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The Great North Sea Flood of 1953, The Deltaworks and the spatial distribution of people

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The Great North Sea Flood of 1953, The Deltaworks and the spatial distribution of people

Trond Grytli Husby, Henri L.F. de Groot, Marjan W. Hofkes
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November 30, 2012

Abstract

Large shocks, such as natural disasters, are often found to have little or no effect on the equilibrium distribution of economic activity across space. Two apparently competing theoretical explanations for this phenomenon are the increasing returns theory and the locational fundamentals theory. This study investigates the population dynamics resulting from the flood that hit the Netherlands in 1953 and from the mitigation measures that followed it. A dynamic difference-in-differences analysis reveals that the flood had an immediate negative impact on population growth, but limited long term effects. The mitigation efforts, gathered under the Deltaworks Programme, are on the other hand found to have had positive effects that are persisting through time. Our results are consistent with both the theory of increasing returns and that of locational fundamentals. The results also suggest that the combined long term effect of the flood in 1953 and the mitigation measures that followed was an increased concentration of population in vulnerable area.

JEL Classification: N32, N94, R12, R23, Q54

Key Words: Regional population growth; Zipf's Law; Natural hazards; Flood risk management; Difference-in-differences regression

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1 Introduction

...historically the Dutch have made the decision that absolutely they will protect their citizens from flooding...[I]t goes without saying that the Dutch WILL protect their people...The citizens of Holland are not even really aware they live and work below sea level. Because it's irrelevant.

Journalist Sandy Rosenthal, accompanying U.S. Senator Mary Landrieu on a congressional delegation visit to the Netherlands (Rosenthal, 2009)

The number of casualties worldwide attributable to natural disasters, such as major floods, have declined steadily over the past decades. Early-warning systems, stricter building codes and better evacuation routines have all contributed to making disasters less deadly. But at the same time, the economic costs of disasters are increasing. The re-insurance company Munich Re estimates the economic costs attributed to natural disasters in 2011 to 380 billion USD, a new record (Munich Re, 2012). *The Intergovernmental Panel on Climate Change* finds in a recent report that the main explanation behind the increase in economic impact lies in an increasing concentration of population and GDP in areas at risk (IPCC, 2012). Thus, as the world grows richer, the ability to protect citizens from disasters also increases. But at the same time, citizens settle and businesses establish themselves in areas at risk, thereby raising the potential damages and thereby disaster costs. This raises an intriguing possibility: can public investment in flood protection lead to a "crowding out" of private self protection, where people ignore the risk of settling in disaster-prone areas?¹ To answer such a question, it is important to investigate the *mechanisms* that lead people and businesses to concentrate in some places and not in others. In a world of climate change and rising sea levels, the dynamics of the spatial distribution of population and economic activity are high on the agenda of policy makers involved in decisions on which level of flood protection should be offered to different regions. But these dynamics are also important for decisions regarding reconstruction of flood-struck locations, such as New Orleans. As argued by Glaeser (2005), reconstructing New Orleans to its pre-Katrina state makes little sense from an economic point of view, as it was a city in decline already before the disaster.

The spatial distribution of population over time as well as its underlying dynamics, have been discussed simultaneously in the urban economics and in the new economic geography literature. Discussions have often been centred around the so-called Zipf's Law — an empirical regularity regarding the log-linear relationship of the city-size distribution. An influential theoretical explanation for Zipf's Law is offered by Gabaix (1999), who applies the famous Gibrat's Law to cities. In this view, cities grow randomly with the same individual expected growth rate and variance, regardless of their initial size. A result is that the rank size distribution of cities follows a power law. As such, a major shock to the economy like a natural disaster should not influence the long term growth

¹See e.g. Boustan *et al.* (2012) for an empirical investigation.

rate — affected areas should after a time of adjustment return to their growth trajectories. One alternative explanations for Zipf’s Law is offered by the theory of increasing returns and another by the theory of locational fundamentals. These less mechanical theories both try to account for the microfoundations behind the spatial distribution of people. The former is mainly based in the literature of urban economics such as Henderson (1974) and the latter has its roots in physical geography. Both theories will be explained later.

This study intends to shed some light on the consequences of historical floods by examining the population dynamics following the major flood of 1953 in the Netherlands. The empirical literature has found that large temporary shocks have discernible effects on the long term spatial distribution of population. But there is evidence that policy interventions can produce long term effects. The flood in 1953 was an impetus behind an extensive construction of flood protection measures, gathered under the name the Deltaworks. We use a data base of municipality-level population in the Netherlands, covering the period 1947 to 2000, to investigate the population dynamics following the flood of 1953 and the Deltaworks programme. We investigate whether our data set exhibits similar dynamics as those found in the empirical literature. If so, we would expect to see some negative impacts from the flood, but only on the short term. Long term impact would be attributable to the Deltaworks programme, but these effects would have the opposite sign. We wish to interpret the results in light of the theories of locational fundamentals and of increasing returns. Instead of arguing in favour of one or the other we follow Redding (2010) and view them as complementary.

The flood in 1953 as study area is relevant in at least two contexts. The flood and the flood defence construction in its aftermath provide a natural experiment, allowing us to contribute to the scholarly debate within economics. But this historic incident may also provide valuable policy lessons. We shed light on some consequences of the historical Dutch ”battle against the water”, a battle fought primarily through heavy investment in protection. The technical expertise of the Netherlands is hailed as offering advices on how other countries should protect their people and property from flooding. Dutch experts are regularly called to provide policy advice to US policy makers.² Our results suggest that the Dutch experience also shows that heavy reliance on protection as a policy strategy may have consequences of its own. As such, not only the technical expertise but also the historical experience of the Netherlands may provide inputs to policy makers in other countries.

In order to clarify the discussion some terms need to be defined. Risk is, as is common in the economic literature, conceptualised as a function of probability and exposure. When referring to flood mitigation this is thought of as actions aimed at preventing a disaster from occurring. Examples of such strategies are building of dikes and closing off of estuaries and sea arms — historically the most important mitigation strategy employed by the Dutch government. Adaptation refers broadly to actions undertaken in order to minimise the impact should a flood occur, including relocation/migration.

The paper is organised as follows: in section 2 Zipf’s Law will be illuminated, using both theoretical explanations as well as empirical results. Section 3 presents the historical background of floods and flood protection in the Nether-

²See e.g. NY Times (2012) and Aerts & Botzen (2012).

lands. The collection and processing of the data will be accounted for in section 4, followed by a discussion of the methodology in section 5. Finally, section 6 discusses results while conclusions are drawn in section 7.

2 Zipf's Law

Besides the random growth theory in Gabaix (1999), the links between growth and population distribution have been dealt with by two distinct theoretical approaches. The theory of increasing returns explains the size of cities as a result of tensions between agglomeration and congestion forces inherent in modern economies. Such agglomeration forces include knowledge spillovers, labour market pooling and transportation costs. One important element in this theory is the possibility of multiple equilibria: there may be several candidate long term growth rates, and as such the theory is not necessarily consistent with Gibrat's Law. The theory of increasing returns is however not at odds with Zipf's Law. The self organisation of cities resulting from agglomeration forces may well produce a stable city size distribution over time (Gabaix & Ioannides, 2004).

