properties is reduced by 27% from the baseline by year 30. This is similar to experiment 7 but also includes the need for developers to build all new properties with SUDS.

In the model the trend in development reflects the growth trajectories outlined for Camden, Under all the experiments the total number of developments follow a very similar trajectory over the 30-year time period (Fig. 7b), even under experiments 6 and 7 where 50% less properties can be built annually. This is because in the ABM the local developer focuses the majority of new developments in specified Opportunity Areas (OAs) reflecting areas designated by the council for large development, and with a maximum limit on total houses (Camden Council, 2016). The OAs begin to be full by around year 22 and so the trajectory begins to slow and converges with that of experiments 6 and 7 which increase at a steadier rate over time.

Fig. 7a highlights a clear divergence in trajectories for properties at risk of SW flooding. Certain options, such as demonstrated under experiment 7, act as stronger barriers to the development of properties in areas of high SW flood risk. Interestingly, as the local developer aims to build in the most profitable areas, which are often areas of high flood risk in the case of Camden, the requirement to build all properties with SUDS (experiment 6) actually results in more properties being built in areas of SW flood risk overall (Fig. 7a). This reflects the assumption that SUDS would reduce any flood damage by 35% (Defra, 2011) in the model. This lowering of flood risk means that more properties are deemed to have an acceptable level of SW flood risk and subsequently receive government approval, which otherwise would not be the case. These findings highlight the complexities in identifying the right balance in flood risk reduction actions by developers and local government and shed light on the potential trade-offs which will need to be made between managing flood risk, developing in flood plains and meeting housing targets.

The importance of coordinating the developer and local government risk reduction strategies is further highlighted by experiment 8. Although the developer builds all new properties with SUDS and the local government reduces the acceptable level of flood risk and must consider this alongside the development approval ratio for all proposals, the level of flood risk is marginally higher than seen under experiments 5 and 7. This is as under this experiment properties at the highest level

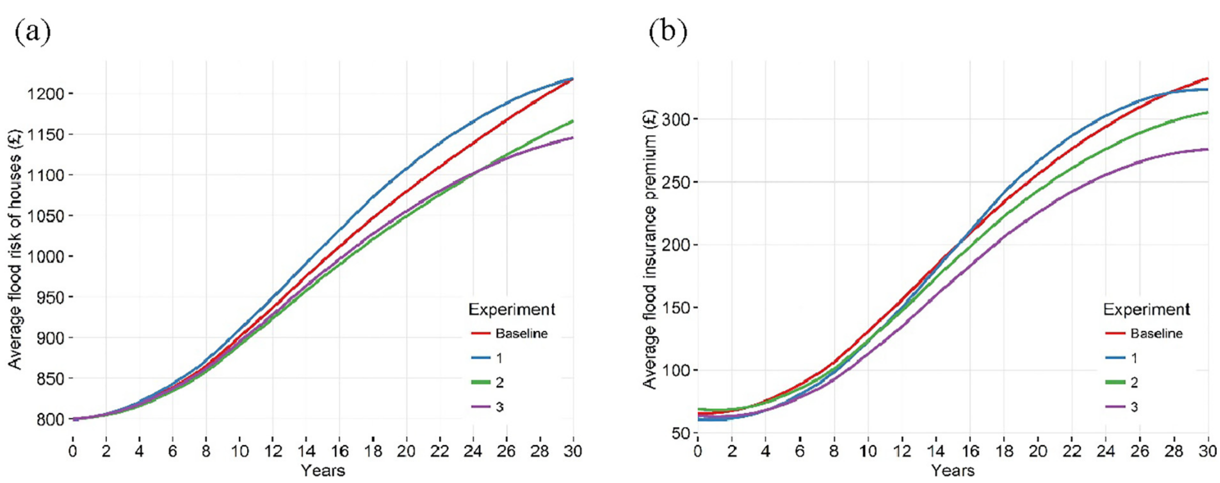

Fig. 3. a) Average household SW flood risk and b) average flood insurance premium of all houses in flood risk estimated under experiments 1–3.

