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The Strategic Bombing of German Cities during World War II and its Impact on City Growth

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THE STRATEGIC BOMBING OF GERMAN CITIES DURING WORLD WAR II AND ITS IMPACT ON CITY GROWTH

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THE STRATEGIC BOMBING OF GERMAN CITIES DURING WORLD WAR II AND ITS IMPACT ON CITY GROWTH

Abstract

We construct a unique data set to analyze whether or not a large temporary shock had an impact on German city growth and city size distribution. Following recent work by Davis and Weinstein (2001) on Japan, we take the strategic bombing of German cities during WWII as our example of such a shock. The goal of this paper is to analyze the impact of this shock on German city-growth and the resulting city-size distribution. If city-growth follows a random walk this would imply that the war shock had a permanent impact on German city-growth. If, however, as a second group of theories predicts, the random walk hypothesis is not confirmed this would mean that the war shock at most had a temporary effect on the city growth process. Our main finding is that city growth in western Germany did not follow a random walk, while city growth in eastern Germany did follow a random walk. Different post-war economic systems are most likely responsible for this outcome.

JEL Classification: R11, R12, F12.

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1. Introduction

City size distributions are remarkably stable over time. The relative size differences between large and small cities have often found to be fairly constant and to change only very slowly. The general conclusion in the literature is that it is still not very well understood why city sizes vary in a systematic way. Basically, three types of explanations have come to the fore. First, models based on economic forces. In these models externalities or increasing returns to scale determine city growth. Second, models which assume city growth to be completely scale-invariant and random. As a result the current size of a city does not matter for its growth prospects. Third, models based on physical geographical characteristics of certain locations in which, for example, a city near a navigable waterway will be larger than a land-locked city (see for a survey of various theories Brakman, Garretsen, and Van Marrewijk (2001)).

In an attempt to discriminate between the various theoretical explanations Davis and Weinstein (2001) use the case of Japanese agglomerations. They not only analyze the variation and persistence of the Japanese regional population density over the course of 8000 years (!) but, more importantly for our present purposes, they also investigate whether or not a large temporary shock (*in casu*, the bombing of Japanese cities during WWII) had a permanent or only a temporary effect on Japanese city growth and the city-size distribution in the post-WWII period. This is a first step to distinguish between the three a fore mentioned theoretical approaches. On the one hand the fundamental or physical geography approach predicts that a large random shock will only have temporary effects while at the other extreme the random growth approach predicts that there will be permanent effects on city-growth. Davis and Weinstein (2001) conclude that the evidence is most favorable for the fundamental geography approach. With respect to the "bombing" shock, it turns out that this shock had at most a temporary impact on the relatively city growth in Japan. Japanese cities quickly recovered from the WWII experience and quite soon after WWII they were back on their pre-war growth path.

In the present paper we build upon the analysis of Davis and Weinstein (2001) on the impact of allied bombing on Japanese cities during WWII. We do so by taking the strategic bombing of German cities during WWII as another example of a large, temporary shock. In doing so we also take the split 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 policy reaction by the two governments to the same shock might be relevant for post-war city growth in both countries. The primary goal of this paper is to analyze whether or not the destruction of German cities during WWII had an impact on German city growth after WW II.

The paper is organized as follows. In the next section we provide some background information on the scope of the allied area bombing of Germany during WWII. We also give some (qualitative) information on post-WWII policies with respect to the (re-) building of German cities. Section 3 presents our data set and gives information on the German city-size distribution for the period 1925-1999. For this period we have data on 103 German cities (81 West German and 22 East German cities), and the city-specific information in section 3.1 not only includes the city-size but also the degree of war damage. The information in section 3.2 on the variation and persistence of relative city- sizes is based on well-known proxies like the rank correlation of city-sizes and the slope of rank-size curve. In section 4 we perform growth regressions to test the impact of the "bombing" shock on post-WWII city growth. We present estimations for the FRG, GDR as well as for Germany as a whole. Section 5 evaluates our findings and section 6 concludes.

2 The Strategic Bombing of German Cities during WWII [2]

2.1 Allied Bombing and the Degree of Destruction

In the Second World War (WWII), allied forces heavily bombed Germany. During the first period from 1940 to early 1942 the targets selected by the English RAF were mostly industrial targets, such as, oil, aluminum, and aero-engine plants, and transportation systems. Marshaling yards were to be treated as secondary targets, but the heavy bombardments on these yards showed that the primary targets were initially difficult to find. In general, it turned out that the bombing of a complete economy was not easy: prior to 1943, air raids probably had little effect on the German production capacity. It was estimated, for example, that a big raid on Kiel, prior to the summer of 1943, aimed at attacking submarine production facilities only delayed production three weeks. The USA (1945) survey finds no clear-cut indication that before 1943 the production of German economy was smaller than it would have been without the air raids.

