Flood Risk, Climate Change and Housing Economics: The Four Fallacies of Extrapolation

Yu Chen,[a] Gwilym Pryce[b], and Danny Mackay[c]*

[a] *Urban Studies, University of Glasgow, Glasgow, G12 8RS; email: yu.chen@glasgow..ac.uk .*

[b] *Urban Studies, University of Glasgow, Glasgow, G12 8RS; email: gwilym.pryce@glasgow.ac.uk*

[c] *Public Health and Health Policy, University of Glasgow; email: Danny.Mackay@glasgow.ac.uk*

**Corresponding author*

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Abstract

This paper argues that major gaps exist in the research and policy understanding of the intersection of flood risk, climate change and housing markets. When extrapolating the research on historical flooding to the effects of future floods—the frequency and severity of which are likely to be affected by global warming—housing economists must be careful to avoid a number of methodological fallacies: (a) *The Fallacy of Replication*, (b) *The Fallacy of Composition*, (c) *The Fallacy of Linear Scaling*, and (d) *The Fallacy of Isolated Impacts*. We argue that, once these are taken into account, the potential magnitude and complexity of future flood impacts on house prices could be considerably greater than existing research might suggest. A step change is needed in theory and methods if housing economists are to make plausible connections with long-term climate projections.

1. Introduction

Issues of flood risk and flood recovery have moved up the political and scientific agendas in recent years following increases in the frequency and severity of flood incidents, and the likelihood that this trend will continue as a consequence of climate change (Stern, 2008; Pitt, 2008; IPCC, 2007). According to IPCC (2007, p.5), "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level". The consequent rise in flood risks has potentially significant implications for human geography, economic and financial systems, and quality of life, particularly in countries like the UK which have extensive coastlines and where major cities are located on the coast or major rivers (Foresight, 2004; GHF, 2009).

Efficient intervention will depend critically on being able to gauge the true costs and benefits of different policy options. House price analysis has a potentially important role to play because it offers a method of placing a monetary value on the impact on wellbeing. If heterogeneities in the type of dwelling can be controlled for, variation in house price across space can, in principle, be used to value differences in the quality of life. Understanding the impact of future flood risks (with and without the mitigating effect of intervention) on house prices, provides a potentially powerful guide to planning and investment decisions, and policy interventions in general.

Moreover, house prices have important implications for financial stability and personal wealth. Houses are a major source of mortgage market collateral, and falling house prices can have a destabilising effect on the financial system. They can also profoundly affect the wellbeing of households for whom the value of their home entails an important financial resource for retirement. Understanding the implications of climate change and future flood risk for housing is therefore an important priority for housing economists, both in terms of providing quality of life estimates for cost benefit analysis of intervention, and in terms of anticipating the direct effect on housing and mortgage systems.

In this article we argue that housing economics research on flooding has been limited in two respects. Firstly, there are methodological problems arising from poor data and inadequate statistical techniques and sampling methods. While these “technical difficulties” can be addressed using more advanced estimation methods and better research design (as in Bin *et al*. (2008) and Pope (2008)), there is a second category of problem, which is more fundamental. It arises from the premise of a stable climate. When extrapolating the results of existing studies, which rely on this premise, to quantify the implications of future flooding in an *unstable* climate, the housing economist is in danger of falling foul of a number of *fallacies of extrapolation*.

To obviate these fallacies, we must challenge conventional wisdom on the house price impacts of floods and argue for a step change in both theory and empirical estimation. We do not disregard the contribution made by authors of existing work. Rather, we highlight the startling misunderstandings that can arise when the results are applied simplistically and uncritically to the emerging “silent crisis” of climate change (GHF, 2009). We seek to highlight priorities and offer guidance for research going forward. Our focus is on the UK but many of our arguments will be applicable to other countries facing anticipated increases in flood frequency and severity (see GHF, 2009, pps. 15-16, 20, 40, 49).

The paper proceeds as follows. Section 2 summarises the evidence on climate change and the anticipated implications for flood risk in the UK. Section 3 surveys the existing housing economics literature on flood risk and notes some of the common statistical and technical irregularities. Sections 4 and 5 discuss the “bounce-back” effect and our reasons for being sceptical about applying it to the impacts of future floods. Our arguments are structured so as to demolish four “straw men” labelled: (i) *The Fallacy of Replication*, (ii) *The Fallacy of Composition*, (iii) *The Fallacy of Linear Scaling*, and (iv) *The Fallacy of Isolated Impacts*. Section 6 concludes with implications for housing research.