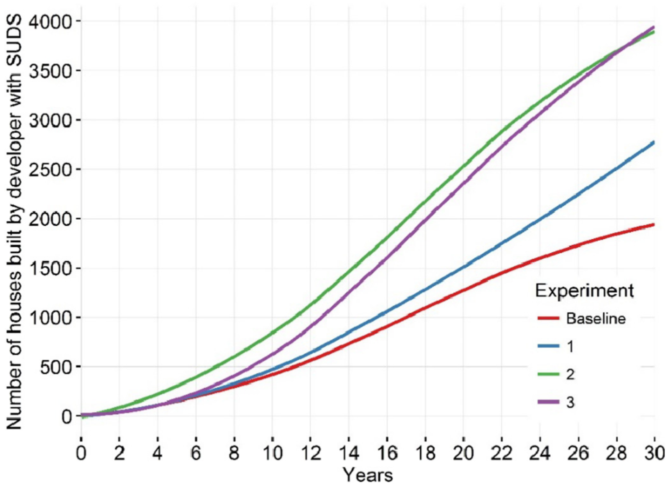

Fig. 4. The number of new build houses in the model simulation built with SUDS in place.

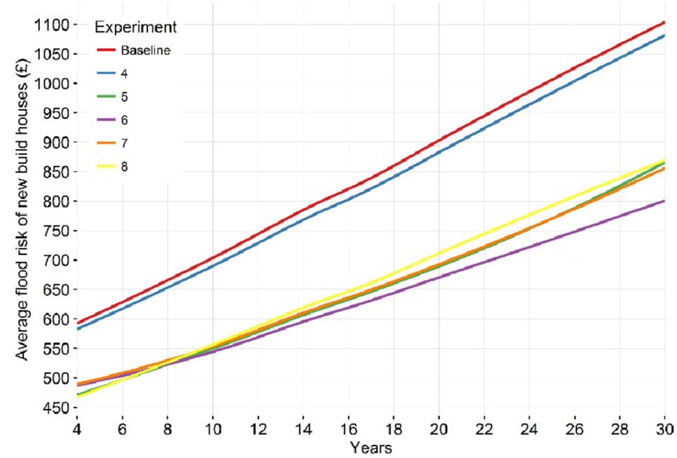

Fig. 6. Average household SW flood risk of new builds built in areas of flood risk. Baseline climate scenario.

of flood risk, even with SUDS in place, can still be approved if they are considered profitable. This is further highlighted in Fig. 7a, where experiment 8 results in the largest number of houses being built in SW flood risk in the model by year 30.

Fig. 8 highlights the upper and lower bounds of the model results, in terms of the average flood insurance premium across existing and new build houses, and across a sub-set of the experiments. All the experiments, except for experiment 1 (where there were no government restrictions placed on the developer), are beneficial in terms of reducing average household premiums from the baseline. Results under experiments 3, 6 and 8 are most beneficial compared to the baseline. This appears counter intuitive when, for example, results for experiments 6 and 8 are compared to Fig. 7a where they are shown to result in a larger number of properties being built in areas of flood risk. The reason for this is that in these experiments all new properties are built with SUDS in place, which allows more properties to be approved by the local government whilst also reducing the SW flood risk and premiums. The potential for counteractive effects when combining constraints and measures targeted to developers and the local government is a key finding of this research and an area that warrants further investigation.

Lastly, it is highlighted that the magnitude and trends in average flood premiums can differ when future climate change is considered (Appendix B, Fig. B2). For the future climate scenarios experiment 1 results in premiums higher than the baseline experiment, whilst under all other experiments benefits in terms of reduced premiums are seen. However, as SW flood risk increases over time the options that are most beneficial change. As such, issues of continued development and flood risk management should also be viewed in a longer-term context given the threat of climate change and negative consequences for flood frequency and intensity.

5. Discussion

Partnerships have been receiving significant attention since the turn of the century within the sustainable development, disaster risk management and climate change fields. MSPs in particular are seen as "the

