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The strategic bombing of German cities during World War II and its impact on city growth

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Abstract

We construct a unique data set in order to analyse whether or not a large temporary shock has an impact on city growth. Following recent work by Davis and Weinstein on Japan, we take the strategic bombing of German cities during World War II as an example of such a shock, and analyse its impact on post-war German city growth. If the war shock has only a temporary impact, then there will be a tendency towards mean reversion. Our main finding is that the bombing had a significant but temporary impact on post-war city growth in Germany as a whole as well as in West Germany separately, but that this is not the case for city growth in East Germany.

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1. Introduction

The relative size of individual cities and the resulting city size distribution are remarkably stable over time for most countries. Evidence for some cities suggests that even wars or other large shocks do not always change the relative size of cities significantly over time (Glaeser and Shapiro, 2001). Various theories exist to explain city growth and the possible impact of shocks on the growth process. In their attempt to discriminate between the theoretical explanations, Davis and Weinstein (2002) use the case of Japanese agglomerations. They not only analyse the variation and persistence of Japanese regional population density over the course of 8 000 years (!) but, more importantly for our present purposes, they also investigate whether or not a large temporary shock (the bombing of Japanese cities during World War II) had a permanent or only a temporary effect on Japanese city growth in the post-WWII period. With respect to the 'bombing' shock, it turns out that there was at most a temporary impact on relative city size in Japan. Japanese cities completely recovered from the impact of WWII and were back on their pre-war growth path quite soon.

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In this paper we build upon Davis and Weinstein (2002) by taking the strategic bombing of German cities during WWII as another example of a large, temporary shock to their growth and development. We also take the division of Germany into the Federal Republic of Germany (FRG) and the German Democratic Republic (GDR) in 1949 into account. In this respect the German case is quite unique. The different nature of the policy decisions by the two ideologically distinct governments to the same war-related shock could be relevant for the post-war city growth in both countries. We find that city growth for Germany as a whole as well as for the FRG is characterized by mean reversion, but that this is not the case for city growth in the GDR. Differences in the post-war economic systems between the former FRG and GDR are most likely responsible for this result.

The paper is organized as follows. In the next section we introduce a general theoretical framework drawn from urban economics. It encapsulates the basic theoretical explanations offered by Davis and Weinstein (2002), and allows us to put the question about the possible impact of large shocks on city growth into perspective. In Section 3 we provide some background information on the scope of the allied bombing of Germany during WWII and the destruction it caused, after which we present our data set. We have city specific data on 103 German cities (81 West German and 22 East German cities). This city specific information not only includes the city size but also various city specific measures related to the degree of destruction. In Section 4 we perform growth regressions to test for the impact of the 'bombing' shock on post-WWII city growth. We present estimations for the FRG, the GDR, and for Germany as a whole. We also address some potential problems that may arise from our basic estimations, and in addressing these problems we also provide additional estimation results that back up our main findings. Section 5 looks more closely at the relevance of post-war reconstruction policies, and Section 6 relates our main findings to the general theoretical framework.

2. Urban economics and temporary shocks

In urban economics one can distinguish two basic views about the possible impact of large temporary shocks on city growth. The first view is based on the pioneering models of urban growth in the Alonso–Muth–Mills tradition. In these models each city has its own optimal or natural city size. Following a large shock, like the WWII shock, and assuming a fixed city specific level of productivity, after some time each city has returned to its natural city size. With a fixed city specific level of productivity, changes in the city size population, due to for instance a 'war' shock, cannot influence city productivity. As a result, and assuming that housing will be rebuilt (see below), the war shock will not have a permanent impact. In the second view city productivity is a (positive) function of the city size population and possibly also of the interactions (spillovers) with other cities. Changes in the level of population will change city productivity and city growth. In this case, the prediction would be that a large shock probably has a lasting impact. It is beyond the purpose of this paper to develop both approaches in detail so we limit ourselves to a stylized outline of the underlying framework.[1]

1 For the sake of simplicity the framework in this section discusses the impact of a temporary shock from the perspective of a single city. Though useful it should be kept in mind that a partial equilibrium perspective is of limited use when we consider a system wide shock like a war shock that may affect all cities. It also means that we do not refer in our discussion to recent (endogenous) growth models like Eaton and Eckstein (1997) or Black and Henderson (1999) that are concerned with (the stability of) the overall city size distribution. Our

To illustrate the first approach, assume that for city *i* its productivity is A_i (which equals the city wage). Also assume that the function $C(pop_i)$ denotes that congestion costs C (think of commuting and rental costs) increase with the size of the city population, pop_i and that this cost function is not city specific. People migrate to city *i* until the (fixed) outside reservation utility U equals A_i—$C(pop_i)$. The solution to this equation yields the optimal or natural city size. If, due to a large temporary (negative) shock the size of the city's population falls, with U and A_i unchanged, it is easy to understand that city *i* will (gradually) move back to its natural size.[2] This conclusion holds with one important caveat. After a shock, the city size population will only return to its pre-shock level if sufficient houses are (re-)built. Following Glaeser and Gyourko (2001) this will only happen if housing prices exceed construction costs. If housing prices are less than reconstruction costs, the housing stock and the city size population will not return to their pre-shock levels and in that case a temporary shock can have a permanent impact. In Section 6 when discussing our main findings, we will return to relevance of taking the durability of housing into account in the assessment of the impact of the WWII shock on German cities.

In the second (and more recent) view about city growth, the relevance of the endogeneity of city growth can be understood by allowing the city productivity of city *i* to depend on the population level: $A_i(pop_i)$ with $A' > 0$. A_i need not be a function of the city's population only, but might also be a function of the interaction with other cities (e.g. knowledge spillovers). What matters for our purposes is that A_i is no longer given, but depends positively on the size of the population. Again people move to this city until $U = A_i(pop_i) - C(pop_i)$. In this case it is no longer obvious why a city should have a natural size, this depends very much on the assumptions made with respect to the curvature of the A and C functions. So, in the second view there is no obvious 'limit' to city size. The implication is that a large temporary shock can have a permanent impact. If we take the negative WWII shock as an example, this could change the growth path towards a new equilibrium city size. This will happen if the shock is large enough to render the initial city size equilibria unstable and cities will not return to their former relative size. Mean reversion is, however, not impossible. If path-dependency is really strong even a large shock like a war need not to overturn the initial city size equilibrium. In this case the shock may only have a temporary impact again assuming that housing market conditions are such that housing prices exceed construction costs. The probability that this happens will, however, in general be smaller because productivity has gone down in case of a negative population shock and this depresses housing demand. The bottom line is that, compared to the first view, a temporary impact of the war shock is *less likely*.