An alternative view is the locational fundamentals theory. This theory posits that the economic attractiveness of each location is determined by some fundamental geographical factors. One example of such factors is access to communication, represented by be closeness to water.³ The theory locational fundamentals is consistent with Gibrat's Law in the sense that growth rates are independent of city size. But, in contrast with the random growth rates, the locational fundamentals theory posits that it is the locational factors, instead of the growth rates themselves, which follow a random distribution. The rank size distribution following the random distribution of locational factors is in line with Zipf's Law (Krugman, 1996).

The two theories differ with regards to predictions of the effects of a large and temporary shock. In accordance with the theory of increasing returns, such a shock could well have a permanent effect on the distribution of population. One of the main features of models under this category is, as mentioned, the existence of multiple equilibria. A large shock could, for example, push a city from equilibrium to another. The locational fundamentals theory would, on the other hand, predict greater persistence in population distribution: as long as a shock does not alter the geographical characteristic locations, the spatial distribution of population should not change. Empirical studies have investigated the population dynamics following large shocks in order to find evidence supportive of any of the theories. In an influential study, Davis & Weinstein (2002) find that the bombing of Japanese cities during WWII had (surprisingly) little effect on the long term rank size distribution. Accordingly, they conclude that their evidence is largely supportive of the locational fundamentals theory. In a similar fashion, Bosker *et al.* (2008) investigate the impact of Allied bombing on the city size distribution of German cities. They reach the opposite conclusion, namely that WWII had a long term effect on the rank size distribution. The authors find their results to be more in line with the theory of increasing returns. However, Redding & Sturm (2008) argue that the division and subse-

³Hallegatte (2011) shows for example that the rapid economic development in high risk locations — predominantly in coastal areas — can be consistent with rational and well informed decisions.

quent reunification of Germany were the main driving force behind the changes in rank size distribution. They suggest that the temporary shock did not have lasting effects on the city size distribution, but that policy interventions did. Such a result is somewhat puzzling, as it apparently does not seem to favour any of the two theories mentioned. Instead, the two theories should be seen as complementary rather than competing (Redding, 2010).

3 Historical background

3.1 Historical floods and policy: the Dutch case

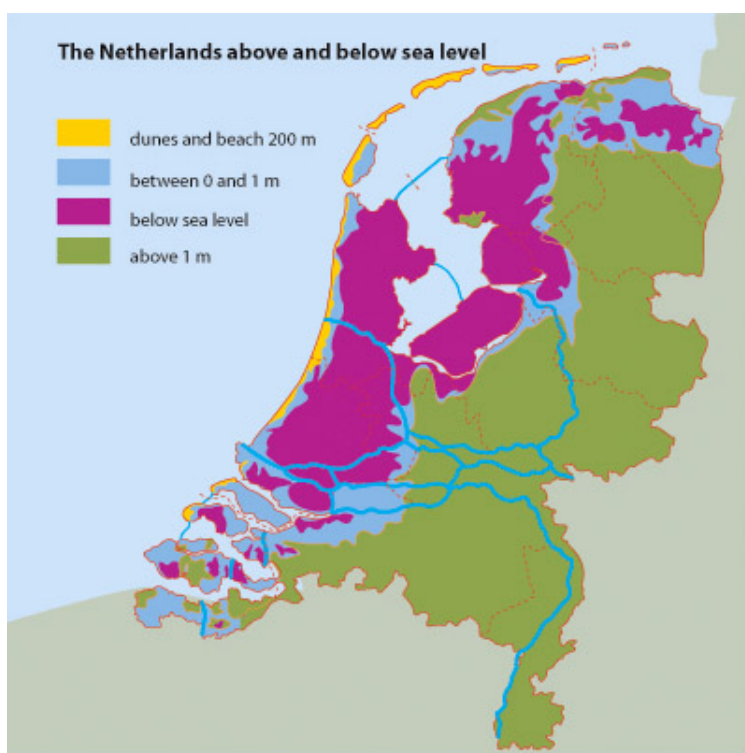


Figure 1: The Netherlands. Source:Deltaworks (n.d.)

The mere topography of the Netherlands indicates the central role of flood protection in national policy making. One quarter of the land is situated below mean sea level and the country hosts the estuary of four large rivers. In case of a storm surge at sea or high river discharges, as much as two thirds of the country would be inundated. Not surprisingly, Dutch history and institutions are marked by the constant fight against water. The Dutch Water Boards, dating back to the twelfth and thirteenth century, were given the responsibility for the flood safety in their particular regions. Following their establishment a systematic enclosing of rivers and formation of polders begun. Current flood defences are to some extent an extension of protection strategies outlined centuries ago.

The main protection against river flooding continues to be dikes, whereas dunes offer the most important defence against sea-water intrusion. The country has nevertheless been hit by several major flood disasters over the centuries.⁴ Some of them have played a large role in shaping flood management policies. The flood of 1916 is one clear example of the influence of floods on the policy process. Although not among the deadliest or the costliest in economic terms, the flood provided an important impulse for the creation of the Afsluitdijk which protected the North-Western part of the country by closing off the Zuiderzee. The construction of the Afsluitdijk also exemplifies another important feature of Dutch flood policies: motives other than flood protection are often important in the political decision making. Closing off of the Zuiderzee led to the creation of the IJsselmeer and enabled the creation of the Flevoland. This secured fresh water supply and made large areas of new land available. Studies conducted before WWII had already concluded that the flood protection in the South-eastern part of the Netherlands would offer inadequate protection under certain extreme weather conditions. However, WWII and the reconstruction in its aftermath, had pushed concerns for flooding down on the political agenda.

3.2 The flood



Figure 2: Flooded areas following the 1953-flood.

Saturday 31 January 1953 at 18:00 o'clock, an emergency telegram was sent out from the Royal Netherlands Meteorological Institute (KNMI), reporting strong northwestern winds and unusually high water in the North Sea. Due to poor early-warning routines, the message was largely unnoticed by the population in the Southwestern Netherlands. In the early morning when the peak of the tide occurred, a large part of the population was sleeping. The combination of high water and storm resulted in simultaneous dike breaches across the Southwestern provinces (Gerritsen, 2005). Poor building quality as well as inadequate evacuation routines probably resulted in an inflated number of casualties

⁴See e.g. De Kraker (2006) or Deltaworks (n.d.) for a list of historical floods which have hit the Netherlands.

(van der Klis *et al.*, 2005). The disaster could, however, have had far graver consequences. The dikes on the north side of the Hollandse IJssel which protect the populous and economically important Randstad-region, were in poor condition and only through some desperate and unorthodox action was a major catastrophe avoided.⁵ A major flood in the Randstad-region would most certainly have led to a more than tenfold increase in the number of casualties and almost unimaginable economic damage (Deltaworks, n.d.). The devastations resulted in a total of 1836 casualties and in the destruction of 4.500 houses. Some 140.000 hectares of land remained flooded for a longer period, leading to the evacuation of approximately 100.000 people (De Kraker, 2006).

3.3 The response



Figure 3: The Deltaworks. Source: Deltaworks (n.d.)