2. Climate Change and UK Flood Risk

According to the International Energy Agency (IEA, 2007), overall global carbon dioxide emissions are likely to reach 12-15 gigatons (Gt) by 2030. "There seems little doubt that, under [Business as Usual], the annual increments to stocks [of CO_2] would average somewhere well above 3ppm CO_2e, perhaps 4 or more, over the next century. That is likely to take us to around, or well beyond, 750ppm CO_2e by the end of the century. If we manage to stabilize there, that would give us around a 50-50 chance of a stabilization temperature increase above 5°C" (Stern, 2008, p.5) [1]. Such an increase would lead to rising sea levels of ten metres or more as a result of thermal expansion of the oceans and melting ice sheets (Houghton, 2009).[2]

Combined with increased storminess and precipitation, the effect will be to exacerbate flood risks significantly in many areas. Foresight (2004) estimated that the number of people in England and Wales at high risk from coastal and river flooding could increase "from 1.6 million today, to between 2.3 and 3.6 million by the 2080s. The increase for intra-urban flooding, caused by short-duration events, could increase from 200,000 today to between 700,000 and 900,000" (Foresight, 2004, p.18). These figures are likely to underestimate the overall flood risk as they do not consider pluvial (surface water) flooding. Urbanisation and road building, and more intensive agricultural methods have increased the problems of both urban and rural run-off (Hollis 2003 quoted in RICS 2009, p.17). The Environment Agency estimates that around 3.8 million properties are at risk of surface water flooding (RICS, 2009).

Such increases in flood risk could reshape the social-welfare geography of Britain. With changed flood risk will come changes to the landscape of deprivation, housing shortages and homelessness, as the house price fluctuations sort households by their ability to afford accommodation in low-risk areas. The adjustment could entail social upheaval, economic disruption and welfare loss for significant proportions of the population, not least for those whose main source of saving for retirement has been depleted by the impact of rising flood risk. This provides an imperative for housing economists to understand likely scenarios of geographical and economic consequences of rising flood risks. Unfortunately, the existing literature on the relationship between house prices and floods may not be a reliable guide, as we now explain.

3. Methodological Problems in the Housing Economics of Floods

Until recently, the housing economics literature on floods was largely limited to North America. Improved data and major flood events have started to attract research in the UK and elsewhere. Methods employed have included t-tests on average prices of properties before and after a flood event or within and outside of floodplain locations (Zimmerman, 1979; Babcock and Mitchell, 1980; Tobin and Montz, 1989); repeat sales analysis (Hallstrom and Smith, 2005; Lamond and Proverbs, 2006), and difference-in-difference methods (Bartosova *et al*., 1999; Bin and Polasky, 2004). Hedonic approaches (MacDonald *et al*., 1987; Bin and Kruse, 2006; Pope, 2008) have also been employed, yielding an estimate of the implicit price ("willingness to pay") for a reduction in flood hazard while controlling for property attributes (Freeman, 1979; Palmquist, 1984). In an efficient market, such willingness to pay should be capitalised into property value, resulting in price differentials between those with and without flood risk.

Many studies do indeed show that properties located in a floodplain are valued lower than comparable ones outside of the floodplain. But the magnitude of such a price discount varies, and is sometimes negligible. MacDonald *et al*. (1987) find that floodplain location in Monroe, Louisiana, lowers house prices by 6% to 8%. Speyrer and Ragas (1991) show that high flood risk in New Orleans reduces house prices by 4.2% to 6.3%. Pope (2008) reported that floodplain location results in house price discount of 3.8% to 4.5% in North Carolina. A few studies show zero, or even positive (Morgan, 2007), impacts of flood risk on house prices. Zimmerman (1979), for example, found no significant difference between average house values for properties located within and outside of floodplains in New Jersey (though the results were based on simple t-tests without controlling for property attributes). Similar conclusions were reached by a recent repeat-sales study in the UK (Lamond, 2009), reporting that high flood risk has no effect on property values in areas with no recent flood events (though sample sizes in some areas are very small).