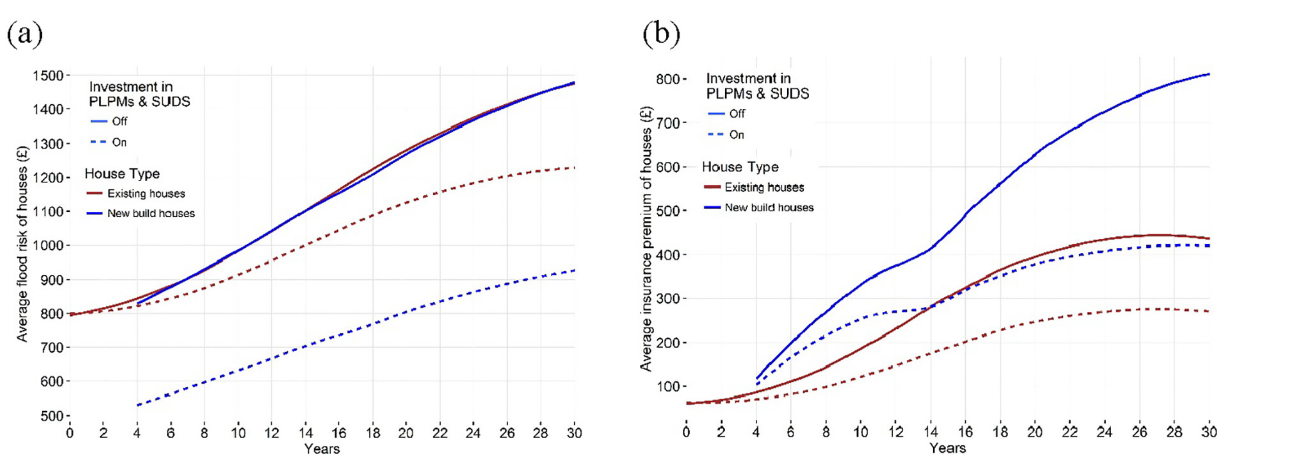

Fig. 5. (a) The effect of different flood protection measures on average household SW flood risk for existing and new build houses; and (b) the effects of these flood protection measures on average flood insurance premiums. Baseline Climate scenario.

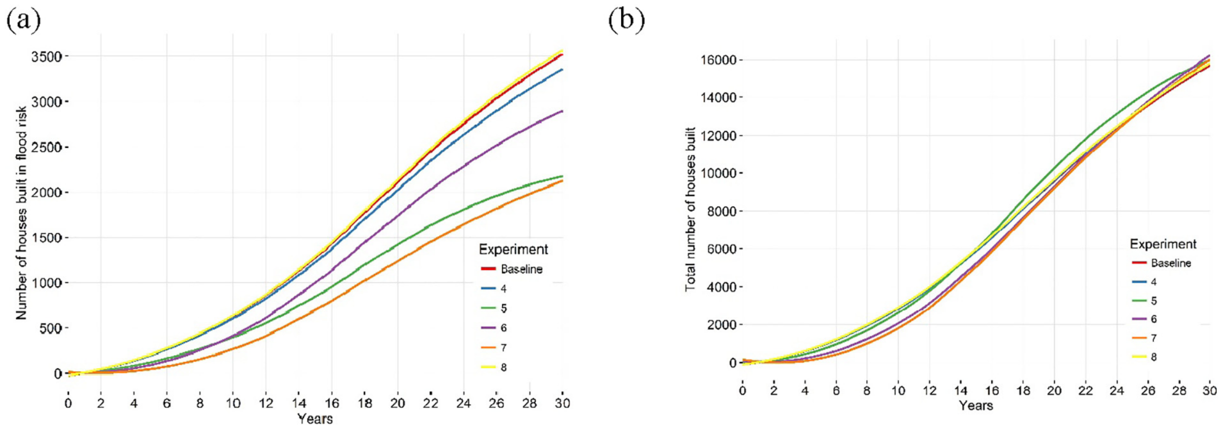

Fig. 7. Total number of (a) houses built at risk of SW flooding; and (b) houses built.

paradigm of the 21st century" and the best approach to deal with complex and multi-faceted problems (Pinkse and Kolk, 2012). Yet, despite this positive rhetoric, little research has been done on how partnerships can facilitate and incentivise disaster risk reduction (e.g. Sherlock et al., 2004; Pinkse and Kolk, 2012; Chen et al., 2013). One of the common criticisms of partnerships is that they often involve the 'usual suspects' and do not engage with all the relevant actors (Sherlock et al., 2004). In the case of Flood Re, it is unlikely to encourage adaptation to rising flood risks from climate change if it is not part of a wider strategy that also considers land use planning, investment in structural flood defences, policies to control floodplain development, building regulations and water management (Horn and McShane, 2013). Flood Re itself acknowledges that it does not have strong direct levers to influence flood resilient decisions due to its design (Flood Re, 2016).

Our analysis of the UK's flood insurance partnership, using the case study of the London Borough of Camden, suggests a range of options for strengthening the current arrangement and role of the local developer and government in the face of rising SW flood risk. For example, the local developer is key as properties built after 2009 are excluded from Flood Re, yet if and how new developments go ahead in flood risk areas will still have implications for insurers who are likely to still

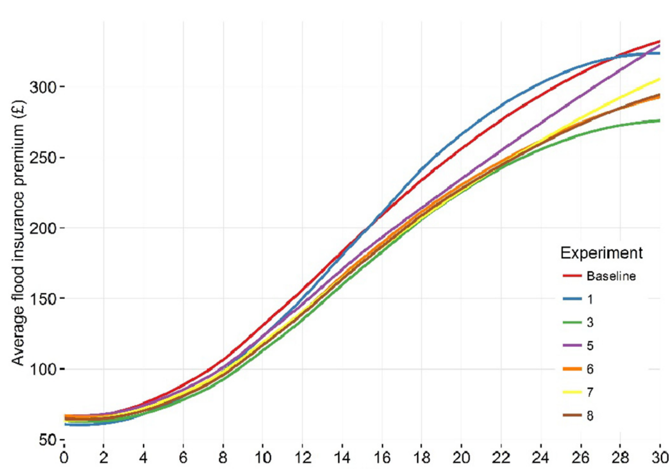

Fig. 8. Average flood insurance premium of all houses in flood risk.