The work by Davis and Weinstein (2002) and our own empirical analysis can be used as a first step to discriminate between these two basic views. In Section 6 we try to assess our empirical findings against this theoretical background. Davis and Weinstein (2002) use a more broadly defined and somewhat different theoretical classification. They distinguish three basic theoretical approaches, in their terminology, fundamental

focus on the impact of shocks on the size or growth of individual cities is, however, in line with the empirical specification in Davis and Weinstein (2002), see Section 4.1 and in particular equation (4) because there the impact of the war shock on the relative growth of *individual* cities is analysed.

2 A city will not have a natural size if, due to for instance exogenous technological change, A_i increases over time. For our present purposes it is important to emphasize that A_i is not a function of pop_i.

geography, increasing returns and random growth. In case of fundamental geography, exogenous and fixed characteristics like access to waterways, climate, and other fixed endowments determine city growth. This approach belongs to our first view.[3] The increasing returns approach is in line with our second view. The WWII shock can have permanent or non-permanent effects. The outcome depends on whether or not the initial situation was an equilibrium, and if so, whether or not that equilibrium was stable. If path-dependency is strong even a large shock like WWII need not to disrupt the initial city size equilibrium. Finally, they introduce what they call the random growth approach, which predicts that the evolution of city sizes by definition follows a random walk and a large, temporary shock like the WWII shock must have a permanent effect.

3. The strategic bombing of German cities and the data set[4]

3.1. Allied bombing and the degree of destruction

During the WWII, allied forces bombed Germany heavily. During the period from 1940 to early 1942 the targets selected by the Royal Airforce were mostly industrial targets, such as, oil, aluminium, and aero-engine plants, and transportation systems. The success of this first bombing campaign by the allied forces was rather limited. The USA (1945) survey finds no clear-cut indication that before 1943 the production of the German economy was smaller than it would have been without the air raids. It was only towards the end of the war that the effects of the air raids on the German economy really became destructive for the German war economy.[5]

The initially limited success of the air raids led to a change in bombing tactics. From March 1942 onwards, Royal Air Force Bomber Command headed by Sir Arthur Harris, inaugurated a new bombing method.[6] The emphasis in this new programme was on area bombing, in which the centres of towns would be the main target for nocturnal raids.[7] The central idea of the new strategy was that the destruction of cities would have an enormous and destructive effect on the morale of the people living in it. Moreover, the destruction of city centres implied the destruction of a large part of a city's housing stock. This led to the dislocation of workers, which would disrupt industrial production even if the factories themselves were not hit. This strategy also implied that targeted cities were not necessarily large, industrialized cities. On the contrary, relatively small cities with, for instance,

3 Because a bombing shock destroys buildings, Glaeser and Shapiro (2001, p. 13) criticize the Davis and Weinstein approach for not including a housing model.

4 To a large extent the information in Section 3 is based on the following sources: (i) USA (1945). After the war a team of experts prepared a survey on the effects of the air offensive on Germany during the war, members of the staff that carried the major responsibility (as mentioned in the report) were John Kenneth Galbraith (Director), Burton Klein (Assistant Director), Paul Baran, James Cavin, Edward Denison, Samuel Dennis, Thomas Dennis, Griffith Johnson (Jr), Nicolas Kaldor, James McNally, and Roderick Riley; (ii) *Dokumente deutscher Kriegsschäden*, volume 1 published by government of the FRG in 1958; (iii) *Statistischen Jahrbuch Deutscher Gemeinden*, vol. 37, published in 1949. See Section 3.2 for more information on the data.

5 Before 1944 only a small part of the heavy bomber force was equipped to carry the gasoline necessary for deep penetration into German air space. Also aircrafts and radar systems improved, making the attacks more effective.

6 Harris was not responsible for the decision to bomb German cities, although he fully supported it. A week after the directive was issued he became the new head of Bomber Command.

7 During the war the US Army Air Force joined the British RAF. The two forces did not agree upon the most effective bombing strategy: the British preferred night attacks, while the Americans preferred daytime attacks. In practice this resulted in an almost continuous attack.

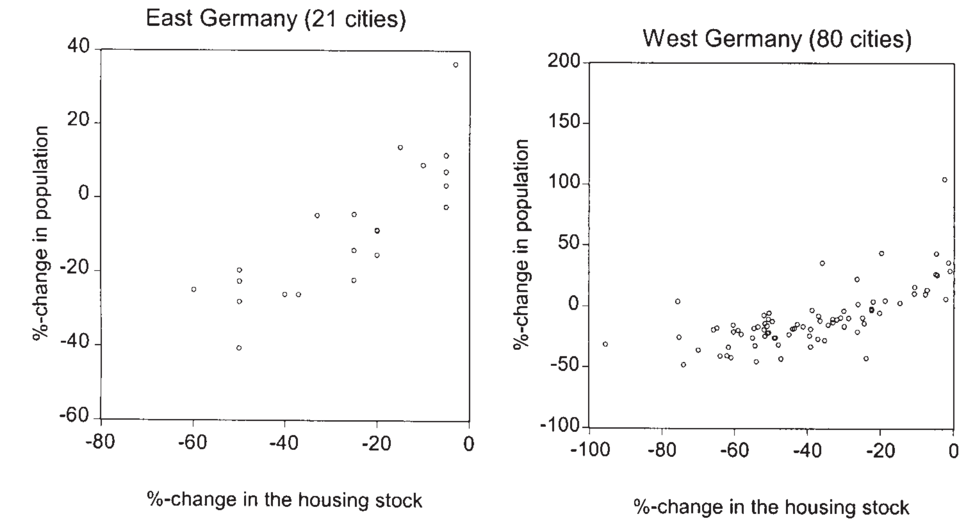

Figure 1. Housing stock destroyed and city size growth in East and West German cities, 1939–1946.