As was the case with the flood in 1916 and the Afsluitdijk, the flood in 1953 provided an immediate stimulus for action. Some strengthening of dikes had already been implemented by 1950, but the 1953-flood set the stage for the establishment of the Deltacommission which in effect had the task of determining Dutch flood management for several decades. The response took the form of the Deltaworks plan which aimed at closing certain river mouths and sea arms as well as strengthen existing and build new dikes.

The first project of the Deltaworks was the storm barrier at the Hollandse IJssel, finalised in 1958. This was a direct response to the devastations resulting from the 1953-flood. The project included strengthening existing dikes as well as the construction of storm surge barrier, consisting of huge steel screens which could be lowered into the water in case of exceptionally high water levels. The next phase of the Deltaworks Plan was The Three Islands Plan which included the construction of Veerse Gat and Zandkreekdam, both finished in 1961. These

⁵Such actions included jamming a ship in a dike to plug gaping holes thereby preventing water from flowing through.

were built to improve safety in areas affected by the flood. The Grevelingendam (1965) and Volkerak (1969) were secondary dams, meaning that their primary function was to facilitate the construction of other dams. Grevelingendam and Volkerak were built to facilitate the construction of two of the most complex constructions of the Deltaworks Programme: the dam at Haringvliet and the Brouwersdam (both completed in 1971)(Deltaworks, n.d.; Pilarczyk, 2007).

4 Data

The data base used for this research is population data on municipal level in the period 1947–2000. Data was retrieved from two sources: the Historical Database of Dutch Municipalities (HDNG)⁶ and from Statistics Netherlands(CBS). The former covers the time period from 1947 to 1959, while the latter covers 1960 to 2000. The data set was limited to this period as this covers a reasonable before/after period for the 1953-flood and the construction of the Deltaworks.⁷

The use of such long time series obviously poses some challenges as the size and number of municipalities has changed substantially over the years.⁸ The number of municipalities in 2000 is not even half of that a 100 years earlier. In order to create a consistent data set it was therefore necessary to account for municipal changes. This was achieved through the creation of a concordance table, using the municipalities as they were defined in 2000 and then tracing them back in time. From 1960 this proved to be a relatively straightforward, although tedious, procedure, as both the number of inhabitants as well as the area transferred between municipalities are listed by the CBS. Before 1960 the information about municipal changes comes from van der Meer & Boonstra (2006) which only includes information about border changes but not about the number of people "transferred" between municipalities. For a more thorough discussion of the data set see Appendix I.

5 Methodology

5.1 Panel data regression

The data described was organised in a panel with population for $i = 531$ municipalities in $t = 54$ time periods. Population growth is defined using the natural logarithm. As Figure 10 suggests, heterogeneity across both time and space is present in the data. Both time- and individual effects were subsequently confirmed by an F test, justifying the use of both time- and individual effects. A Hausman-test furthermore confirmed that a fixed effects model was more appropriate than a random effects model.

⁶The HDNG is a data base consisting of municipal level statistics from the Dutch censuses starting in 1795 until present(Beekink *et al.*, 2003).

⁷It was decided to make an upper cut-off at 2000, as it was assumed that any additional years would not greatly improve the analysis.

⁸See e.g. Beekink *et al.* (2003, page 158)

5.2 Difference in differences with response functions

The central topic of this research is to investigate whether post-disaster trends in population growth rates diverge between municipalities which were (treatment group) and were not (control group) affected by the flood in 1953. An important prerequisite for such an analysis is that the treatment and control group follow similar trends *before* the disaster. Figure 4 plots growth rates in treatment and control groups over time. The visual presentation does already suggest that there is a common, downward trend in population growth in both groups in the period right after 1947. Then there is change in the direction of the trend in both groups. In Figure 5, the treatment group consists of municipalities which were affected by the Deltaworks programme and the control group of non-affected municipalities. This figure paints a very similar picture as Figure 4.

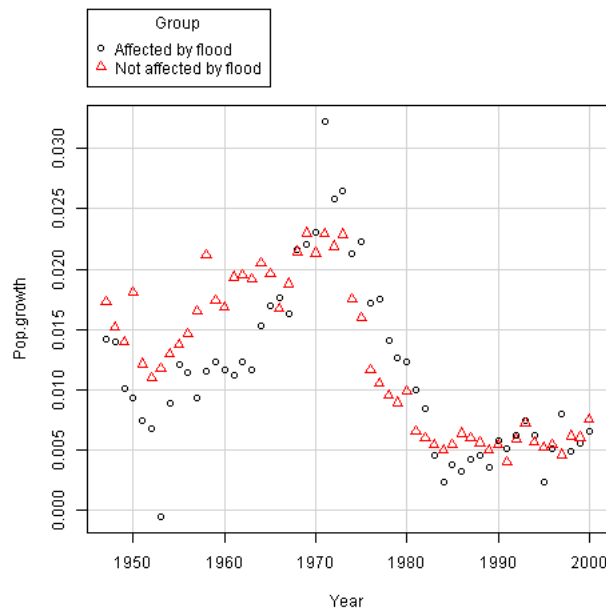


Figure 4: Mean population growth in control and treatment group, flood in 1953

Initially an ordinary "before-after" difference-in-differences analysis was attempted, with affected municipalities as treatment group and non-affected municipalities as control. This approach did, however, prove to be inadequate due to the nature of the research question which supposes that the effects of flooding are non linear in time. It was decided to follow the approach in Wolfers (2006), which involves establishing a *response function* consisting of yearly dummy variables substituting the before-after dummy variable. The following models were estimated:

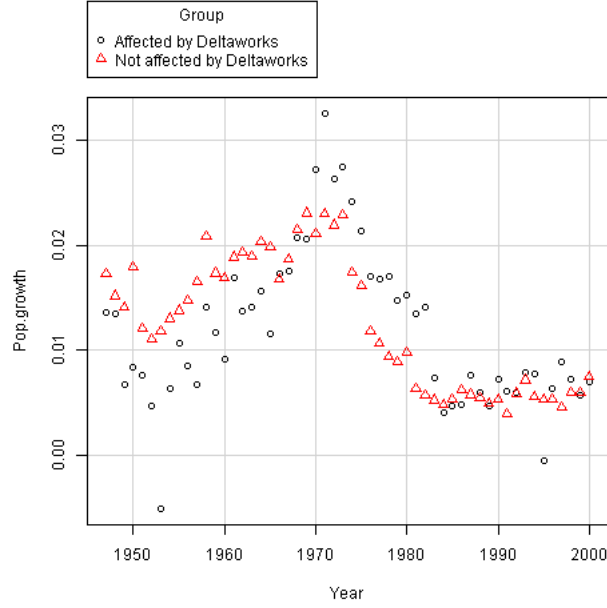


Figure 5: Mean population growth in control and treatment group, Deltaworks

$$\begin{aligned}
p\dot{p}_t = & \alpha + [\beta \text{Flood}_{m,t}^{BA}]_{\text{Model 1 and 2}} + [\delta_k \sum_{k \geq 0} \text{Flood}_{m,k}^{RF}]_{\text{Model 3 and 4}} \\
& + [\text{Trend}_t]_{\text{Model 2 and 4}} + \sum_t \text{TFE}_t + \sum_m \text{MFE}_m \tag{1}
\end{aligned}$$

$$\begin{aligned}
p\dot{p}_t = & \alpha + [\gamma \text{DW}_{m,t}^{BA}]_{\text{Model 1 and 2}} + [\eta_k \sum_{k \geq 0} \text{DW}_{m,k}^{RF}]_{\text{Model 3 and 4}} \\
& + [\text{Trend}_t]_{\text{Model 2 and 4}} + \sum_t \text{TFE}_t + \sum_m \text{MFE}_m \tag{2}
\end{aligned}$$

$$\begin{aligned}
p\dot{p}_t = & \alpha + \gamma \text{DW}_{m,t}^{BA} + [\beta \text{Flood}_{m,t}^{BA}]_{\text{Model 1 and 2}} + [\delta_k \sum_{k \geq 0} \text{Flood}_{m,k}^{RF}]_{\text{Model 3 and 4}} \\
& + [\text{Trend}_t]_{\text{Model 2 and 4}} + \sum_t \text{TFE}_t + \sum_m \text{MFE}_m \tag{3}
\end{aligned}$$