cover these high-risk properties, and for home-owners who may ultimately face higher insurance premiums. The role of the local government and developer is particularly important here as although they do not have a formal relationship with Flood Re their actions can determine future risk levels for both existing and new build properties. As shown through the ABM, approval to build in areas of high flood risk or without any in-built resilience measures can affect the number of eligible properties potentially ceded to Flood Re and affect its longer-term sustainability.

The benefits of local government investment in SUDS (applied to existing houses) and PLPMs are clearly shown in the ABM results. Local government investment in these measures is beneficial to the insurer as the risk portfolio is reduced and to households whose premiums are reduced. The ABM also shows that for Camden a stricter approval process for new development, with a greater weight given to flood risk, does have a clear impact on the overall flood risk, but also leads to trade-offs for the local government in terms of generating income from new developments, meeting housing targets and reducing flood risks.

The ABM was developed and parameterised for Camden, and as such is reflective of the specific levels of SW flood risk, local housing market, demographic make-up, and local government development trajectories. For example, new developments are focused in defined OAs, which due to limited land availability in the Borough are often situated in areas of SW flood risk. While specific results are not directly transferable a benefit of the ABM framework is that it can be applied to other regions, and an important area of further research would be to conduct a comparative analysis with other London Boroughs to understand the influence of such factors on the suitability of different hypothetical constraints and policies.

A second benefit of the ABM approach is its ability to investigate different combinations of restrictions placed on the developer and local government, and the impacts and trade-offs that this can have on future developments and insurance premiums. The ABM results suggest that while a stricter local government stance on the approval of developments in flood risk areas in Camden does reduce insurance premiums, the strategies that result in the lowest premiums also lead to a larger number of developments in areas of flood risk.

This underlines the current lack of understanding with regards to the interplay and dynamic feedbacks between physical and social processes when investigating flood risk (Di Baldassarre et al., 2015), and highlights the potential broader role of the ABM framework in helping to explore such dynamics and trade-offs. Indeed, beyond the Camden case study there is evidence that such trade-offs are already occurring, with local authorities encouraging developers to build in flood plains as the revenue stream this provides is one of a few ways in which they can finance large flood protection or resilience projects. Yet, such strategies are not sustainable in the long-term and a better understanding of these trade-offs is an area that warrants further investigation at a broader scale.

Another important point that needs to be considered at a broader scale, is the impact of climate change and other risk drivers on insurance premiums. We find that over time current strategies for maintaining low insurance premiums and managing flood risk may become less effective, unless adjusted to the new risk trends. This highlights the importance of engaging with multiple actors to strengthen the partnership, and allowing a flexible framework that can be modified over time as different risk thresholds are passed.

The study demonstrates the potential of using an ABM to inform and support the development of enhanced flood insurance partnerships to incentivise flood risk reduction and adaptation to climate change. Filatova (2015) highlights the need to move from conceptual modelling experiments to simulating real life situations using available data if an ABM is to be applied for policy analysis and be seen as robust by relevant stakeholders. In this study, the model has been parameterised based on a large array of data sources, developed around GIS data, and repeated simulations carried out to provide an assessment of uncertainty. However, a limitation of this is that the ABM inevitably becomes more complex and potentially more chaotic. As with all models, the results must be carefully interpreted given the number of underlying assumptions necessary given this complexity. Model verification has been used to test principle components are accurately captured, and the model outputs remain robust given available evidence.

One benefit of the ABM framework is the flexibility that allows future revisions to be quickly made. For example, if appropriate literature becomes available then updates could be made to model the benefits of PLPMs and SUDS in a more heterogeneous manner given different severities of flood depth. Secondly, if data was available then additional user selections could be added, in the same manner as used to represent SUDS, to capture specific options included in the London Sustainable Drainage Action plan such as the role of, and potential economic benefits of, detention basins or stormwater tanks (for example see De Paola and Ranucci, 2012). Alternatively, if future updates are made to the underlying Drain London SWF maps, e.g. hydraulic modelling scenarios included hypothetical or proposed implementation of structural defences like detention basins, then the set of synthetic flood events used here could be extended and incorporated into the ABM to capture and compare these additional scenarios. Lastly, while the ABM presented here is focused on a case study of Camden, the modelling approach is also transferable to other regions in the UK and internationally given the availability of relevant data that would be reflective of local levels of SW flood risk, legislation and approaches to flood risk management, and demographic make-up etc.