Source: Own calculations based on Kästner (1949); Volks-und Berufszählung 1946. City growth for each city *i* is the total population in 1946 minus the population in 1939 divided by the population in 1939. If we use *relative* city growth a similar conclusion emerges; relative city size is defined as the size of each city relative to the total population.

distinguished historic (and thus highly flammable!) town centres were also preferred targets under this plan.[8] The recent study by Friedrich (2002) documents in detail that targeted cities were not only selected because they were particularly important for the war effort, but that they were also selected for their visibility from the air (depending, for example, on weather conditions or the visibility of outstanding landmarks such as a cathedral) and whether a city centre would be susceptible to area bombing with incendiary bombs (see also Section 4.2). What should be stressed here is that the economic importance of cities was often not decisive in the selection of targets after Harris took over Bomber Command.

Until the end of the war this new line of attack would continue, and many cities were attacked more than once. Cologne, for instance, was bombed at least 150 times. Some cities were nearly completely destroyed: almost 80% of Würzburg disappeared, and many other large cities were also largely destroyed like Berlin, Dresden or Hamburg (see the Appendix for the spatial distribution of the housing destruction for all major German cities). On average 40% of the dwellings in the larger cities was destroyed [which is roughly comparable with the corresponding figures in Davis and Weinstein (2002) for Japan]. An estimated 410 000 people lost their lives due to air raids, and seven million people lost their homes. As a result in 1946 the population of quite a few German cities was (in absolute terms) considerably lower than the corresponding population in 1939. To illustrate the extent of

8 Harris described the strategy as follows 'But it must be emphasized . . . that in no instance, except in Essen, were we aiming specifically at any one factory . . . the destruction of factories, which was nevertheless on an enormous scale, could be regarded as a bonus. The aiming points were usually right in the centre of the town . . . it was this densely built-up centre which was most susceptible to area attack with incendiary bombs (Harris, 1947).

destruction Figure 1 presents for each of the cities in our sample the share of housing stock destroyed (horizontal axis) and the change in city size from 1939 to 1946 (vertical axis).

Following Glaeser and Gyourko (2001), both for the East German cities (left panel) and West German cities (right panel) there is a clear (and expected) positive correlation between the change in population between 1939 and 1946, and the degree of the destruction of the housing stock. Cities in which 20% or more of the housing stock was destroyed, typically had a *negative* growth between 1939 and 1946.[9]

Whether or not the method to bomb city centres shortened the war or had indeed an effect on the morale of the German population is not relevant in this paper. What is important is that many cities in Germany were to a very significant degree destroyed by the end of WWII. The destruction was primarily caused by the bombing campaign but, in contrast to Japan, also by the invasion of Germany by the allied forces. The fighting between the allied forces and the German army in West Germany implied additional and severe damage to cities that were on the frontline. The same holds for the fighting between the Russian and German army in East Germany. But it was not only the destruction of cities that had an impact on city sizes. The collapse of Germany in 1945 led to an enormous flow of refugees in the aftermath of WWII. The inflow of millions of German refugees (*Vertriebene*) from former German territories and East European countries more than compensated for the loss of lives in Germany itself (see Section 5).[10]

3.2. Data set

Our sample consists of cities in the territory of present-day Germany that either had a population of more than 50 000 people in 1939 or that were in any point of time in the post-WWII period a so called *Großstadt*, a city with more than 100 000 inhabitants. This gives us 103 cities in total. Our sample of 103 cities consists of 81 West German and 22 East German cities.[11] To analyse post-WWII city growth, we need cross-section data about the WWII-shock and time series data on city population.

With respect to the former, Kästner (1949) provides West German cross-section data about the loss of housing stock in 1945 relative to the housing stock in 1939, and rubble in m^3 per capita in 1945. From Friedrich (2002) we derive the number of war casualties for a subsample of the 103 German cities in our sample. These three variables, that measure the degree of destruction, are potential instruments for our estimations, as will become clear below. For 21 of our East German cities data about the relative loss of housing stock are available (source: *Amt für Landeskunde in Landshut*, cited by Kästner, 1949). Data on rubble are only available for West German cities.

9 Another indicator of destruction for West German cities (m^3 rubble per capita per city in 1945) leads to a similar conclusion (see Section 3.2 on our data set). A simple regression in which the change in population is regressed on the change in housing stock and a constant confirms the message from Figure 1. The housing stock coefficient is 0.824 ($t = 6.4$) for West German cities and 0.829 ($t = 8.6$) for East German cities which, in line with the findings of Glaeser and Gyourko (2001) for the US, indicates a tight connection between (changes in) population and the housing stock.

10 Rough estimates indicate that between 11 and 14 million refugees had to find a new home in Germany (both in East and West Germany).

11 The East German city of Görlitz fulfilled the 1939 criterion, but was excluded because part of the city became the Polish Zgorzelec after WWII.

Time series data of city population are from the various issues of the *Statistical Yearbooks* of the FRG and GDR, and for 1946 from the *Volks- und Berufszählung vom 29. Oktober 1946 in den vier Besatzungszonen und Groß-Berlin*. As we will run regressions on the relative size of cities before and after the WWII (city size relative to the total population), we also need statistics on the national population. This is not as easy as it might seem, because the German border changed after WWII. There are pre-WWII time series of population for the part of Germany that became the FRG in 1949 (*Federal Statistical Office*), and similarly for the years 1933, 1936, and 1939 statistics of the population for the part of Germany that became the GDR are available (*Statistisches Jahrbuch der DDR*, 1960).

For the German case it is in our view not straightforward to include the number of casualties per city as a variable measuring the degree of destruction. Systematic data on casualties are lacking and if they were available they include prisoners of war (PoWs), foreign workers (*Fremdarbeiter*), and refugees and are therefore not a good indicator of the destruction of a city. For a subset of cities, based on Friedrich (2002), we have city data on casualties and from these data we know that PoWs, refugees and foreigners often contributed more than proportionally to a city's death toll (they were often denied shelter during bombardments). The distribution of these 'temporary' inhabitants of a city was often not linked to the size of the city. This means that, as opposed to the case of Japan as analysed by Davis and Weinstein (2002), the number of casualties may not be a good indicator of city destruction compared to the change in the housing stock.