In addition to research on *flood risk*, there have been a number of studies examining the house price effect of a particular *flood event*. Again, the results are mixed: some find the flood effects to be negative (Harrison *et al*., 2001; Bin & Polasky, 2004), while others show evidence of muted or positive impacts, possibly as a result of post-flood renovation and improvements (Babcock and Mitchell 1980; Tobin and Montz, 1989). The methods used are often primitive. Tobin and Montz (1989), for example, use simple Kolmogorov-

Smirnov tests without controlling for property attributes. That some studies (Fridgen and Schultz 1999, Bin and Polasky 2004) have found evidence of price falls following a flood for properties on recognised floodplains does at least suggest that flood risks are only partially capitalised into property values.

To summarise, there seems to be a lack of empirical consensus, both on the house price effects of flood risk and of flood events. The variable results may be due to genuine differences in socio-economic dynamics across study areas, but may equally be the consequence of methodological weaknesses and inconsistencies. Some studies are based on small samples[3], and others fail to adequately control for property attributes (house type, location and waterfront amenities)[4] which can cause significant bias (Daniel *et al.*, 2009).

4. The Bounce-Back Effect

Improved sample sizes and econometric proficiency will not, however, be sufficient to address the deeper set of problems that arise from extrapolating the results of historical studies which assume climate stability. Consider, for example, the question of whether the "bounce-back effect", first proposed as a theoretical possibility by Tobin and Newton (1986) and then observed in a number of empirical house price studies, will characterise housing markets in a world subject to global warming.

Tobin and Newton (1986) identified three profiles depicting flood impact on land/property values. Their first stylised outcome was characterised by a "bounce-back" effect where house prices fall immediately after a flood event and then recover. This profile occurs when a long time gap exists between two flood events and people tend to forget flood risks. Montz (1992) further indicated that post-flood house prices might exceed pre-flood levels because of renovation and quality improvement. A second possible outcome was substantial fluctuation of property values over time, as a result of periodic flooding and the ability of the market to recover. This profile occurs when the market has sufficient time between two flood events to recover. Finally, should flooding occur frequently, property values would remain low because the market does not have enough time to recover between events. In this case, flood risks have become entirely capitalised into house prices, and future floods have no impact on property values.

A number of empirical studies have apparently confirmed the bounce-back effect (Tobin and Montz, 1994; Eves, 2002). Lamond and Proverbs (2006), the first UK analysis of the house price impacts of floods to be based on transactions data,[5] found that the effect of the 2000 flood in a small town in Yorkshire was indeed temporary, lasting less than three years (p.363). They concluded that their results gave "confidence to the community, lenders and insurer to invest in the reinstatement of the property" (p.375). Subsequent work by Lamond (2009) on 13 locations in England and Wales during 2000 and 2006 provided further evidence that flood impact on property values in the UK tends to be temporary, leading Brown (2009) to conclude that, "for the majority of homeowners, the medium term investment potential of their flood-plain properties is sound" (p.19).

Under the assumptions of perfect information and climatic stability, the bounce-back effect might indeed be interpreted as evidence of market resilience. However, if the housing market is imperfectly informed, the bounce-back finding could indicate failure of markets to consistently price risks, with ominous implications if those risks are set to rise. Reversion of prices to pre-flood levels could be due to market *amnesia*—the tendency for markets to forget, and market *myopia*, the tendency for markets to have short time horizons (Pryce *et al*., 2011). Such failures permit significant discrepancies to emerge between risk-adjusted and observed prices, including dwellings subject to coastal erosion (DEFRA 2009). However, prices must adjust eventually—once a dwelling falls into the sea, its price will be zero, even if the market is spectacularly buoyant. This is the adjustment of the worst kind: sclerosis followed by catastrophic tipping-points.

Unfortunately, the dysfunctionality observed in contemporary market dynamics may be analogous of how the housing system will adjust to climate change. If that is the case, a policy priority should be to help markets adjust gradually and in a timely fashion, so as to minimise the distortions to current planning and investment decisions (consider, for example, 133,600 new homes were constructed on floodplains in the UK over the period from 1996 to 2005 (Kenna, 2008)).