Yet, for Flood Re the validation of model outputs will only be possible once the first few years of claims and premium data are available, and as more information on behaviour of the actors emerge. In addition, our model is designed around those actors deemed most relevant in this context, but we acknowledge that other key actors, such as water companies and mortgage providers, may have a critical role to play in providing a more holistic approach to flood risk management (Kunreuther and Michel-Kerjan, 2009; Sargent et al., 2009). How to better integrate these actors in flood risk management decision-making to better incentivise flood risk reduction is a critical issue for further research.

6. Conclusion

Insurance is an important tool for addressing flood risk. Yet, developing the right flood insurance arrangements to incentivise flood risk reduction and adaptation to climate change remains an international challenge (Surminski, 2014; Surminski et al., 2015; European Commission, 2013). This paper provides insights on the importance of MSPs in order to utilise insurance for flood risk reduction, suggesting ways in which different policy options and actions from local government and property developers could reduce SW flood risk, help maintain affordable insurance premiums and strengthen the current flood insurance partnership. Yet, our findings also show the many trade-offs that actors may face. Finding the optimal strategy for reducing SW flood risk; maintaining low insurance premiums; constraining development in flood plains; and meeting housing targets will be challenging under current conditions, let alone in the face of rising risks.

For partnerships this is an important aspect as overall the partners tend to agree on a common aim, but their objectives and their understanding of roles and responsibilities are likely to differ. For Flood Re the overarching aim is the availability and affordability of flood insurance, but views differ on who to pay, what to cover and how to design the scheme. Interestingly Flood Re itself has now acknowledged that risk reduction efforts are essential for the future affordability of flood insurance, and have pledged to collaborate closer with other stakeholders on this (Surminski, 2016).

Regarding the role of government, it is important to highlight that different governance layers are relevant for the flood insurance partnership. Public policy is shaping the way insurance is designed and provided: directly through regulation such as mandating cover or instigating the development of new schemes; and indirectly by providing the enabling infrastructure and environment, for example through a broad risk reduction framework, including building codes, planning regulations and better flood risk data provisions. Therefore, a stronger policy approach to flood risk management would make the insurance partnership more viable. For this, collaboration between the national and local authorities, planners, and developers is crucial.

Engagement with those other actors could take many different forms. This is especially apparent in the case of property development. Flood Re explicitly excludes new build to avoid moral hazard from property developers. However, this position could in future come under pressure. If new property developments in high risk areas were to continue, as current trends suggest (Committee on Climate Change, 2015), this could create political pressure on Flood Re to expand its remit and to offer cover to those new build properties. In the context of our assessment, this would not strengthen the partnership, but remove the only risk reduction incentive that Flood Re has. Instead, engaging with property developers could be more effective beyond the core risk transfer. The insurance industry itself, as the world's largest institutional investor, clearly has a role to play. Ironically, investment decisions by insurers do not usually consider the climate risk knowledge gained on the underwriting side. Far too often property and infrastructure investment decisions go ahead without any reflection on climate risks (Surminski et al., 2016). A closer reflection on flood resilience when making investment decisions could therefore have positive implication for the flood insurance provision.

In a similar way, it would be important to investigate the options for collaboration between insurance and local government. One recent example that may lead to more resilience is the Resilience Zone concept (e.g. see Ceres, 2013). Resilience zones are urban areas, specifically vulnerable to climate change risks, which are earmarked for regeneration via comprehensive risk management– a process that brings together insurers, developers and local governments. While this is at an explorative phase, our ABM could be applied and provide useful insights into how different actors and policy options may influence risk levels.

Likewise, while the ABM presented here is focused on a case study of Camden, the modelling approach and findings are highly relevant for wider discussions on the potential of insurance schemes to incentivise flood risk management and climate adaptation in the UK and internationally. There is clear momentum at the international level to use insurance to incentivise risk prevention and adaptation (Surminski et al., 2016). This can include investment and support for more structural measures such as those classified as part of SUDS. The engagement of multisectoral partners and the clarification of their roles and responsibilities will determine if and how those new schemes can support climate resilience.

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Appendix A. Overview of the Agent Based Model and key assumptions

The ABM has been parameterised based on a large array of data sources and developed around GIS data. A copy of the model and full documentation, including an ODD protocol, description of model parameters, values and sources, model verification and sensitivity analysis are available online at https://www.openabm.org/model/4647/version/3/view.