4. Model specification and estimation results

4.1. Model specification and basic estimation

As a formal test of the WWII shock on German city growth, we follow the methodology employed by Davis and Weinstein (2002). Their approach is basically to test if the growth of city size (with city size as a share of total population) follows a random walk. The relative city size s for each city i at time t can be represented by (in logs):

$$s_{it} = \Omega_i + \varepsilon_{it} \tag{1}$$

where Ω_i is the initial size of city i and ε_{it} represents city specific shocks.

The persistence of a shock can be modeled as:

$$\varepsilon_{i,t+1} = \rho\varepsilon_{i,t} + \nu_{i,t+1} \tag{2}$$

where ν_{it} is independently and identically distributed (i.i.d.) and for the parameter ρ it is assumed that $0 \leq \rho \leq 1$.

By first differencing (1) and by making use of (2) we get

$$s_{i,t+1} - s_{i,t} = (\rho - 1)\nu_{i,t} + (\nu_{i,t+1} + \rho(\rho - 1)\varepsilon_{i,t-1}) \tag{3}$$

If $\rho = 1$, all shocks are permanent and city growth follows a random walk; if $\rho \in [0, 1)$, the shock will dissipate over time. With $\rho = 0$ the shock has no persistence at all, and for $0 < \rho < 1$ there is some degree of persistence but ultimately the relative city size is stationary and hence any shock will dissipate over time: the growth process is characterized by mean reversion. As Davis and Weinstein (2002, p.1280) note the value for the central parameter ρ could be determined by employing a unit root test.

The power of such a test is, however, quite low and the reason to use such a test is that usually the innovation v_{it} cannot be identified. In our case, as in the Japanese case of Davis and Weinstein (2002), the innovation can be identified as long as we have valid instruments for the war shock ($s_{i,1946} - s_{i,1939}$) that serves as v_{it} in the estimations.

The basic equation to be estimated is (in logs):

$$s_{i,1946+t} - s_{i,1946} = \alpha(s_{i,1946} - s_{i,1939}) + \beta_0 + error_i^{12} \quad (4)$$

where $\alpha = \rho - 1$.[13] If $\alpha = 0$ city growth follows a random walk. If we find that $-1 \leq \alpha < 0$ this is evidence that a random walk must be rejected and hence that the war shock had no effect at all ($\alpha = -1$), or at most a temporary effect ($-1 < \alpha < 0$) on relative city growth in Germany. So, $-1 \leq \alpha < 0$ is evidence for (a tendency towards) a mean reverting growth process. Equation (4) in fact tests a random walk with drift; the 'drift' is captured by β_0 and describes possible long-run trends towards more or less urbanization due to for instance changes in the industrial structure that might influence city growth.

To estimate equation (4) we have to choose a t for the left-hand side variable $s_{i,1946+t} - s_{i,1946}$. We have chosen $t = 4$ (indicating 1950), because this is the first year after the formal split of Germany into the FRG and the GDR. For the long run, and more importantly as adjustment period, we have opted for $t = 17(18)$ (indicating 1963, 1964 respectively) which corresponds with the time horizon used by Davis and Weinstein).[14] Although the reconstruction effort in Germany took far longer than just four years, in the case of Germany $t = 4$ is interesting because the post-war economic development for the two Germanies took a very different path from 1945 on. To highlight the very different post-war history of West and East Germany we estimate equation (4) separately for both Germanies as well as for Germany as a whole.

Before we turn to the estimation results we first briefly discuss our choice of the instrumental variables (IV). We can use the following three city specific variables as instruments: the destruction of the housing stock between 1939–1945, the rubble in m^3 per capita in 1945 and finally the number of war casualties. As we have already explained in Section 3, the number of war casualties for each city might, a priori, not be a satisfactory instrument in the German case. However, we analyse the power of all three instruments. In order to test for the power of the three potential instruments we ran regressions in which the variable $s_{i,1946} - s_{i,1939}$ is to be explained by the instruments, see Table 1. It turns out that the instruments have the right sign but that indeed the number of war casualties is not significantly different from zero (second column). The number of observations is limited, due to the lack of data on war casualties per city. In the third column we drop war casualties as an instrument, and add rubble per capita (m^3). For the sample of West German cities, both instruments are significantly different from zero, and have the right sign. For West Germany we will also show the results using both instruments. Our preferred instrument, the destruction of the housing stock, is presented in column four: it has the right sign, is highly significant and we have data

12 Note that we can include a constant because the summation over all s is not equal to 1 (the share of a city is relative to the total population, and not to the sum of city sizes in our sample).

13 Note that the measure of the shock (or innovation) is the growth rate between 1939 and 1946, which is correlated with the error term in the estimating equation. This indicates that we have to use instruments.

14 If we take substantially longer time horizons, like $t = 35$, the 'war' has no longer any effect on city growth.

Table 1. Instrumental variable equation (dependent variable = rate of growth in relative city population between 1939 and 1946, in logs)

Independent variable	Coefficient	Coefficient	Coefficient*
Constant	0.59 (1.87)	0.24 (3.02)	0.4 (7.05)
Housing stock	−0.27 (−4.09)	−0.07 (−2.06)	−0.18 (−11.10)
Casualties	−0.02 (−0.88)	—	—
Rubble in m^3	—	−0.11 (−4.83)	—
R^2	0.36	0.64	0.56
No. of observations	46**	78***	102****

*The housing stock is also significant with the right sign for East and West Germany separately; ** Subsample for which war casualties are known; ***West German cities only; ****East and West German cities; *t*-values in parentheses.

Table 2. The impact of the 'bombing' shock on relative German city growth

	α	β_0	Adj. R^2
West, $t = 4$	−0.42 (−4.03)	0.01 (0.35)	0.20
West, $t = 17$	**−0.52 (−5.47)**	0.05 (1.87)	0.40
East, $t = 4$	0.05 (0.88)	0.007 (0.48)	<0
East, $t = 18$	**0.003 (0.02)**	0.11 (2.53)	<0
East + West $t = 18$	**−0.40 (−4.91)**	0.07 (2.91)	0.13

t-values in parentheses; instrument: % of houses destroyed in 1945 relative to 1939.
West: West German cities, number of observations = 79 [Wolfsburg (founded in 1938) and Salzgitter (founded in 1942) are excluded]; East: East German cities number of observations. = 21 (no data for Weimar).
Additional estimates of equation (4) without β_0 did not change α notably and are not shown.

for West and East German cities. We therefore, stress the IV results with the housing stock as instrument.