5. The Four Fallacies of Extrapolation

Having considered an example of how sanguine interpretations of observed historical patterns (the bounce-back effect) can belie portentous consequences (the looming failure of markets to adjust efficiently to climate change), we now present a shortlist of critical pitfalls and boondoggles which could beset the housing economist. We present our concerns under the guise of four “straw men” which we shall seek in turn to demolish: (a) *The Fallacy of Replication*, (b) *The Fallacy of Composition*, (c) *The Fallacy of Linear*

Scaling, and (d) *The Fallacy of Isolated Impacts*. We propose that these are not so much failings of the existing research, as of attempts to extrapolate them to a future that is likely to be characterised by climatic instability.

(a) The Fallacy of Replication: *"Properties that currently experience floods are of type x and not type y. Therefore, properties that experience floods in the future will also be of type x, and not type y."*

This syllogism is false because properties that currently experience floods may not be typical of those that experience floods in the future. The fallacy is akin to the sample selection problem—the data on which we base our estimation may give a distorted picture because they are not typical of those for which we are making predictions. For example, studies which look at the impact on average prices derived from transactions, face the problem of favourable selection bias: properties that trade may be the least badly affected by floods. Consider the effect of Hurricane Katrina which destroyed or severely damaged 217,000 properties in 2005 (Paxson and Rouse, 2008). Even if the selling prices of transacted properties in New Orleans had apparently rebounded in the following year, the observed trajectory would ignore the value of homes that did not transact, including those that did not trade because of abandonment and devastation. Hence, it is important to distinguish the average value of the housing stock from the average value of houses that transact. The latter may underestimate the impact of floods on wellbeing and the true economic cost.[6]

There are a number of reasons to believe replication bias will increase when we use past events to predict future effects. Firstly, the proportion of flooded dwellings that have waterfront views may decrease. It is only relatively recently that hedonic studies of flood risk have considered the amenity value associated with waterfront location (views and access to boating etc.).[7] Bin and Kruse (2006), for example, find that dwellings on floodplains far from coastal waters have property values significantly lower than those on floodplain but with waterfront locations, which suggests that there exist significant premiums associated with proximity to coastal water (see also Bin *et al*., 2008).

An important implication of climate change is that it is likely to extend considerably the range of dwellings affected by floods (Foresight, 2004); i.e. we may see a much higher proportion of properties being flooded that do not benefit from offsetting price effect of waterfront views. Moreover, we must not neglect the possibility of heterogeneous preferences. It is feasible, for example, that individuals who place a high value on waterfront views and who are also unperturbed by the prospect of occasional floods already live in those locations. We cannot assume that the wider population of owners of houses subject to flooding in future will respond in quite the same way.

Similarly, climate change may expose to flood risk properties that have low physical resilience. Dwellings in areas with a history of flooding may have greater resilience because of the cumulative effect of building control (only properties with flood-resilient designs have been built) and/or natural selection (only flood-resilient properties have survived repeated floods). If climate change implies that a much wider geographical spectrum of houses will be affected by flooding and subsidence (caused by swelling and contraction of underlying soil) then future price effects will greatly exceed those observed in the past.

Thirdly, the behavioural response to floods may change as the climate changes. If, in future, we see floods in areas with no previous experience of flooding, the price effect may be greater because it will entail "virgin risks" updating their prior beliefs (Kousky *et al.,* 2008). One of the implications of Tversky and Kahneman's (1973) classic paper on behavioural responses to uncertainty is that the increase in perceived risk will be much greater for virgin risks than for "experienced risks" (Kousky *et al.,* 2008). These behavioural heterogeneities suggest that we must be cautious about extrapolating price falls from areas that have been flooded frequently to elsewhere.

(b) The Fallacy of Composition: "Significant financial safety nets are viable if a single area is flooded. Therefore, significant financial safety nets will be viable if all areas are flooded."

This fallacy says that behaviour of the entire system will reflect the behaviour of its constituent parts. The "paradox of thrift" is perhaps the best known economic illustration of this category of error, where one mistakenly assumes that because increased saving from a single household is beneficial to that household, the same will be true of all households if they all increase their propensity to save (the deleterious effects are all the more acute during recessions where increased savings rates exacerbate the downward spiral of aggregate demand). Another example is that of bank runs. It is of little consequence to a bank if a single customer decides to withdraw her savings; the effect is catastrophic if all depositors decide to withdraw.