A key input to the ABM is a probabilistic SW flood event set (Jenkins et al., 2017b). This provides time series data of spatial SW flood events for a baseline period (1961–1990), the 2030s (2020–2040), and 2050s (2040–2060) under high (H) emission scenarios (comparable to Representative Concentration Pathways 4.5 and 8.5 respectively). The SW flood event set was developed using Drain London (Greater London Authority, 2017) SW flood depth maps for 1/30, 1/100, and 1/200 year return periods. The SW flood depth maps were based on modelling a virtual representation of the ground topography, including underlying sewer networks, road gullies, large culverts and road underpasses and then applying water to the surface using a computational algorithm to determine the direction, depth and velocity of the resulting flows. This included flooding from run-off generation, sewers, drains, groundwater, small watercourses, and ditches which occurs as a result of heavy rainfall. The modelling accounted for rainfall onto roofs, which is then distributed to represent the routing of rainfall into the network through gutters and drainpipes (e.g. see details in The Royal Borough of Kensington and Chelsea SW Plan (2014)).

To identify the occurrence and spatial extent of individual flood events the corresponding return level of extreme precipitation events of 1/30, 1/100, and 1/200 year return periods were estimated for the baseline period (1961–1990) using an hourly Weather Generator (WG), conditioned upon the UK's probabilistic climate projections (UKCP09). The rainfall return levels are then used as thresholds to rescale the SW flood depth maps for each simulated flood event to generate corresponding spatially heterogeneous flood outlines (Jenkins et al., 2017b). By overlaying the spatial flood maps onto residential building data properties at risk of SW flooding, and the flood depth, were identified. Economic damages to residential buildings were estimated using established flood depth-damage functions (Penning-Rowsell et al., 2010).

Based on the estimated economic damage to houses for given flood return periods, a probability-damage curve is estimated annually for every house in the model, and SW flood risk calculated as the area under the curve. Based on the formula in Bevan and Hall, 2014, p.17) in any given year (t), the risk ($r_{i\ t}$), is given by:

$$r_{i,t} = \int_0^{\infty} D(x_t) f(x_t) dx_t \quad (1)$$

where, $D(x_t)$ is a damage function with x changing overtime, and $f(x_t)$ is the flood probability distribution.

Household flood risk is recalculated every year to reflect the dynamic changes in the model due to investment in flood protection measures which, if installed, are assumed to reduce the estimated economic damage (D) to houses by between 35 and 75% (outlined below). The household damage from floods of given return periods do not change under the future climate scenarios, but the probability of such events occurring do. To illustrate this the probability damage-curves are adjusted accordingly for each climate scenario to reflect the change in probability of events.

In this analysis we only model the technical side of flood insurance and not the commercial side (i.e. competition between insurers, which might modify the offered premium). As we focus on SW flooding we limit the insurer's attention to the SW flood history of a house and the estimated SW flood risk. In the ABM we assume that an insurer has detailed information that provides an estimate of SW flood risk (Eq. (1)). Based on that risk estimate and a flat administration cost the insurance premium and excess (the fixed value of each claim the homeowner has to pay) is calculated for each house. The insurer first sets the flood insurance excess for all houses. The assumption is made that the flood insurance excess amount is non-negotiable and is initially equal to £200 per claim (Flood Re, 2016) on an annual policy. Houses hit during a SW flood event will see their insurance excesses increase by 1/3rd, up to a maximum of £2500 (House of Commons Environment, 2013).

The SW flood risk estimates of houses are summed across all houses in flood risk in the model, representing the insurers expected annual loss. The insurer deducts from this the total value of excesses paid and the total base flood insurance premium paid by all households in the model, assumed to be £50 per house per year. This provides an estimate of the remaining annual loss that has to be covered. The remaining loss is spread across the households at risk of SW flooding, by increasing their household flood insurance premium proportionally to the flood risk they are in. In this way people owning a house in SW flood risk will receive a higher flood insurance premium.

When switched on in the ABM the insurer has the option to re-insure eligible properties (those built prior to 2009) into Flood Re, with household flood insurance premiums fixed dependent on the property value (approximated according to the local property council tax rate ranging from £210 to £1200 in the study area) The insurer will have to pay to re-insure a household into Flood Re with a fixed premium per policy to the insurer also dependent on the property value. In this way the total compensation the insurer pays following a flood will be lower when the Flood Re option is selected, as they are no longer required to compensate the highest risk houses.