The numbers refer to Table 2, Table 3 and 4 respectively. As such, Model 1 in equation 1 refer to Model 1 in Table 2, Model 1 in equation 2 to Model 1 in Table 2 and so on. The dependent variable (population growth) is calculated using the natural logarithm, $p\dot{p}_t = \ln(\text{pop}_{m,t}/\text{pop}_{m,t-1})$. TFE_t and MFE_t are time-fixed effects and municipality-fixed effects, respectively. The trend-variable is calculated as $\sum_m \text{Municipality}_m * \text{Time}_t$. $\text{Flood}_{m,t}^{BA}$ in equation 1 and 3 represents the simple before-after treatment for a flood, and is a dummy-variable that takes one in affected municipalities (control group) in all time periods after a flood and 0 otherwise. The response function in equation 1 and 3 is represented by $\sum_{k \geq 0} \text{Flood}_{m,k}^{RF}$, where $k \in t$ are years since the flood

or finalisation of a protective measure, taking the value 1 in the control-group in period k and zero otherwise. Similarly, DW^{BA} and $\sum_{k \geq 0} DW^{RF}$ in equation 2 and 3 represent the before-after treatment and response function for the Deltaworks Programme.⁹ α represents in this case the population growth of the municipality and time period which were not included as dummy variables.

Population was counted on the December 31, so that the dependent variable actually measures the percentage population growth in t . The interpretation of, for example, the treatment variable $Flood^{BA}$ and its coefficient β is that $p \dot{p}(t|Flood^{BA} = 1) - p \dot{p}(t|Flood^{BA} = 0) = \beta$. $100 * \beta$ therefore represents percent point difference in population growth between treatment and control group at time t .

5.3 Coding of treatment variables

In the case of the 1953-flood it is relatively straight forward to categorise municipalities. It is well documented which municipalities were affected, both in terms of deaths and material damage (van der Klis *et al.*, 2005; Deltaworks, n.d.). For the Deltaworks Programme the definition is a different matter. It is clear that a dike breach around Rotterdam would have affected large parts of the Randstad area, and not only the areas close to the water. But it is not clear whether strengthening of such dikes — a de facto reduction in flood risk — would change perceived flood risk in the whole area which would potentially be flooded. It may just as well be the case that the flood itself did not change the perceived flood risk in the hinterland (after all the catastrophe was avoided). As such, the subsequent decrease in the de facto flood risk may not have changed all that much. In the face of these difficulties with the spatial extent of perceived flood risk, the choice has been to define treatment municipalities as only those directly affected by the mitigation efforts. For example, the treatment group in the first period of the construction of the Deltaworks are municipalities which border the Hollandse IJssel.

6 Results

6.1 Regression results: 1953 flood

The regression results are presented in Table 2, Table 3 and 4. Judging by the discussion above, one would expect an event as the flood in 1953 to have had a dramatic effect on the population in affected areas: crops were affected for years from the intrusion of sea water, giving a striking blow to the agricultural sector. At the same time the destruction of good parts of the housing stock meant that people in many cases had no houses to return to. Such effects were also suggested by Figure 4, in which there appeared to be a flattening out of growth rates in the early 1950s.

It is therefore somewhat of a surprise that Model 1 and Model 2 in equation 1 suggests that the flood had a positive effect on population growth.¹⁰ But in

⁹The variables $Flood_{o15}^{RF}$ and DW_{o15}^{RF} cover the period later than 15 years. There is little guidance in the literature as to how many dummy-variables to include, the number 15 is the same as in Wolfers (2006). We thus define $k = 0, 1, \dots, 15, o15$.

¹⁰Inclusion of a municipality-specific trend variable only serves to strengthen the effect. This sounds at first sight unlikely, and there is reason to suspect that similar effects as those in

line with the locational fundamentals theory with flood risk, the positive results are perhaps not all that surprising. One possible explanation is that the before-after dummy simply picks up the effects of the Deltaworks Programme. As in Wolfers (2006), it is likely that the response function is a more appropriate tool in this context.¹¹

The response function from Model 3 in equation 1, depicted in Figure 6 suggests indeed that the flood had a negative immediate impact. It appears that affected municipalities suffered an immediate drop in population growth, as compared to non-affected municipalities. Thereafter, the results are less clear. There is some weak evidence of a bounce-back effect the year following the flood, but then the response function is mostly negative and insignificant.¹² In terms of stock dynamics, the cumulative effect of the response function indicates that affected municipalities suffered a decline on the size ranking is compared to non-affected municipalities for roughly 10 years.¹³ This result is much more in line with Figure 4. In sum, our results suggest that the flood had some negative impacts on population growth on the short- to medium term: the population growth in affected municipalities did, for a short period, diverge from the trend in non-affected municipalities.

The surprising finding of a positive treatment-variable from Model 1 and Model 2 in equation 1 is also suggested by Figure 4. The treatment group does diverge from the trend growth, but later — around 1970. The regression results do also suggest such an effect. The dummy variable which covers time periods above 15 years after the flood is positive, significant and of the same magnitude as the negative immediate impact.¹⁴ But, as we shall see, it is likely that other factors are as important as the flood in explaining the positive divergence from the trend.

6.2 Regression results: Deltaworks programme

As Figure 7 suggests, the Deltaworks programme had a positive effect overall. One initial factor may have been the construction phase itself, requiring manpower and supplies. The inflow of workers and increase in demand for goods

Wolfers (2006) are at play: the municipality-specific trends also pick up the different evolution of population growth within affected and non-affected municipalities subsequent to the flood, as well as any pre-disaster trends. Thus the trend variable — really a control variable — does partly capture the dynamics of population growth.

¹¹An F-test confirmed that the dummy variables forming the response function were jointly significant — not surprising given the fact that the sum of all the dummies equal the before-after dummy.

¹²The inclusion of the trend variable does only marginally alter the estimates, and, interestingly, the effect seems to be growing in time. This may be the same effect which is discussed in Wolfers (2006): prior to the flood the true trend of population growth is, if anything, slightly negative, and the inclusion of a linear trend variable should therefore not do much to change the estimates. However, from the late 1950s to around 1970 the true trend in population growth is increasing, meaning that the trend variable captures the true trend.