With respect to climate change, there are two important *fallacies of composition* worth highlighting, those with respect to (i) insurance markets, and (ii) state bailouts:

(i) The Moral Hazards of Insurance: In an efficient market, the long-run cost of annual premiums will equate to the long-run cost of flood damage. Therefore, annual insurance premiums should reflect average annual flood damage plus insurance administration costs (Foster, 1976). By implication, the price differential between flood-liable and flood-free properties will, in theory, be equal to the present value of the future flood insurance premiums required to offset the risk of flood loss on properties within the floodplain. While some studies find evidence in support of this theory (MacDonald *et al.,* 1987; Shilling *et al.,* 1985), others have found that the price discount of floodplain location is less than the present value cost of future flood insurance premiums, possibly because property buyers are imperfectly informed and tend to underestimate flood risk (Harrison *et al*., 2001; Chivers and Flores, 2002). Harrison *et al*. (2001)'s study is particularly interesting as it exploits the 1994 National Flood Insurance Reform Act (introduced to increase take-up of flood insurance) as a natural experiment. Perversely, the price discount due to floodplain location was found to be much *greater* after the implementation of the Act in Alachua County, Florida. This result suggests that mandatory insurance increases individuals' awareness of flood risk (see also Raschky and Wech-Hannemann, 2007).

Information imperfections in insurance may have a profound and worrying implication when considered in the context of climate change. This is particularly relevant to the UK where the flood insurance system deviates significantly from the efficient market prototype, as the system guarantees almost complete insurance cover at subsidised rates (ABI, 2007). It is important to note that observed price impacts of recent UK floods have occurred under a benevolent insurance regime, founded on a gentleman's agreement between the Association of British Insurers (ABI) and Government since the early 1960s (Arnell *et al*., 1984; Crichton, 2005). This agreement rests on a stable division of responsibility: government provides flood protection (e.g. defences), and insurers offer comprehensive flood insurance which is typically included in building cover together with fire and theft insurance to households in all areas (Huber, 2004; Crichton, 2005). Essentially, low risks subsidise high risks whose premiums do not reflect their true risk (Huber, 2004).

If current house price adjustment reflects a perception that the gentleman's agreement will perpetuate indefinitely, then it is likely to represent information asymmetry on a grand scale. The UK system is acutely vulnerable to systemic risk; it survives so long as floods remain infrequent and independent (Green and Penning-Rowsell, 2004). Climate change undermines both of these requisites.

Following the huge insured losses for the widespread flooding in the UK in 1998, 2000 and 2007, the ABI has already started to revise its stance by proposing differentiated premiums for homeowners in areas with high flood risks (Crichton, 2005). Although the core of the gentlemen's agreement remains intact, the insurance industry now only agrees to provide flood cover to properties which are defended under the flood risk of once in 75 years, i.e. the probability of properties being flooded in any single year is lower than 1.3%, or to properties where such defences are under construction and will be completed before 2013 (DEFRA, 2008).

Perhaps the most worrying implication of insurance rationing is the knock-on effect for mortgage finance. Mortgage companies are unlikely to offer loans secured on properties vulnerable to flooding but without adequate insurance cover. Existing major UK floods occurred in a financial environment that ensures prospective buyers of flood-liable properties will be able to obtain both insurance and mortgage finance. It is perhaps not surprising that price effects have so far been negligible and temporary. However, once this regime starts to break down, the price effects of floods could be marked, most notably in those flood-prone neighbourhoods abandoned by insurers and mortgage lenders. The current regime of subsidised premiums distorts house price signals and perpetuates the belief that comprehensive insurance will always be available. It weakens not only the incentive for builders to avoid building on floodplains, but also the motivation for households to take reasonable measures to reduce their exposure to floods (Treby *et al.*, 2006).