In the model the local government agent aims to reduce flood risk by investing in SW flood reduction projects in the form of SUDS, and the provision of grants for PLPMs, reflecting current legislation and recommendations (Pitt, 2008; DCLG, 2014). It is assumed that PLPMs and SUDS will reduce the estimated economic flood damage (D) of protected houses by 75% (Thurston et al., 2008) and 35% (Defra, 2011) respectively. The amount the local government can spend on SUDS and grants for PLPMs every year is equal to the annual subsidy they receive from the national government and a small percentage of their income from selling land to the property developer and collecting property taxes from home owners. Initially it is assumed that up to 80% of this budget can be spent annually on SUDS and 20% for PLPM grants.

In the ABM the local government will proactively search for SUDS projects to invest in every year. Every project consists of a minimum of 100 houses that are in close proximity to each other. The projects are selected based on the flood risk of houses and the benefit-cost ratio that the local government would achieve for each project. From the identified projects the local government will try to build as many as it can with the budget it has, starting with the projects with the highest benefit-cost ratio. The second task of the local government is the evaluation of development proposals. The developer will establish the number of houses it wishes to build based on the current unmet demand for housing in the model. The developer selects an area to build based on available land with the highest economic value of surrounding houses and profitability. Based on the development plans of Camden specific Opportunity Areas (OAs) are outlined where the developer can build as many houses as optimal per year, with a maximum limit on total houses (Camden Council, 2016). Outside of the development areas the developer is limited by a maximum number of houses it can build per year (150–200) reflecting the planned housing trajectory of Camden (Camden Council, 2013). It is initially assumed that 50% of all new properties are built with SUDS in place (Defra, 2011).

In the initial model set up a development proposal will be approved by the local government if, i) it is equivalent or greater than the local governments approval ratio. This is set to 1 as default, meaning that a development can be approved as long as the profit from selling land is equivalent or greater than the additional level of flood risk added to the local area. This assumption is based on the premise that demand for housing as well as economic benefits both could provide a case for developers to continue to build on high flood risk land, and for local authorities to approve such developments.

Secondly, a development proposal will be approved by the local government if ii), it is below the governments maximum acceptable flood risk level. However, although regulation on approving development proposals states that local governments should consider flood risk, figures indicate that in 75% of cases flood risk is not looked at (Wynn, 2005). As such in 25% of cases the development proposal will be approved if the proposed flood risk of the development is lower than the government's acceptable maximum flood risk and it is equivalent or greater than the local government's approval ratio. If this is not the case the development proposal may still be approved based on the profitability to the local government. This reasoning reflects the current pressure local governments are put under by central government to develop more houses within their borough, and highlights trade-offs which must be made when addressing flood risk and housing shortages.