Table 2 gives the estimation results for equation (4) with the change in housing stock as the instrumental variable.

From Table 2 it is clear that the estimation results for city growth in East and West Germany are different. To emphasize the importance of $t = 17(18)$, as our preferred long-run adjustment period, estimation results for this period are in bold. The values for α $(=\rho - 1)$ for West Germany are significantly smaller than zero, whereas for East Germany they are not significantly different from zero. This shows that allied bombing had a significant, but temporary, impact on city size in West Germany and that there is a tendency towards mean reversion, while city growth in East Germany does not display mean reversion and can be characterized as a random walk. In West Germany (and for Germany as a whole) the WWII shock has a significant impact on post-war city growth but this impact is temporary. For West German cities the shock was not dissipated in 1950 ($t = 4$), as might be expected in such short period of time, but, more importantly, was still felt in 1963 ($t = 17$). The results for West Germany do not depend on our choice of the instruments. When we use both rubble and the housing stock destruction as instruments we find results that are qualitatively the same as those for IV estimation

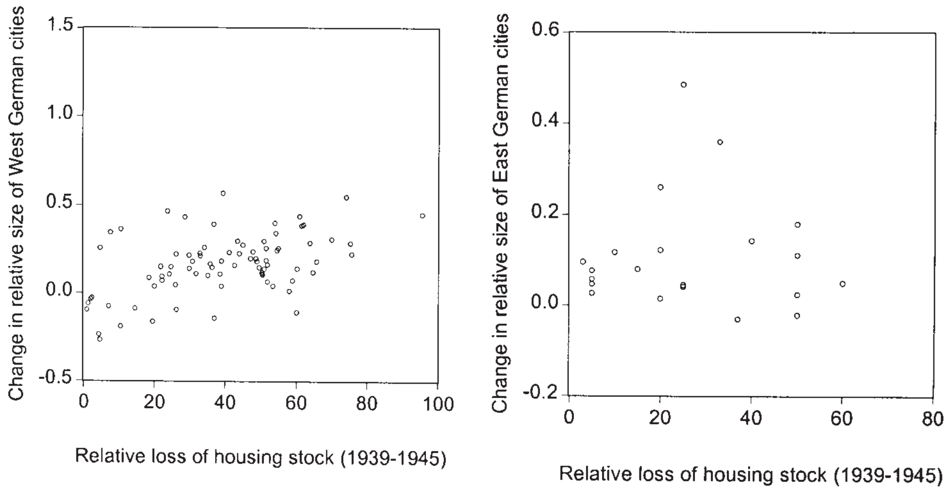

Figure 2. Relative loss of housing stock during WWII (%) and change in relative city size between 1946–1963/64.

with only the housing stock destruction as instrument [for $t = 17$, using both instruments, α equals -0.43 ($t = 4.75$)].[15] The findings for West Gemany are different from the results found for Japan by Davis and Weinstein (2002). They find that $\alpha = -1$ (and thus $\rho = 0$) which means that on average Japanese cities had recovered completely from the war shock in 1960 (their cut-off year).

In East Germany the shock of WWII did, however, change the pattern of city growth and here we find some evidence for the hypothesis that a large temporary shock can have permanent effects, both in the short and in the long run. The results for East Germany should be interpreted with some care, however, due to the limited number of observations. For Germany as a whole we thus also find evidence that relative city growth followed a mean reverting process, indicating the dominance of West German cities in the sample. The main conclusion of the results so far is that the destruction of the housing stock only had a temporary (but significant) effect in West Germany and a lasting effect in East Germany. Note that this difference already shows up straight after the war had ended ($t = 4$). In Section 6 we will return to this difference.

Figure 2 illustrates our findings and the difference between the two Germanies in a different way. It shows for each city the impact of the war shock (measured by the relative loss of the housing stock) against the change in the relative city size from 1946 to 1963 (West Germany) or 1964 (East Germany). In line with our estimation results, Figure 2 shows that for our sample of West German cities there is a positive relationship between the extent of the war shock and post-WWII relative city growth. On average, cities with a relatively large loss of housing stock grew relatively more rapidly after the war. Figure 2 also shows that this is not the case for East German cities. Relatively city size growth in the period 1946–1964 in East Germany seems unrelated to the degree of housing destruction that occurred during WWII.

15 In this case we have 77 observations. The original 79 West German cities from Table 2 minus Saarbruecken and Oldenburg: for these two cities we have no data on rubble per capita.

4.2. Additional estimation results

In theory the strategic bombing campaign of the allied forces might have (systematically) targeted the rapidly growing cities, which could bias α downwards. Although we know that the selection of targets was not solely driven by the economic importance of cities (see Section 3), we control for this by adding a pre-war growth trend (change in growth between 1933–1939).[16] When we do this the results are almost identical to those reported in Table 2, confirming that the selection of targets was not based on their growth potential. Adding this pre-war growth trend gives an α-coefficient (t-values in parentheses) of -0.52 (5.44) for West Germany with $t = 17$ and -0.008 (0.43) for East Germany with $t = 18$.

Furthermore, one could argue that our estimation results are to some extent the combination of two shocks, the WWII shock and the division of Germany into the FRG and the GDR in 1949. It might be the case that the post-war growth of some German cities (for instance cities located near the FRG-GDR border (the so-called *Zonenrandgebiet*)), is significantly influenced by this division. This would mean that the left-hand side variable in equation (4) not only depends on the war shock but also on the positioning of the city in post-1949 Germany. In order to control for this possibility, we re-ran equation (4) for West German cities while adding as an explanatory variable the minimum distance to the nearest East German district in kilometers. The α-coefficient for West Germany is virtually unchanged. For the IV estimation for $t = 18$ we find that West German cities that are more distant from the GDR grew relatively faster during the period 1946–1963 but this effect disappears when we drop West Berlin (a FRG enclave in the GDR) from our sample.[17]

Another reason why the post-WWII division of Germany into the FRG and the GDR might be important is that the surviving infrastructure of East Germany suddenly, with the creation of the GDR, became less useful. This was because the main transit routes (railways, roads) in East Germany traditionally connected West Germany with eastern Europe (Sleifer, 2003, ch.3). The economy of the GDR was, certainly in the 1950s, more or less cut-off from the outside world. A large part of the pre-war infrastructure was aimed at connecting East Germany with the outside world (mainly the West Germany). This may have hampered the relative growth of the GDR economy and, see Section 6, and may help to explain the difference between East and West Germany city growth after the war.