From the summer of 1943 onwards, the bombing campaign became more effective. Raids on the Ruhrgebiet, for example, resulted in an 8% loss in steel production, but due to large stocks the effect on armament production was only limited. The attacks also had clear effects on the production of ball bearings and crankshafts, which were important for the German war economy, but also here large stocks made that the raids had only a relatively small effect on German armament production. It was estimated that air raids reduced production only by 5% by the end of 1943.

From the middle of 1944, the effects of the air raids on the German economy became more destructive for the German war economy. This was caused by the fact that it became possible for the first time to carry out repeated attacks deep into Germany.[3] During 1944, the results of the air raids quickly became catastrophical for the German economy: the production of ball bearings fell to 66% of the pre-raid average, aviation

[2] To a large extent the information in section 2.1 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, among the experts were John Kenneth Galbraith, Paul Baran and Nicolas Kaldor; (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 3.1 for more information on the data.

[3] 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.

gasoline output declined from 175000 tons in April to 5000 tons in September 1944, rubber production by the end of 1944 fell to 15 % of its January-April average, aircraft production in December was only 60% of the production level of July, and steel output was reduced by 80% (approximately 80% of this decline was due to air attack). In general, from December 1944 onward all sectors of the German economy were in rapid decline. Due to better aircraft and radar systems the attacks became more effective, but also the number of 'sorties' increased dramatically; in March 1944 alone, 10.000 sorties took place. During the landing in France the air offensive was diverted to the support of the Allied landings, but the bombing of German cities soon resumed. More than half of all bombs dropped on Germany during the war, were dropped in the last 10 months.

The initially limited success of the air raids made that from March 1942 onwards, RAF bomber command headed by sir Arthur Harris, inaugurated a new bombing tactic[4]: the emphasis in this new program was on area bombing, in which the centers of towns would be the main target for nocturnal raids.[5] The introduction of the four-engined Lancaster plane, an improved radar system for navigation, and a better organization of bomber crews made the new tactic possible. The Germans themselves had also used the tactic of bombing city centers before 1942: Rotterdam in The Netherlands and Coventry in the UK stand out as examples. The central idea of this method 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 centers 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.

Arthur Harris and his staff had a strong faith in the morale effects of bombing and thought that Germany's will to fight would be weakened by the destruction of German cities. Furthermore, Harris, as a WW I veteran, thought this line of attack could help to prevent the slaughter of ground forces that he had witnessed in the trenches of WW

[4] 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.
[5] During the war the British RAF was joined by the US Army Air Force. The two forces did not agree upon the most effective bombing strategy: the British preferred night-time attacks, the Americans day-time attacks. In practice this resulted in an almost continuous attack.

I. This strategy implied that targeted cities were not necessarily large, industrialized cities. On the contrary, relatively small cities with for instance distinguished historic (and thus highly inflammable!) town centers were also preferred targets under this plan.[6] Targets were also selected more or less at random, depending for example on weather conditions. The first German city to fall victim to this new strategy was Lübeck, in the night of March, 28-29, 1942. Although the destruction of the city center was enormous, the effect on production was only limited: within a week the production was back at 90% of normal production levels. Approximately 300 people lost their lives in this attack. The next large city would be Cologne in the night of May, 30-31, 1942. In thise case approximately 500 people lost their lives. Until the end of the war this 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. All in all, by the end of the war 45 of the 60 largest German cities were ruined. The extent of the destruction is illustrated by Figure 1 which gives for all major German cites the share of dwellings (*Wohnraum)* that was destroyed by the end of the war. On average 40% of the dwellings in the larger cities was destroyed (which is roughly comparable with the corresponding figures in Davis and Weinstein (2001) for Japan).