¹³The cumulative effect refers to the adding up of the individual dummy variables over a time period. For example, the dummy variable for 1953 suggests that municipalities affected by a flood had a growth rate 0.75 percent points lower than non-affected municipalities. The dummy variable representing 1954 suggests that the growth rate was 0.08 percent point higher. Adding these two up, the growth rates of affected municipalities was 0.67 percent point lower in affected municipalities in the two first years.

¹⁴Intriguingly, the inclusion of a trend has a large impact on the last dummy variable: inclusion of the trend inflates the coefficient by nearly 16%.

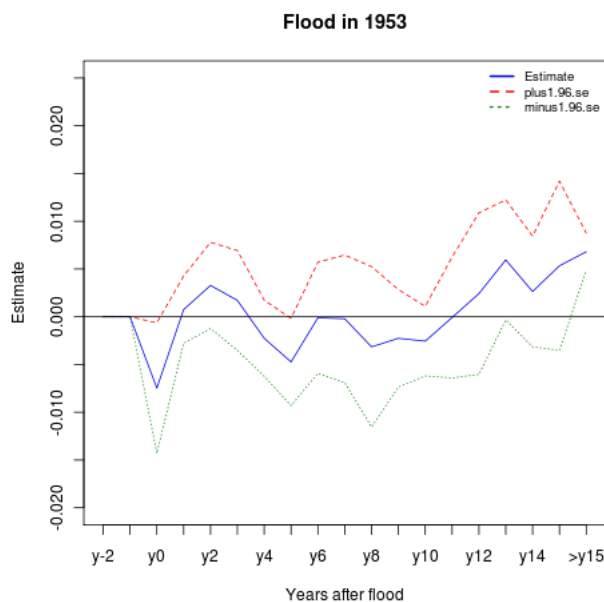


Figure 6: Coefficients from the 1953-flood estimation, Model 4 in Table 2

may have caused positive ripple effects in local economies. Reconstruction of the housing stock and normalisation of the agricultural sector may also have played a part. However, as suggested by both Figure 5 and the regression coefficients in Figure 7, the largest difference between control and treatment group seems to occur from 1970 onwards. In other words, the construction and finalisation did themselves have a positive effect, but the effect is large and positive to the early 1980s — ten years subsequent to the finalisation of the major parts of the Deltaworks programme. This suggests again that other factors, other than the more immediate ones discussed above, may be at play. One possible explanation is that the lowering of risk led households to move back or households living elsewhere to settle in affected areas. But it is likely that the lowering of risk was accompanied by changes in land regulations: as more and more areas were offered better protection, more land was made available for development. An interesting follow-up to this research would be an investigation of the interplay between the construction of the Deltaworks and changes in land use regulation, but as the main focus here is the effects of the flood this task is left for future research. The development of land was accompanied by construction of housing, which again may have caused positive ripple effects. Summing up, it seems likely that the positive effects found in the regression for the 1953-flood stem from the construction of the Deltaworks.

6.3 Including Deltaworks as a control variable

A logical next step is to include Deltaworks as a control in the regression for the 1953-flood. Firstly, a model with a before-after dummy for the 1953-flood

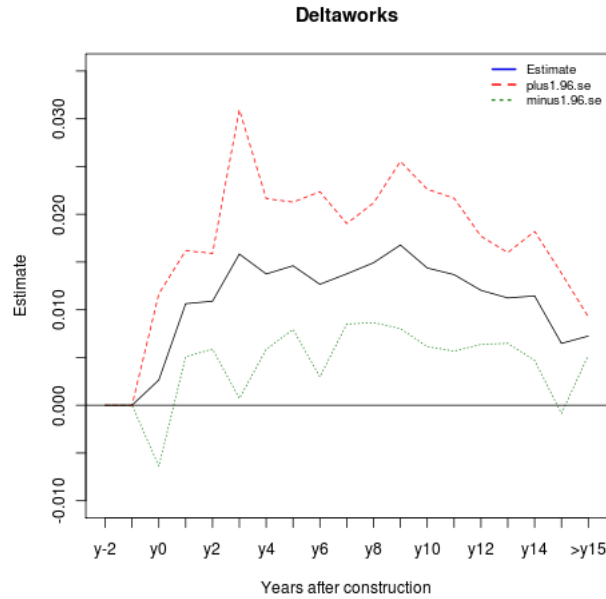


Figure 7: Coefficients from the Deltaworks-estimation, Model 4 in Table 3

was run with the Deltaworks dummy (Model 1 and 2, Table 4). Thereafter the Deltaworks dummy was included in the model with the response function for the flood (Model 3 and 4, Table 4). Controlling for Deltaworks rendered the before-after dummy insignificant, and an F-test revealed that the dummy variables forming the response function were not jointly significant. This does, again, suggest that the Deltaworks Programme is more important in explaining population growth than the 1953-flood. Figure 8 plots the response function, controlling for Deltaworks. Compared with Figure 6, we see that the last part of the dashed blue line is shifted downwards, meaning that positive effects from period 5 onwards are dampened: in this specification, no positive effects remain which are significant on a 5%-level. The first parts of the Deltaworks were finalised 5 year after the flood (1958). Given the positive effects from the Deltaworks construction identified above, these results are not all that surprising.

Figure 9, which plots population growth in non-affected municipalities with the marginal effect of the response function sums up results:¹⁵ it seems the flood in 1953 slowed down the population growth in affected municipalities. There is some weak evidence suggesting that population growth stayed lower in non-affected areas for roughly ten years after the disaster. In the long term population growth in flood-affected municipalities stays above that of non-affected municipalities¹⁶. As suggested above, any positive effects on population growth

¹⁵This figure is produced using the growth rates in non-affected municipalities and coefficients from a response-function consisting of 30 dummy-variables. The estimates are available upon request.

¹⁶There is not perfect correlation between the two treatment groups: some municipalities in the treatment group in the 1953-regression are coded as not directly affected by the Deltaworks. There is of course a possibility that the increased safety also influenced the perceived

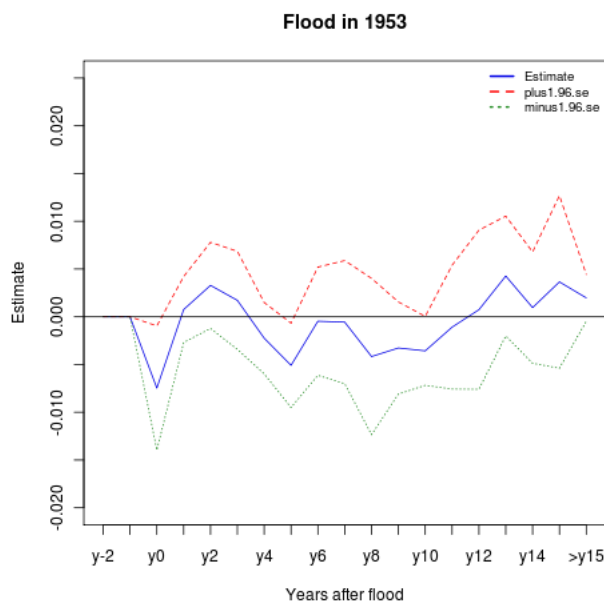


Figure 8: Coefficients from the 1953-flood estimation, controlling for DW. Model 4 in Table 4

is most probably connected to the Deltaworks rather than to the flood itself.