5. Rebuilding policies of the German governments

The distinction in the estimation results between the FRG and GDR policies is not only important because the market economy of the FRG and the planned economy of the

16 As to the variation in the selection of targets, inspection of our data shows that for cities with a population of at least 50 000 people there is indeed a large variation in the war shock ($s_{i,1946} - s_{i,1939}$) across cities.

17 As a further check we looked at possible spatial dependencies. Equation (4) estimates the evolution of city size through time, but does not reveal if there is a systematic bias related to space. It could be the case that the αs we find systematically over- or underestimate the true value of α in specific regions: the (sign) of the error term might systematically vary across space. Although it is a bit of a catch-all, we calculated Moran's correlation coefficient to check for this (Anselin, 1988). It turns out that there is no systematic spatial clustering of error terms. There is thus no clear indication of region-specific effects (with the exception of the FRG-GDR distinction). These results are available in the working paper version of this article, see the acknowledgements.

GDR were based on very different economic principles (see Section 6), but also because when it comes to (re-)building efforts the two countries pursued very different policies. The FRG built relatively far more new houses than the GDR (3.1 million between 1950 and 1961 compared to 0.5 million houses in the GDR which almost three times as much in per capita terms), and its government (both at the federal and state level) also had the declared objective to rebuild the West German *Großstädte* to their pre-war levels. In the mid-1950s a number of FRG cities were back at their 1939 city size levels, while this was not the case in any GDR city. In the GDR on the other hand the (re-)building efforts were explicitly not focused on the rebuilding of the (inner) cities hit by WWII (East Berlin was an exception) but far more on the creation of new industrial agglomerations like Eisenhüttenstadt or NeuHoyerswerda to which industries and workers were 'stimulated' to move. To this date, one can still see the traces of WWII destruction in many former GDR cities in Germany.

The distinction between the FRG and GDR is also important when it comes to actual government funds allocated to the (re-)construction efforts. We have no data for East German cities, but given the difference in policy objectives as outlined above, it seems safe to assume that the GDR only spent a very small fraction of what the FRG government spent in this respect. In his in-depth study of the reconstruction of the West German cities after WWII, Diefendorf (1993) explains how the federal housing law of 1950 in the FRG has been crucial in the post-war allocation of funds to the (re-)construction of houses. This law was a main instrument for the public funding of the housing reconstruction and in the 1950s the public funding accounted for more than 50% of total funding (Diefendorf, 1993, p. 138). At the federal and the state level the following distribution scheme was used in the actual allocation of the funds to individual cities (Diefendorf, 1993, pp.134–135): 50% was based on the post-war population size, 25% on the degree of city destruction (rubble), and 25% on the level of actual industrialization. To check our findings from Table 2 we would like to know if in West Germany the government rebuilding policies help to explain the temporary nature of the war shock and whether they favoured the cities that were relative more damaged.

Note, that at least two factors are important for our research, given the post-war policy response to the war destruction. First, in the FRG city size and the degree of destruction partly determined how much funds a city actually got, this is obviously important in the analysis of the impact of the 'bombing' shock on post-war city growth. Second, the Federal Housing Law in the FRG aimed at 'making funds available for social housing and by granting property-tax relief for new private housing and repaired or rebuilt dwellings' (Diefendorf, 1993, p. 134). Actual government support was based on the aforementioned distribution scheme and we can use this scheme because it gives us the relative support each city got under the Federal Housing law. To be specific, we analyse the support policy, as it was executed by the West German authorities, as follows:

Support = [(0.25 × city's share of rubble) + (0.25 × city's population share 1950) + (0.25 × city's population share in 1960] + [0.25 × geographical size of a city (in km^2) relative to the average size of cities)].

Table 3 gives the estimation results of estimating equation (4) for West German cities when we add government support as an explanatory variable. We only show the estimation results for $t = 17$ because the support variable is based a policy that only came into effect from 1950 onwards.

Table 3. Impact of government reconstruction policies, West Germany

	α	β_0	Gov. support	Adj. R^2	Remarks
West, $t = 17$	−0.58 (−5.89)	0.06 (0.72)	−1.9 (−3.24)	0.447	77 cities, Wolfsburg (founded in 1938), Salzgitter (founded 1942) excluded. No rubble data for Saarbrucken, Oldenburg

t-values in parentheses. Instrument: percentage of houses destroyed in 1945 relative to 1939.

Compared to Table 2, the addition of the government support variable slightly seems to increase the speed at which the war shock dissipates for West German city growth (the α coefficient is somewhat larger, and hence the implied ρ is somewhat closer to zero). The main conclusion remains, however, unaltered. In 1963 West German cities had only partially recovered from the WWII shock but ultimately the impact of the war shock is temporary.

Higher government support is associated with lower growth. It therefore seems that government support *hindered* the adjustment process to the extent that the policy objective of a return to the pre-war relative city sizes was not stimulated by the actual support that took place. Two reasons why this might be the case came to the fore. First, the support variable was not necessarily intended to grant relatively more funds to the cities that were relatively the most destroyed during the war. To see this, note first of all that the support variable puts a rather great weight on a city's post-WWII population (in 1950 and 1960). Given the huge inflow of refugees into Germany (*Vertriebene*) after the war had ended, cities not only consisted of 'initial' (pre-WWII) inhabitants in 1950 or 1960 but also of refugees. From the total number of the estimated 11 to 14 million refugees, about 3.1 million *Vertriebenen* were in 1960 living in the 81 West German cities in our sample. It turns out that these refugees were housed in cities that were relatively *less* hit by the war. That is to say, for the cities in our sample higher values for $(s_{i,1946} - s_{i,1939})$ correspond with a higher share of *Vertriebene* in the total population. This means that cities with relatively more refugees, ceteris paribus, received more government support even though these cities had a relatively lower level of war destruction. The second reason why the government support variable does not promote city growth is that it is biased in favour of large cities. This can be clearly seen from the measurement of war damage by a city's share in the total rubble. This share will be larger for cities like Hamburg or (West) Berlin but what matters is the amount of rubble relative to the city size, like rubble per capita. In fact when we correlate the variable $(s_{i,1946} - s_{i,1939})$ with each city's share of total rubble, there is no relationship whatsoever whereas there is a clear negative relationship when we take the variable rubble per capita instead. Davis and Weinstein (2002) do find a small (and in two out of three cases insignificant) positive effect of government support. However, they explain the rather marginal contribution of government support by the fact that support was geared at rural areas, that were often less hit by the war shock. This corresponds to the German case, in the sense that support not necessarily went to those cities that were hit the hardest.