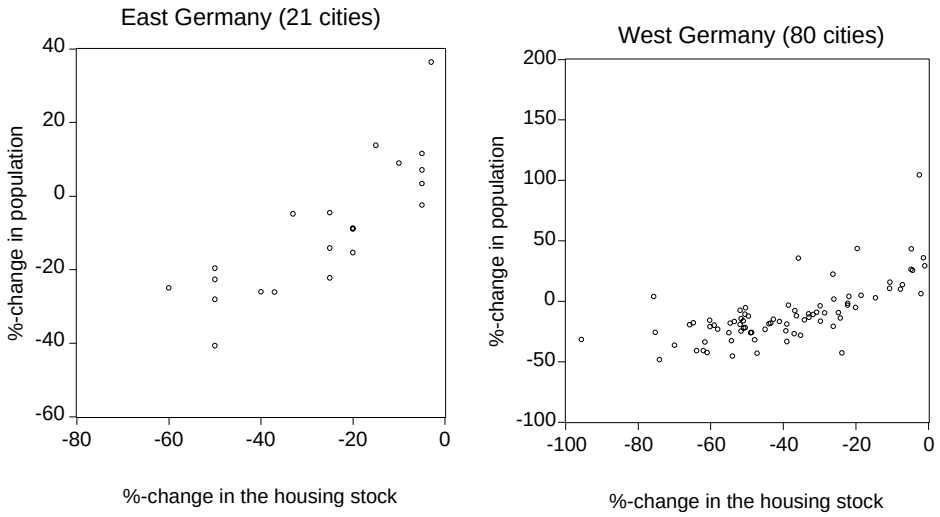
[6] Harris described the strategy as follows "But it must be emphasized (…) that in no instance, except in Essen, were we aiming specifically at any one factory (…) the destruction of factories, which was nevertheless on an enormous scale, could be regarded as a bonus. The aiming points were usually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

Figure 1 Share of dwellings destroyed in major German cities by 1945.

Source: Knopp (2001). The shaded sections indicate the share of dwellings that was destroyed in the respective cities in 1945. The size of the O circle represents the city-size: a small, medium or large O sign indicates that this city had respectively a population of <100.000, 100.000-500.000, or >500.000 people.

Two other city-specific indicators of the war shock, the amount of rubble in m^3 per inhabitant per city in 1945 and the decrease in landtax revenues per city between 1939 and 1946 also confirm the substantial degree of destruction (see also the next section). Hardly any city in Germany was not attacked, and an estimated 410.000 people lost their lives due to air raids, and seven million people lost their homes.[7] 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. As an illustration of the possible relevance of the war damage to German cities, Figure 2 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).

Figure 2 Housing stock destroyed (horizontal axis) and city-size growth(vertical axis) in East and West German cities, 1946-1939,



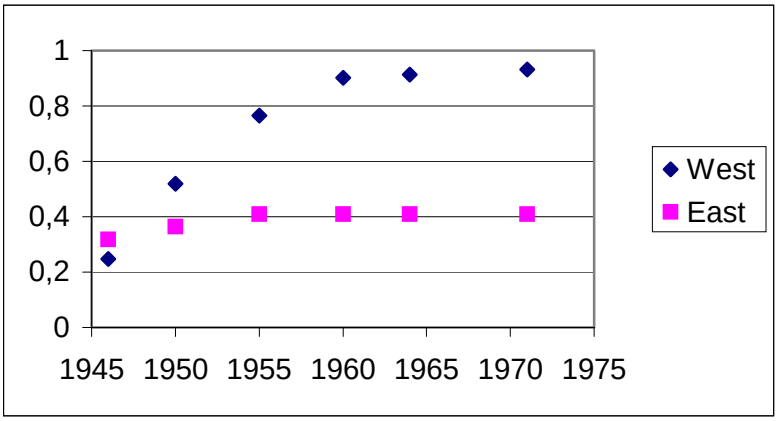
Source: Kästner, F. (1949); Volks-und Berufszählung 1946. City growth for each city *i* is the total population in 1946 minus the population in 1939 divided by the population in 1939. If we use relative city growth a similar conclusion emerges; relative city size is defined as the size of each city relative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

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

[7] Data on the number of people that died at the city level are lacking, there is no systematic acount on this issue for German cities. Even if such data were available these could not be used as indicators of the extent of the WWII shock for individual cities. Data on casualties of air raids not only include inhabitants of a city but to a significant degree also German refugees from previously bombed cities, foreigners and prisoners of war.