7 Conclusions

The results found in this study suggest that a temporary shock — the disastrous flood in 1953 — did not have long-term effects on the spatial distribution of people in the Netherlands. There is no evidence suggesting that population growth in municipalities affected by the flood shifted to a different trend after the disaster. Our results suggest instead that the policy interventions following the flood produced long term effects: the average long term growth in municipalities affected by the Deltaworks Programme is higher than that in non-affected municipalities.

In terms of the theoretical explanations offered in the literature, our results can be interpreted through a combination of two theories. The absence of long-term effects on the trend growth rates from the flood would mainly favour the locational fundamentals theory. Since the disaster did not alter fundamental characteristics, the relative attractiveness of each location would remain the same as before the disaster. But the absence of long term effects would not discard the increasing returns theory. It is, for example likely, that the initial reconstruction efforts were concentrated on restoring remaining infrastructure and productive activities. A flood may not cause institutional changes either, such as alterations to property rights regimes. If the pre-disaster structure of flood risk in these municipalities. This could explain the robust positive effects in the 1980s.

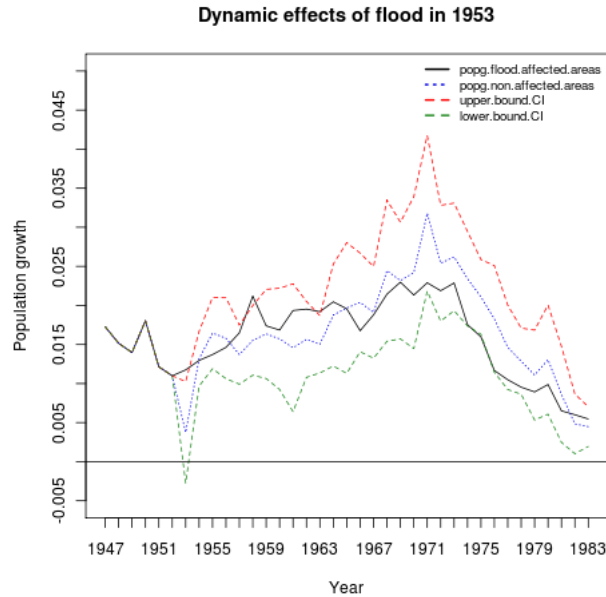


Figure 9: Population growth (mean) in control group with estimated effect of 1953-flood and a 95% confidence interval.

the economy is restored and there are few institutional changes, growth rates may well return to their pre-disaster levels.

Similarly, a long term impact on growth rates from flood mitigation policies appears most in line with the theory of increasing returns. Most importantly, several of the constructions of the Deltaworks Programme had other purposes than flood protection: they also provided freshwater supply as well as transport infrastructure. It is likely that local economies were fundamentally changed by these massive constructions. Subsequent to the construction of the protective measures, new land would be made available. In the Netherlands, a country with one of the greatest population densities of the world, it is possible that new land available at lower prices led people to move to areas protected by the Deltaworks. However, the effect of policy interventions are not incompatible with the locational fundamentals theory. Proximity to water is usually a positive force, attracting people and businesses. However, in the context of floods and flood mitigation, proximity to water also represents a negative force, namely a risk of flooding. Flood mitigation efforts aim precisely at permanently altering the relative strength of these two forces. In the Netherlands, the government essentially declared that such a disaster should never happen again.¹⁷

Besides providing support to economic theories of the spatial distribution of population, our results also have important practical implications. Most importantly, they suggest that, since the 1970s, there has been an increasing concen-

¹⁷The Deltaworks Programme set very high legal safety standards were set for each *dike ring*. In most cases the flood protection was required to withstand floods not even recorded in human history.

tration of population, and presumably also wealth and productive activities, in areas near the coast or big rivers — often below sea level. Using the definition of flood risk from the introduction, we can interpret the construction of the Deltaworks as an immediate reduction in probability. However, the reduction in probability was followed by an increase in exposure. Thus, paradoxically, the one-off *reductions* in flood risk, were followed by a slow but steady *increase* in flood risk. Consequently, the value of what the Deltaworks aimed at protecting has increased many fold. There is substantial agreement in the literature that such increases in exposure is the main driving force behind the increased disaster losses over the past decades. But in addition, the frequency and magnitude of disasters may increase in the future due to climate change. Some authors suggest that the heavy reliance on mitigation efforts and technological solutions have led to a policy path dependency (Wesselink, 2007). According to this view the dramatic increase in exposure further mitigation the only viable solution. As argued by Bockarjova *et al.* (2009) and Meijerink (2005), evacuations from near-floods in Limburg in the 1990s as well as the devastations of Hurricane Katrina in New Orleans in 2005 have lead policy makers to think differently: there is increasing recognition that sole reliance on protection is insufficient as a response to future climate change.¹⁸

Referring to the literature, we have suggested some underlying mechanisms which seem to be in line with findings in the existing literature. Our story is essentially a demand side story where changing attributes of an area affect expectations. But our results are only suggestive. An investigation of house prices in the same time span would reveal whether the flood or the construction of the Deltaworks actually changed expectations. There is also reason to believe that the policy interventions affected the supply side of the land- and housing market. As such, an investigation of house prices could also tell something about whether this is primarily a supply side or demand side story.¹⁹ In sum, our narrative is not complete and there is plenty of room for further research. We hope therefore that our results will stimulate further research which can shed more light on the distribution of population and economic activities and underlying mechanisms. Such research can provide valuable inputs in the process of preparing for the effects of future climate change.

¹⁸The challenges posed to long term flood management in the Netherlands are acknowledged by current Dutch policymakers (Deltaprogramma, 2012). However, the rethinking of flood management strategy takes time to implement and has been faced with social resistance (Wolsink, 2006).

¹⁹In the present study population dynamics are also interpreted as a rough proxy for economic growth. In a subsequent paper, Davis and Weinstein use industrial data to investigate multiple equilibria in population as well as in spatial distribution of size and composition of industries (Davis & Weinstein (2008)). Their results largely confirm the findings in Davis & Weinstein (2002), suggesting that the bombing had a similar effect on general economic indicators as on population.

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Appendix I: Data quality

Figure 10 plots the mean of population growth in the different municipalities with the bars representing 95%-confidence interval. What is readily seen is that there is a large difference in variance in the data between the years before around 1950 and the years thereafter. A closer inspection revealed that the standard deviations in population growth start decreasing from 1947, the year of the first census after the war. However, the year 1948 did see a huge increase in the variance in population growth. This was however caused by an outlier — the municipality of Leeuweradeel in Friesland — which, according to the data saw a population decrease of almost 150%. The source of error is either erroneous typing of data by the creators of the HDNG or problems with the original sources.²⁰ The solution here is simply to remove this particular observation, which yields Figure 11. Subsequently the standard deviations drop drastically from the year 1947.