(ii) *The Moral Hazards of State Bailouts:* We succumb to a similar fallacy if we assume that, because governments can provide relief and enhanced defences in the aftermath of moderate, infrequent and isolated floods,[8] they will be able to do the same when floods become extreme, frequent and commonplace. As much as political parties would like to promise limitless resources for resilience and adaptation, pressures on public sector borrowing, finite tax revenues (particularly during recessions), and competing demands on public funds (health, education, social security, pension commitments, defence) will present governments with "tough choices". In the UK, it is not at all clear that households are aware of the limits to government intervention. As noted, under the "gentleman's agreement", responsibility for compensating households for flood damage rests squarely with private insurers. Only limited emergence relief is available through means-tested Mayors' Funds (Arnell *et al.*, 1984; Treby *et al.*, 2006). The uninsured are therefore largely unprotected, often to the surprise of those affected. For example, immediately after the 2007 Hull floods, victims expressed despair at the lack of government aid (Stevens, 2007).[9] Moreover, the ability and responsibility of government to provide comprehensive flood defences can be widely overestimated. The Welsh Audit Office (2009) report, for example, notes that, "many residents of coastal areas still believe coastal defence to be entirely a responsibility of the authorities" (WAO, 2009, p.10), even though the report makes it clear that this is not the case, and increasingly less likely in future. Note that, even where expectations of government help are not entirely misplaced, state-dependence can have negative effects. For example, "charity hazard" can occur where households neglect obtaining insurance cover or take mitigation measures against natural disasters because they expect financial aid from government or donations from elsewhere (Browne and Hoyt, 2000; Raschky and Wech-Hannemann, 2007).

(c) The Fallacy of Linear Scaling: "The impact of a flood of severity, y, is of magnitude z. Therefore, the impact of a flood twice the severity of y, will be twice the magnitude of z."

This fallacy presumes that one can linearly extrapolate from the effects of small floods to gauge the effects of large floods. Such reasoning is flawed because it fails to recognise likely tipping-points. Small, shallow floods of low velocity may have no effect on house prices. Beyond a certain scale of flood severity and frequency, however, the house price effect is likely to increase disproportionately. Structures entirely unaffected by 2cm of flooding from slowly moving water, could be completely obliterated by floods one hundred times the depth moving at one hundred times the speed. Flood frequency may have similar non-linear effects. Bartosova *et al*. (1999), for example, found that property values increased by 2.3% as expected flood intervals lengthened by 10 years, but the effect disappeared entirely once the time-lapse between floods exceeded 33.3 years.

We now set out three additional reasons why we should be sceptical of linear extrapolations:

(*i*) *Labour market effects:* A fundamental driver of residential land value is access to employment, determined by both the proximity and size of employment centre (Fujita 1989). Small floods with low frequency may have minimal or temporary implications for employment, as local firms successfully weather the storm (Sarmiento 2007). Beyond a certain scale or frequency, however, we would expect floods to cause firms to relocate as the benefits of moving to a low flood risk area outweigh the costs. How far firms have to move to find an economically viable location depends crucially on the extent of flood vulnerability. The more firms move away, and the further they move, the more difficult it is for other firms to remain. Component suppliers, retail outlets, distribution firms, maintenance firms and office suppliers are all interconnected in a chain of production, which leads to possible tipping-points in the out-migration of industry. This in turn produces tipping-points in household location, housing demand and house prices.

(ii) Social Network Effects: Most residential moves are local (Clark and Huang, 2003) due to workplace, family and social networks. Sustained out-migration again implies tipping-point effects as networks unravel. As each additional person in a network moves away from an area of flood risk, there is less of a social incentive for the rest to stay, and this induces systemic instability and non-linear dynamics. Moreover, those that remain, may be the least mobile and least economically productive, exacerbating local economic decline. The existence of non-linearities in social networks is well recognised (e.g. Quercia and Galster, 2000), though the role of floods as a catalyst appears to be under-researched. We do know that Hurricane Katrina displaced about 650,000 people in 2005 and only 49.5% of households displaced had returned by August 2006; 66% by June 2007 (Paxson and Rouse, 2008). An important factor in households' decision to return was how successfully they anticipated being able to rebuild their existing network or find new social networks (Paxson and Rouse, 2008). Both may be highly contingent on expectations of government aid, and the anticipated timescale and severity of repeat floods which are likely to be adversely affected by climate change.