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.[8] This level of destruction is bound to have some impact on the growth of cities in the post-war period. Of the 19 western German cities that faced a decrease in population of more than 25% in the period 1939-1946, 2 cities returned to pre-war population level before 1951, 8 cities returned to pre-war population level before 1956, and 16 cities returned to pre-war population level before 1961. Only West Berlin never returned to its pre-war level. The development of city growth in eastern Germany is totally different, of the 5 cities that faced a decrease in population of more than 24% in the period 1939-1946, 4 cities never returned to the pre-war population level. Figure 3 illustrates this difference between west and east Germany by showing for the period 1946-1975 the proportion of west and east German cities that had returned to their pre-war, that is to say 1939, population level (Note that in our estimations in section 4 we will not be concerned with the population levels of cities but with *relative* city size growth as to which Figure 3 gives no information).

Figure 3 Proportion of cities that returned to pre-war population level



Whether or not the method to bomb city centers shortened the war or had indeed an effect on the morale of the German population is not relevant for 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

[8] Our two other indicators of destruction for west German cities (m^3 rubble per capita per city in 1945 and change in landtax revenues 1946-1939) lead to a similar conclusion.

fighting between the allied forces and the German army in the western part of 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 the eastern part of Germany.

To sum up, German cities were on average severely hit by the war and this was in particular (but not exclusively) due to the allied bombing campaign and there is a considerable degree of variation in the degree of destruction across cities (see Figure 1). The destruction of German cities during WWII can be looked upon as a prime example of a large, temporary shock that can be used to test the (stability of) relative city-size growth in 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.[9] We consider this inflow of refugees also as part of the WWII shock.

2.2 Rebuilding efforts and the distinction between the FRG and the GDR

Before we turn to our data set, model specification and estimation results we must also briefly discuss the post-war reconstruction and building efforts because they obviously are potentially relevant for post-war city-growth. The distinction between the FRG and GDR policies is not only important because the market economy of the FRG and the planned economy of the GDR were based on very different economic principles, but also because when it comes to (re-) building efforts the two countries pursued very different policies. The FRG built far more new houses than the GDR (3.1 million between 1950 and 1961 compared to 0.5 million houses in the GDR), 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. As Figure 3 already indicates, in the mid-1950s a number of these cities were back at the 1939 city-size levels. 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 Neu-Hoyerswerda 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 formal division of Germany into the Federal Republic of Germany (FRG) and the German Democratic Republic (GDR) took place in 1949 and in this respect post-war city growth across Germany as a whole (GDR and FRG) is not only influenced by the war destruction shock but by the political split of 1949 as well. In section 4 we will deal with the question whether it is possible to disentangle these two shocks.

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 eastern 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 did 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 to in allocating funds to the (re-) construction of houses. In 1953, for instance, the federal government budgeted 400 million-DM for housing construction, 75% of which was allotted to the Bundesländer and each Bundesland subsequently divided these funds to its cities. At the federal and the state level roughly the same distribution formula was used (Diefendorf, 1993, pp. 134-135): 50% was based on population size, 25% on the degree of destruction, and 25% on the level of actual industrialization. Note thus that in FRG city-size and the degree of destruction partly determined how much funds a city actually got, this is obviously something to take into account in the analysis of the impact of the "bombing" shock on post-war city growth. Finally, even though we will focus in our estimations on the impact of this shock in the FRG-GDR period, we will also briefly look at city-size data for the period 1990-1999 in section 3, that is to say for the period after the re-unification of 1990. It is interesting to see how after 3 large shocks (WWII; the creation of the FRG and GDR in 1949; reunification in 1990) the city-size distribution has evolved.

[9] Rough estimates indicate that almost 11 million refugees had to find a new home in Germany (both in

3 Data Set and the German City-Size Distribution

3.1 Data set

Our sample consists of cities in the territory of present-day Germany that 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 (103 cities in total). These 103 cities consist of 81 West German and 22 East German cities.[10] To analyze post WWII-city growth, we need cross-section data about the WWII-shock and time series data on city population. Kästner (1949) provides West German cross-section data about the loss of housing stock in 1946 relative to the housing stock in 1939, rubble in m^3 per inhabitant in 1945, and the relative change in the revenues of the municipal land tax (*Grundsteuer B*) in 1946 relative to 1939. For 21 of our sample of East German cities data about the relative loss of housing stock are available (source: *Amt für Landeskunde in Landshut*, cited by Kästner, 1949). Time series data of city population are from the various issues of the *Statistical Yearbooks* of FRG and GDR (and, after 1990, of unified Germany), and for 1946 also 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 straightforward as it might seem, because the German border did change after WW II. There are pre-WW II 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, 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 useful to include the number of casualties per city as a variable measuring the degree of destruction, because this number includes prisoners of war, foreigners, and refugees and is therefore not a good indicator of the destruction of a city. The housing stock is our preferred indicator of the population of a city also because it has been found that the link between the

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East and West Germany).