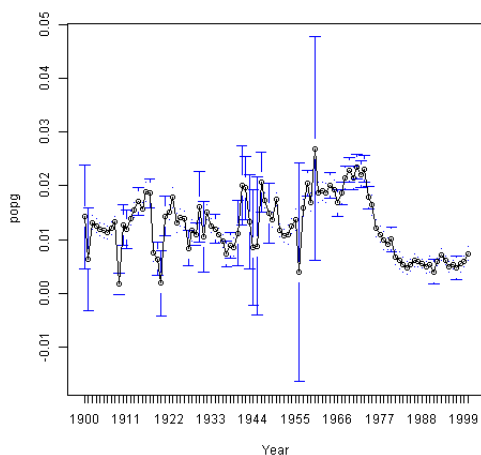


Figure 10: Mean of population growth over time with 95% confidence interval

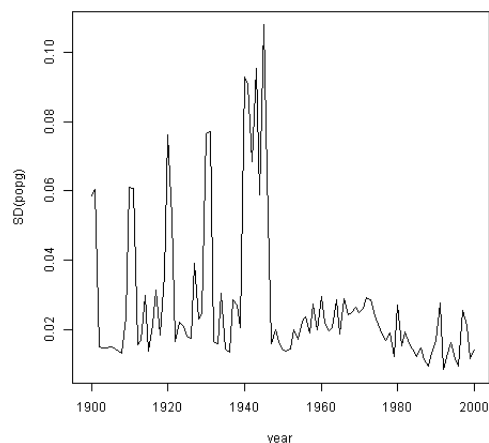


Figure 11: Standard deviation of population growth over time

There are few universal rules of thumb for identifying outliers, and in this particular data set the definition of an outlier is likely to vary between the years. We know from other sources that there were large interregional variations in population growth rates, and an outlier could simply be a high growth municipality in a high growth region. Nevertheless, a plot showing outliers over time with a universal definition of outliers, can give some useful informations about the data.

²⁰The HDNG appears to be riddled with errors in the years of WWII. Especially the year of 1944 is problematic: several municipalities are registered with a 150-200% population drop, just to experience an *increase* of a similar magnitude the following year. Again, sources behind the errors are something of an enigma. Inaccuracies in the code may well be one source of error. But also lacking or erratic information about municipality changes as well as typos in the original data sets may have caused deviations.

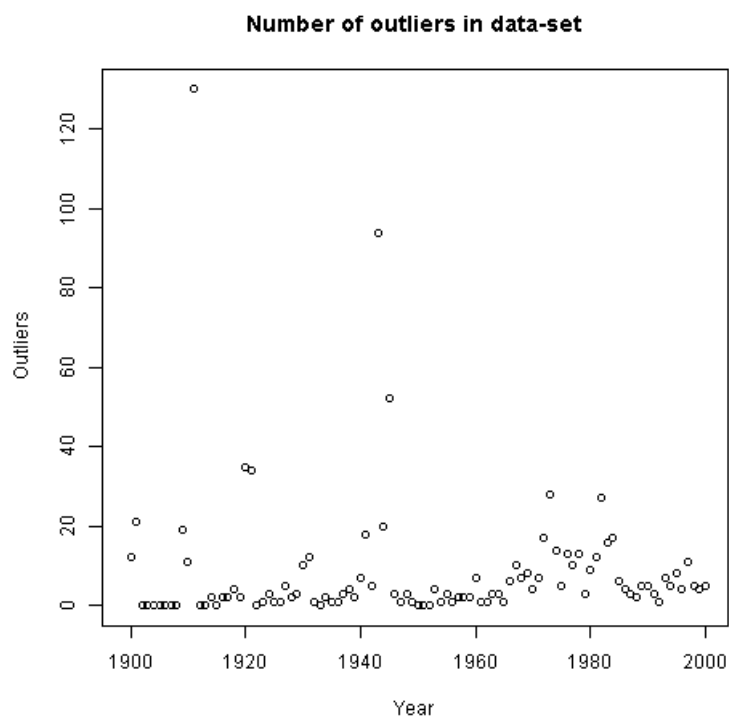


Figure 12: An outlier was here defined as population growth ten times higher than the aggregate growth rate.

Figure 12 plots the number of outliers per year, where an outlier was defined as over ten times larger than the aggregate growth rate (in absolute number). Some peculiar patterns appear, which again raise questions about the reliability of the pre-1947 data. There were no censuses between 1930 and 1947, meaning that any data points between these years are results of extrapolations. The sharp increase in the number of outliers in the years of WWII is therefore highly suspicious, as the data for these years should be based on the same extrapolations used for the data in the 1930s. We also see an increase in the number of outliers around 1980, but this may have a more natural explanation. The aggregate population growth was dropping fast towards the end of the 1970s, but with regional variations, possibly resulting in an increase in outliers. Another point is that all observations from the province of Flevoland are left out of the data-set. This province was created with the closure of the Zuiderzee and subsequent land fill, and data series for the municipalities in the province are therefore incomplete.

Figure 13 depicts the total population in the Netherlands from the original data-set as well the total population in the data-set with the reconstructed 2000-municipalities. The right bar shows the deviation between the two (in percentages). The line represents population (left axis), while the bars represent deviations (right axis). As is readily seen from the figure, deviations are systematically negative before WWII. After WWII the error-margins become smaller and fluctuate between positive and negative. This means that before WWII the reconstructed data set systematically underestimate total population and produces larger errors.

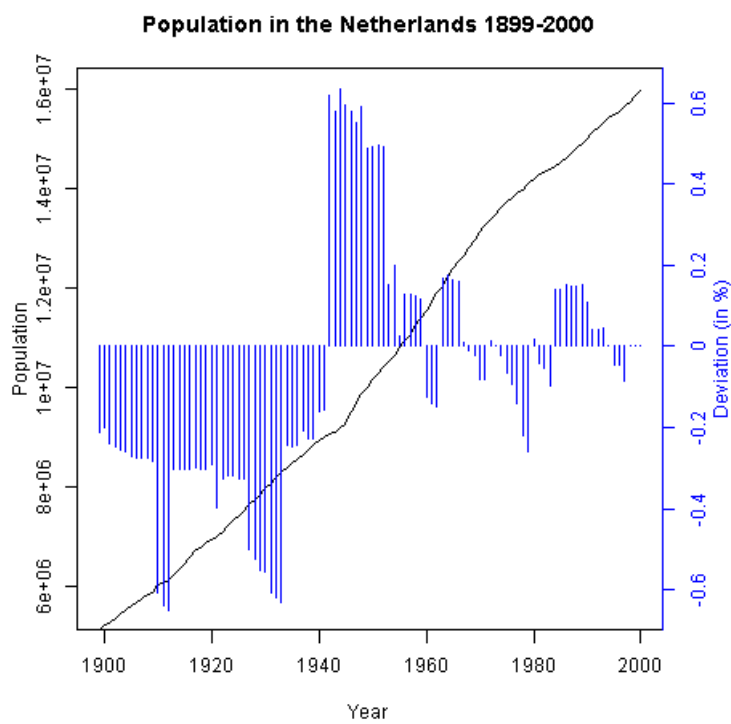


Figure 13: Population in the non-adjusted data set and deviation in the adjusted data set.

Appendix II:tables

	Provinces				
	N. Holland	Z. Holland	Zeeland	N. Brabant	Total
Number of flooded municipalities	2	19	10	7	38
Share	0.1	0.5	0.3	0.2	1

Table 1: Crosstabulation of flooded municipalities by provinces.