6. Empirical findings and urban economics

In Section 2 we stated in very general terms that there are basically two views about the possible impact of a large, temporary shock on city growth. According to the first view the productivity of a city is determined by innate urban characteristics and as long as the destruction of the housing stock and the change in population do not change productivity one would expect that the destruction of German cities in WWII would at most have a temporary impact on post-war city growth. For Germany as a whole and for our subsample of West German cities we find confirmation for this view. This is not the case for cities in the former GDR. For East German cities the WWII shock seems to have had a permanent impact since we find that for this subsample relative city size displays no mean reversion. This is not necessarily in contrast with the view that cities have a natural size. Following Glaeser and Gyourko (2001) and Glaeser and Shapiro (2001), war-struck cities will only be rebuilt if the housing prices exceed the construction costs. Given the well-documented correlation between the size of the housing stock and a city's population, the return to pre-war city size is only possible if this is accommodated by a post-war rebound of the housing stock. In East Germany in the GDR-period neither housing supply nor demand conditions favored a post-war recovery of the housing stock. As opposed to the *Wirtschaftswunder*-era of the 1950s in the FRG, the GDR government did not try to stimulate housing demand by offering tax reductions for rebuilding, or stimulate supply in the way the FRG did through its re-construction policies (see Section 5). The GDR economy did not experience a rapid growth or a large inflow of new inhabitants (the *Vertriebene*) that could have stimulated housing demand. In short, in the GDR positive housing supply and demand shocks were lacking compared to the case of the FRG. As a result it may simply have been that housing prices exceeded construction costs in the FRG but not in the GDR. Although we have no post-war GDR data to test this, it may thus very well be that because of these differences in post-war housing market developments, it was economically viable to (re)build (new) housing in West German cities while this was not the case in East Germany. Klasen (1999, p. 93) shows for West Germany that on average the reconstruction costs were DM 12 000 and that housing rents only exceeded the reconstruction costs through government rent support. This is certainly a topic for future research.[18]

Different post-war housing market conditions may help to explain the different impact of the WWII shock on West and East German cities but the possible relevance of this explanation for the observed FRG-GDR distinction must not be overstated for two reasons. First, as was argued before, the subsample for East German cities is quite small and estimation results for such a small sample should be interpreted with care. Second, and perhaps even more importantly, East Germany is a special case and one could doubt whether the period of the GDR could be used to test these theoretical approaches

18 In the housing model of Glaeser and Gyourko (2001) the housing supply curve displays a kink at the point where housing prices (p) equal the (fixed) construction costs (c). For $p < c$ the housing supply is perfectly inelastic and the housing stock does not change but housing prices can. If $p > c$, the housing supply curve is elastic meaning that changed conditions on the housing market not only imply price changes but also changes in the housing stock. In Section 3 we showed that for the case of Germany there is, at least for the WWII period a strong positive correlation between changes in the population and changes in the housing stock, which is in line with the findings of Glaeser and Gyourko (2001) for the US. A first indication of the relevance of their analysis for Germany is that in the GDR in 1946 about 40% of the cities had a population level that was at least equal to the 1939 level but that this percentage stayed more or less the same after 1946. In the FRG only 30% of the cities had in 1946 a population level that was at least equal to the 1939 level, but after 1946 this rapidly increased to 90% in 1960! The Glaeser and Gyourko housing model is in levels and assuming, as they do, a tight positive connection between city population and city housing stock, this finding is consistent with a stagnant (=1946 level) housing stock in the GDR and an increasing housing stock in the FRG, and this is in line with the GDR (FRG) being on the inelastic (elastic) part of the kinked supply curve from their model.

to start with. All of these theories assume that individual agents, be it workers or firms, are free to choose a location. In a market economy this is a valid assumption, but not in a centrally planned economy like the GDR. In the West German market economy, well-defined property rights and a well-functioning financial sector stimulated the rebuilding of houses after 1949.[19] To some extent property was nationalized, but property was partly still also in private hands and quite often in the hands of absentee proprietors (who migrated to West Germany). Formally property rights were well defined, but in practice they were not. This provides another reason as to why incentives for reconstruction were lacking in East Germany. Furthermore, the state gave priority to rapid industrialization that used up the scarce investment funds. In addition, the communist party wanted to destroy the remnants of the old Germany, and left the war struck inner cities to decay. The switch from a market economy to a planned economy implied that market forces that were possibly relevant for West German city growth, were no longer or at least less relevant for East German city growth after the creation of the GDR.[20] In this respect the finding that the WWII shock had a permanent impact on East German city growth is not only caused by the war itself but also by the fact that East Germany became a centrally planned economy after the war.

What about the second basic view introduced in Section 2 about the impact of a shock like our bombing shock on city growth? If agglomeration economies are really strong and there is no natural city size, it is less clear why mean reversion should occur at all. The destruction of housing and the resulting decrease in population may alter a city's productivity to the extent that it will never return to its pre-war growth path. The pre-war equilibrium will not be restored. But this needs not to be the case. Models of agglomeration economies are often characterized by path-dependency and it cannot be excluded that even a large shock like the bombing shock is not large enough to reach a new (stable) equilibrium. At any rate, our results for West Germany suggest that, similar to the findings by Davis and Weinstein (2002, p. 1281) for Japan, the stability of the initial equilibria is much stronger than, for instance, recent new economic geography models predict. Even though the first view on shocks and city growth is more in line with our main findings, our analysis cannot provide a conclusive test of competing theories. A more encompassing test should include more city specific data apart from the housing stock and population. If one sticks to the first view more data are required. As has been stressed by for instance Henderson (1974), city sizes may differ because different cities produce different goods. Each city has an optimal size that corresponds to the types of goods produced in that city. City size depends on the strength of external economies with respects to a particular commodity or industry. One would like to know whether and how WWII and the post-war policies influenced the industrial structure and the location decisions of specific industries. Davis and Weinstein (2003) find for the case of Japan a