Appendix B. Selected results for the 2030H and 2050H climate scenarios

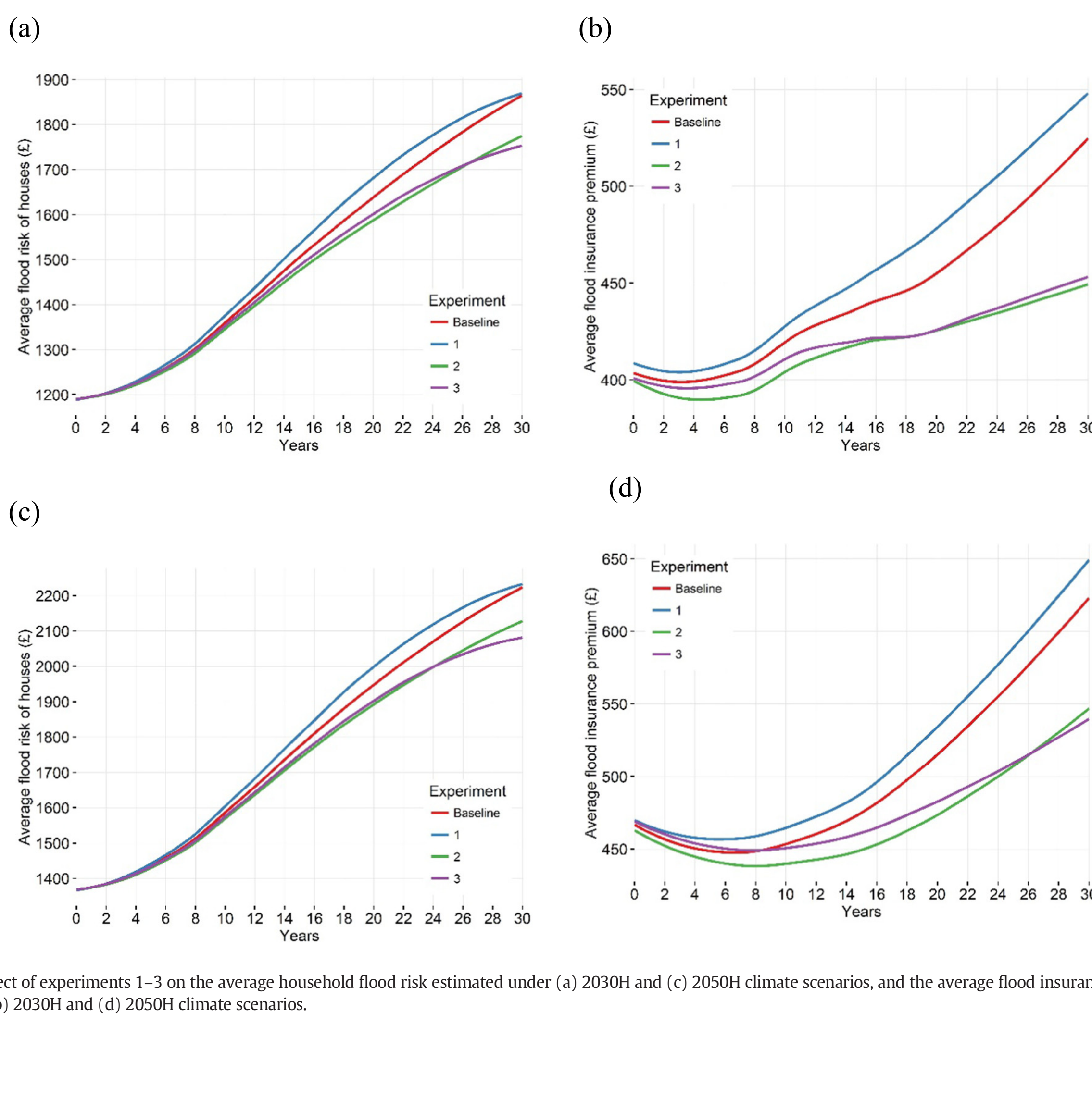

Fig. B1. The effect of experiments 1–3 on the average household flood risk estimated under (a) 2030H and (c) 2050H climate scenarios, and the average flood insurance premium estimated under (b) 2030H and (d) 2050H climate scenarios.

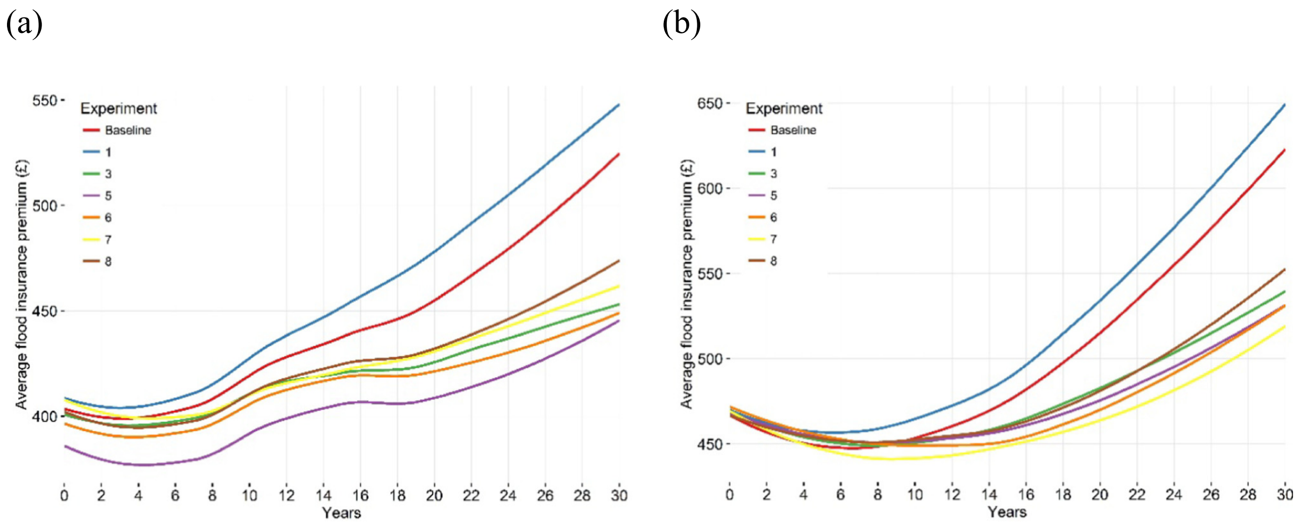

Fig. B2. Average flood insurance premiums of houses in flood risk under (a) 2030H and (b) 2050H climate scenarios.

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