(*iii*) *Psychological and Informational Effects:* Humans have a tendency to underestimate risks that appear distant or global, or which others seem to accept without concern (Kousky and Zeckhauser, 2006). Recent studies indicate that buyers may not have full information about properties due to high search costs and sellers' unwillingness to reveal information about dis-amenities such as flood risk (Chivers and Flores, 2002; Lammond, 2009). Disclosure of flood risk is therefore likely to decrease market value (Troy and Romm, 2004; Pope, 2008). While individuals may underestimate flood risk, this may not be true if floods become frequent and ubiquitous, because flood events raise people's awareness of potential risk (Bin and Polasky, 2004). Even in years when a particular dwelling is not flooded, the prevalence of flooding elsewhere, communicated via accounts in news reports and social dialogue, will act as constant reminders of the household's flood risk. People will not forget because the climate and media will not be permit them; and the bounce-back effect will become a thing of the past (Pryce *et al.*, 2011).

(d) The Fallacy of Isolated Impacts: "The price of house A is reduced because it is flooded. House B is not flooded and, therefore, its price will not be reduced, irrespective of its proximity to A."

This fallacy leads us to conclude that the effects of floods at one location will not have implications for neighbouring houses that do not experience flooding. The conclusion is spurious because of *spatial spillovers*. Hallstrom and Smith (2005), for example, found a 19% decline in house prices in floodplains close to, but not directly affected by, Hurricane Andrew. In the follow-up survey of those who had moved away as a result of Hurricane Katrina, Paxson and Rouse (2008) found that 36 percent of those who had ***not*** experienced flooding had not returned to New Orleans. Clearly, those in neighbourhoods and communities surrounding flooded areas can experience upheaval because of the impacts on infrastructure, supply chains and access to amenities. Spatial spillovers may also arise due to households updating their prior beliefs about flood risks in the aftermath of nearby floods.

Spatial dependencies lead to an important methodological error in studies that compare the prices of houses that were flooded with those that were not. If dwellings that were not flooded were nevertheless subject to a negative price impact of the flood due to spatial spillovers, then the house price impact of the flood computed from such a comparison could greatly underestimate the true impact. This is essentially a failure to establish the counterfactual. In order to gauge the true impact of a flood, the trajectory of prices for flooded houses has to be compared with the trajectory that would have occurred if there had been no flood. Unfortunately, neighboring houses that were not flooded cannot be assumed to provide a reliable guide to the latter trajectory.

Another important implication of spatial spillover effects is that they can overlap, especially when floods occur simultaneously in different locations in the same region. In the past, the likelihood of simultaneous disasters may have been remote. However, this is less likely to be the case in future due to the combined effect of rising sea levels, more potent and frequent extreme weather events and storm surges. Overlapping spillover effects from multiple hot-spots of risk could imply spatial tipping-points in areas caught at the intersection of concentric house price ripples. Understanding these spillover effects and their interactions is therefore vital to our understanding of the effect of climate change on the house price map of countries like the UK where many major cities are located on coastlines or in flood-prone areas.

6. Conclusion

How can housing economics contribute to our understanding of the socio-economic consequences of climate change? One of the most potent consequences of global warming is the prospect of significant increases in flood risk. The intrinsic spatiality of flood risk, and the potential for house prices to reveal the money value of spatial variation in human welfare, indicate that housing economics may be uniquely placed to enhance our understanding of the flood impact on wellbeing. House price effects are also of interest because of their implications for financial stability, both for lenders using real estate as collateral, and for households relying on housing wealth as a source of saving for retirement.

Unfortunately, the housing economics literature on floods has so far developed largely under the assumption of climatic stability. This is not necessarily a criticism of the existing studies. It does, however, raise two imperatives going forward. First, we must be aware of the fallacies associated with extrapolating future impacts from these results. Second, there is a need to provide housing economics with appropriate theoretical and methodological frameworks to facilitate meaningful connections with climate change.