19 Hans-Juergen Wagener pointed out the relevance of these institutional features of the GDR economy.

20 A further illustration of the relevance of the market economy/planned economy distinction for the case of the GDR is the fact that the relative city size growth in the GDR in more recent (=partly post-reunification) times turns out to depend *negatively* on the same growth rate during the early days of the GDR in 1946–1964. We ran the following simple regression for the 21 East German cities in our sample, $s_{i,1999} - s_{i,1981} = \varphi(s_{i,1964} - s_{i,1946}) + \text{constant} + error_{\text{i}}$. The φ coefficient enters significantly with a negative sign implying that a relatively strong growth in the early GDR period is associated with the opposite for the period 1981–1999.

tendency of specific industries to move back to cities where they were situated before the war (cited in Head and Mayer 2003, p. 48).

7. Conclusions

In this paper we describe a unique data set on the post-WWII growth of German cities in order to analyse the impact of a large, temporary shock on city growth. Inspired by Davis and Weinstein (2002), we use the strategic bombing of German cities during WWII as an example of such a shock. The main (but not sole) determinant of the destruction of German cities in this period was the strategic area bombing campaign by the allied forces. City specific variables enable us to determine the impact of WWII and its aftermath on post-war city growth. Taking the 1949 division of Germany into the FRG and GDR into account, we estimate the impact of WWII destruction on post-war German city growth. For Germany as a whole we find that the impact on relative city size has been significant but temporary. This conclusion also holds for West German cities taken in isolation, but not for the smaller group of East German cities. For the latter we find evidence that WWII and the ensuing establishment of the GDR had a permanent impact on relative city size. Our results for West Germany provide tentative support for those urban growth theories that predict that large, temporary shocks will have at most a temporary impact.

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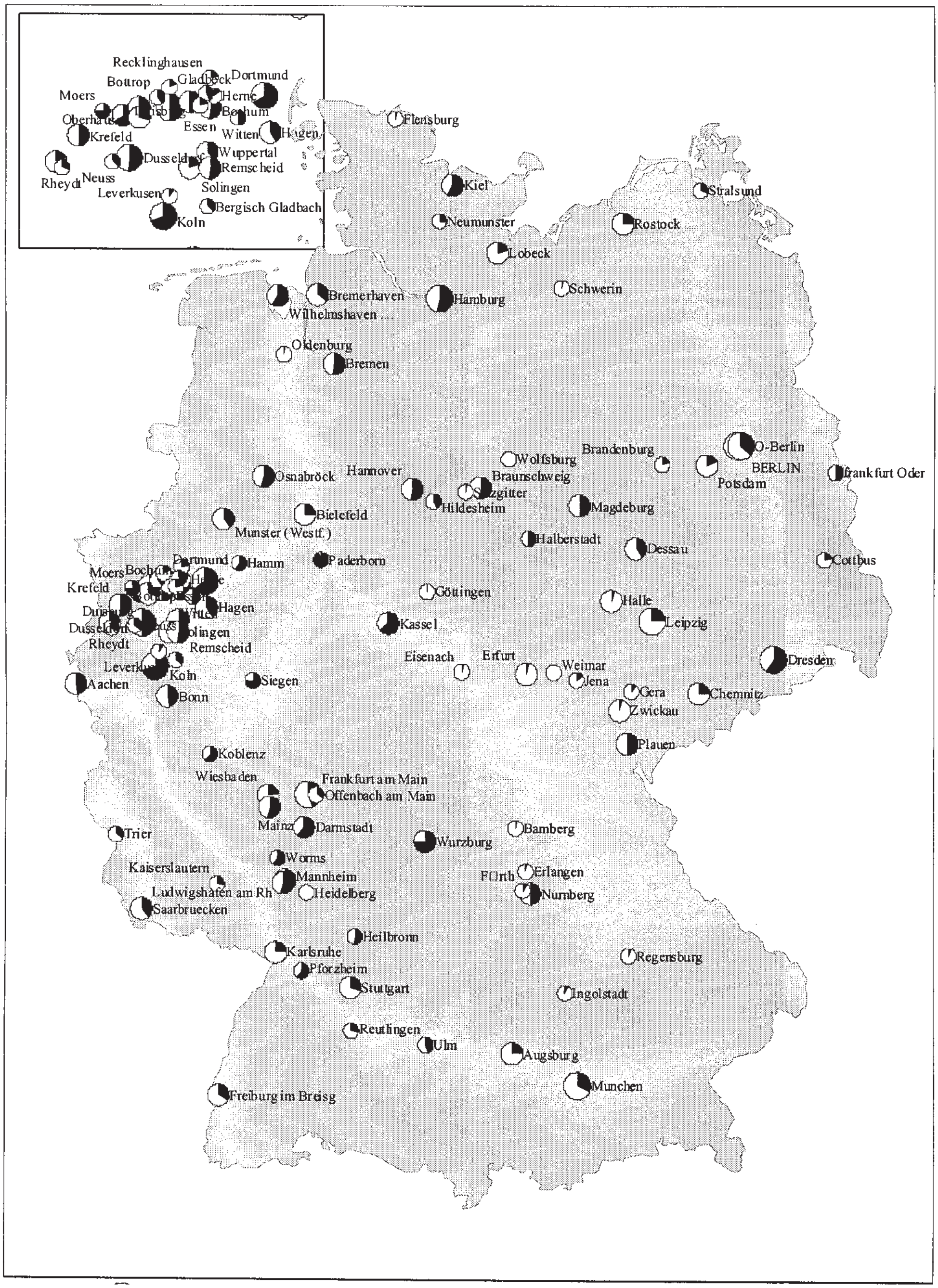
Appendix: Destruction of housing stock in German cities



Source: own calculations, data described in Section 3.2: smallest circle indicates city with <100 000 inhabitants, medium circle indicates a city with >100 000 but <500 000 inhabitants, largest circle indicates city > with 500 000 inhabitants. The shaded sections in a circle indicate the percentage of housing destroyed in 1945 relative to 1939.