Table 2

	Model 1	Model 2	Model 3	Model 4
(Intercept)	0.0150 *** (0.0022)	0.0140 *** (0.0022)	0.0150 *** (0.0022)	0.0138 *** (0.0022)
$Flood^{BA}$	0.0040 *** (0.0009)	0.0045 *** (0.0010)		
Trend		-0.0000 *** (0.0000)		-0.0000 *** (0.0000)
$Flood^{RF}$			-0.0075 * (0.0035)	-0.0075 * (0.0035)
$Flood_1^{RF}$			0.0007 (0.0018)	0.0008 (0.0018)
$Flood_2^{RF}$			0.0032 (0.0023)	0.0033 (0.0023)
$Flood_3^{RF}$			0.0016 (0.0027)	0.0017 (0.0027)
$Flood_4^{RF}$			-0.0024 (0.0020)	-0.0023 (0.0020)
$Flood_5^{RF}$			-0.0049 * (0.0023)	-0.0047 * (0.0023)
$Flood_6^{RF}$			-0.0003 (0.0030)	-0.0001 (0.0030)
$Flood_7^{RF}$			-0.0004 (0.0034)	-0.0002 (0.0034)
$Flood_8^{RF}$			-0.0034 (0.0043)	-0.0032 (0.0043)
$Flood_9^{RF}$			-0.0025 (0.0026)	-0.0023 (0.0026)
$Flood_{10}^{RF}$			-0.0028 (0.0019)	-0.0026 (0.0019)
$Flood_{11}^{RF}$			-0.0003 (0.0032)	-0.0001 (0.0032)
$Flood_{12}^{RF}$			0.0021 (0.0043)	0.0024 (0.0043)
$Flood_{13}^{RF}$			0.0057 † (0.0032)	0.0060 † (0.0032)
$Flood_{14}^{RF}$			0.0023 (0.0030)	0.0026 (0.0030)
$Flood_{15}^{RF}$			0.0050 (0.0045)	0.0053 (0.0045)
$Flood_{o15}^{RF}$			0.0062 *** (0.0010)	0.0068 *** (0.0010)
N	28673	28673	28673	28673
R^2	0.2281	0.2285	0.2298	0.2304
adj. R^2	0.2120	0.2125	0.2134	0.2140
Resid. sd	0.0188	0.0188	0.0187	0.0187

Robust standard errors in parentheses

† significant at $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$

Table 3

	Model 1	Model 2	Model 3	Model 4
(Intercept)	0.0151 *** (0.0022)	0.0139 *** (0.0022)	0.0151 *** (0.0022)	0.0139 *** (0.0022)
DW^{BA}	0.0100 *** (0.0009)	0.0104 *** (0.0009)		
Trend		-0.0000 *** (0.0000)		-0.0000 *** (0.0000)
DW^{RF}			0.0028 (0.0046)	0.0026 (0.0046)
DW_1^{RF}			0.0103 *** (0.0028)	0.0106 *** (0.0028)
DW_2^{RF}			0.0106 *** (0.0025)	0.0109 *** (0.0026)
DW_3^{RF}			0.0155 * (0.0077)	0.0158 * (0.0077)
DW_4^{RF}			0.0134 *** (0.0040)	0.0137 *** (0.0040)
DW_5^{RF}			0.0142 *** (0.0034)	0.0146 *** (0.0034)
DW_6^{RF}			0.0122 * (0.0049)	0.0127 * (0.0049)
DW_7^{RF}			0.0133 *** (0.0027)	0.0138 *** (0.0027)
DW_8^{RF}			0.0145 *** (0.0032)	0.0149 *** (0.0032)
DW_9^{RF}			0.0163 *** (0.0045)	0.0168 *** (0.0045)
DW_{10}^{RF}			0.0139 *** (0.0042)	0.0144 *** (0.0042)
DW_{11}^{RF}			0.0132 ** (0.0041)	0.0137 *** (0.0041)
DW_{12}^{RF}			0.0115 *** (0.0029)	0.0120 *** (0.0029)
DW_{13}^{RF}			0.0107 *** (0.0024)	0.0112 *** (0.0024)
DW_{14}^{RF}			0.0109 ** (0.0034)	0.0114 *** (0.0034)
DW_{15}^{RF}			0.0060 (0.0037)	0.0065 † (0.0037)
DW_{o15}^{RF}			0.0067 *** (0.0010)	0.0072 *** (0.0010)
N	28673	28673	28673	28673
R^2	0.2304	0.2310	0.2313	0.2319
adj. R^2	0.2144	0.2150	0.2148	0.2154
Resid. sd	0.0187	0.0187	0.0187	0.0187

Robust standard errors in parentheses

† significant at $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$

Table 4

	Model 1	Model 2	Model 3	Model 4
(Intercept)	0.0151 *** (0.0022)	0.0139 *** (0.0022)	0.0151 *** (0.0022)	0.0139 *** (0.0022)
DW^{BA}	0.0100 *** (0.0009)	0.0104 *** (0.0009)	0.0084 *** (0.0012)	0.0086 *** (0.0012)
$Flood^{BA}$	-0.0000 (0.0011)	0.0003 (0.0011)		
Trend		-0.0000 *** (0.0000)		-0.0000 *** (0.0000)
$Flood^{RF}$			-0.0075 * (0.0033)	-0.0075 * (0.0033)
$Flood_1^{RF}$			0.0007 (0.0018)	0.0008 (0.0018)
$Flood_2^{RF}$			0.0032 (0.0023)	0.0033 (0.0023)
$Flood_3^{RF}$			0.0016 (0.0026)	0.0017 (0.0026)
$Flood_4^{RF}$			-0.0024 (0.0019)	-0.0022 (0.0019)
$Flood_5^{RF}$			-0.0052 * (0.0023)	-0.0051 * (0.0023)
$Flood_6^{RF}$			-0.0006 (0.0029)	-0.0005 (0.0029)
$Flood_7^{RF}$			-0.0008 (0.0033)	-0.0006 (0.0033)
$Flood_8^{RF}$			-0.0044 (0.0042)	-0.0042 (0.0042)
$Flood_9^{RF}$			-0.0035 (0.0025)	-0.0033 (0.0025)
$Flood_{10}^{RF}$			-0.0038 * (0.0018)	-0.0036 † (0.0018)
$Flood_{11}^{RF}$			-0.0013 (0.0033)	-0.0011 (0.0033)
$Flood_{12}^{RF}$			0.0005 (0.0042)	0.0007 (0.0043)
$Flood_{13}^{RF}$			0.0040 (0.0032)	0.0043 (0.0032)
$Flood_{14}^{RF}$			0.0007 (0.0030)	0.0010 (0.0030)
$Flood_{15}^{RF}$			0.0033 (0.0046)	0.0036 (0.0046)
$Flood_{o15}^{RF}$			0.0014 (0.0012)	0.0020 (0.0013)
N	28673	28673	28673	28673
R^2	0.2304	0.2310	0.2310	0.2316
adj. R^2	0.2144	0.2150	0.2145	0.2152
Resid. sd	0.0187	0.0187	0.0187	0.0187

Robust standard errors in parentheses

† significant at $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$