In this paper we have highlighted four fallacies that have the potential to distort our interpretation of the current literature when seeking to understand future risks: (a) *the fallacy of replication* (the assumption that properties flooded in future will be the same as those flooded in the past), (b) *the fallacy of composition* (the assumption that, because significant financial safety-nets are viable when a single area is flooded, equivalent safety-nets will be viable if all areas are flooded), (c) *the fallacy of linear scaling* (the assumption that the negligible, transient effects of small and infrequent floods can be multiplied to give a measure of the impact of substantively more frequent and severe floods), and (d) *the fallacy of isolated impacts* (the assumption that there are no spatial spillovers from the impacts of floods and that there is no overlap of impacts from multiple flood risk hot-spots).

A step change is needed in how housing economics connects with climate modelling. New theoretical frameworks and estimation approaches need to be developed to yield estimates that rest on assumptions more aligned with the predicted climate instability. There are particular areas where housing economics needs to develop in order to avoid the *Four Fallacies*:

Firstly, models need to be based on paradigms that incorporate the tendency for house prices to drift from their risk adjusted levels, and allow this tendency to change as floods become more frequent. Unlike some environmental effects such as pollution, flood *risk* may not directly affect current utility (other than through anxiety). While hedonic methods are useful in measuring the effects of externalities that are current and persistent (such as air pollution – see Boyle and Kiel (2001)), the approach may not yield reliable estimates of the impacts of risk. Bounded rationality and imperfect information mean that human decision making may not cope well with the prospect of uncertain loss (Rabin, 1998; DellaVigna, 2009). Moreover, house price dynamics will be fundamentally different in response to a flood event if it is perceived to be a one-off event, rather than a portent of inexorable rise in risk. The theoretical paradigm underpinning empirical modelling needs to shift from one that assumes perfectly informed and efficient markets to one that allows for amnesia and myopia (Pryce *et al*., 2011). One interpretation of the bounce-back effect, for example, is that it is evidence of these effects rather than of genuine market resilience.

Secondly, models need to account for the fact that current insurance premiums may not fully reflect the risk of flooding, and that this arrangement may be neither desirable nor sustainable. Insurance provision and state safety nets may become very different in a world of frequent and severe flooding. Therefore, adjustments need to be made for the impacts of insurance rationing and associated mortgage rationing.

Last, but not least, models of flood impacts need to differentiate the impacts of floods on different house types so that anticipated changes in the types of dwellings affected by future floods can be simulated. Empirical modelling should also attempt to trace out the non-linear nature of house price responses to floods of different severities and frequencies, allowing for spatial spillovers and potential spatial tipping-points.

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[1] Even these estimates may prove optimistic because they omit the very real possibilities for feedback loops to occur in the carbon cycle due to, for example, “release of methane from the permafrost, the collapse of

the Amazon, and thus the destruction of a key carbon sink, and reduction in the absorptive capacity of the oceans" (Stern, 2008, p.5).

[2] "At an increase of 5^{o}C, most of the world's ice and snow would disappear, including major ice sheets and, probably, the snows and glaciers of the Himalayas. This would eventually lead to sea-level rises of 10 meters or more... There would be severe torrents in the rainy season and dry rivers in the dry season... Storms, floods, and droughts would probably be much more intense than they are today" (Stern, 2008, p.6)

[3] Tobin and Montz (1989) base their conclusion of market resilience on the comparison of prices of just 62 properties before and after the 1985 flood in California. The Lamond and Proverbs (2006) findings of negligible house price impacts of floods are derived from 159 property sales during 2000 and 2006.

[4] Some studies, particularly those which compare average house prices using analysis of covariance (ANCOVA) or simple t-tests, such as Soule and Vaughan (1973) and Montz (1992), do not control for housing quality.

[5] All previous UK research had relied on surveys of expert opinions such as BFRG (2004) and Eves (2004) or other indirect methods.

[6] Note that transactions bias could be exacerbated if repeat sales methods are used since the sample is only comprised of properties that were sold at least twice over the period of interest.

[7] Earlier work by BFRG (2004) and Eves (2004) mentioned positive values of floodplain amenities through views of chartered surveyors.

[8] For example, in the Lamond and Proverbs (2006) case study area, government provided £10m for flood defense improvements following the flood event.

[9] Such effects are not limited to flood risk. Nelson (1981), for example, attributed the failure to find any significant impact on house prices of Three Mile Island nuclear to residents' expectation of government aid (see Boyle and Kiel (2001) for a review of the wider literature on using house prices to value environmental effects).

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