[10] The east German city Görlitz fulfilled the 1939-criterion, but was excluded because part of the city became the Polish Zgorzelec after WW II .

housing stock and the population is tight (Glaeser and Gyourko, 2001, p. 6). Figure 2 above already suggests that the change in the housing stock and the change in population are clearly correlated and the simple regression below confirms this (where *POP*= population, *H*= housing stock, *i*=city *i*, t-values between brackets).

East Germany (21 cities):

$$\frac{POP_{i1946} - POP_{i1939}}{POP_{i1939}} = \underset{(6.4)}{.824}\frac{H_{i1945:} - H_{i1939}}{H_{i1939}} - \underset{(-21.3)}{.872}$$

adj. R^2= 0.683

West Germany (80 cities):

$$\frac{POP_{i1946} - POP_{i1939}}{POP_{i1939}} = \underset{(8.6)}{.829}\frac{H_{i1945:5} - H_{i1939}}{H_{i1939}} - \underset{(-18.4)}{.779}$$

adj. R^2=0.483

3.2 The German city-size distribution 1925-1999

Before we turn to our growth regressions in section 4, we first provide some summary statistics on the development of the German city-size distribution during the period 1925-1999. To start with, the *rank-size distribution* gives an efficient summary of city sizes and city size distributions.

A rank size distribution can be described by equation (1):

(1) $\log(M_j) = \log(c) - q\log(R_j)$

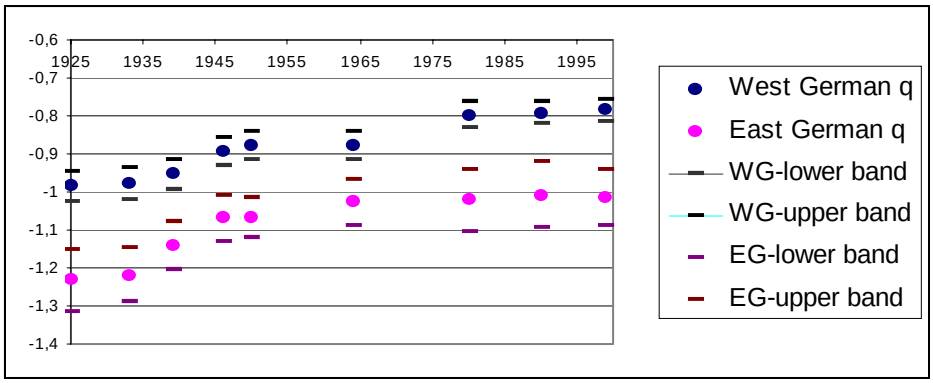
Where *c* is a constant, M_j is the size of city *j* (measured by its population) and R_j is the rank of city *j* (rank 1 for the largest city, rank 2 for the second largest city, etc.). In empirical research *q* is the estimated coefficient, giving the slope of the supposedly log-linear relationship between city size and city rank. Zipf's law is a special case: it is said that Zipf's Law only holds if $q = 1$. If $q = 1$, the largest city is precisely *k* times as large as the kth largest city.[11] If *q* is smaller than 1, a more even distribution of city sizes results than predicted by Zipf's Law (if $q = 0$ all cities are of the same size). If *q* is larger than 1, the large cities are larger than Zipf's Law predicts, implying more urban agglomeration, that is the largest city is more than *k* times as large as the kth largest city. There is, however, *a priori* no reason to assume specific values for *q*. Its

value is a matter of empirical research (see, Brakman, Garretsen, Van Marrewijk (2001), chapter 7 and Soo (2002) for a survey of the main findings).

By calculating the value of q for all years in our sample, we can trace the evolution of the rank-size distribution in Germany. We have calculated the q-coefficient for Germany as a whole (not shown here) and, as displayed by Figure 4, for East and West Germany separately. A number of observations come to the fore as Figure 4 illustrates. First, before the war the (absolute) value of q was, certainly for West Germany, relatively close to 1. WWII drastically changed the city size distribution in the sense that city sizes became more equal (the absolute value of q drops between 1939 and 1946). Second, although the war changed the city size distribution, Figure 4 also shows that the trend towards smaller (absolute) values for q persisted after the war, for both West and East Germany there is no return to the pre-war rank-size distribution. This change in q towards a more even city-size distribution in the post-war period is not uncommon to the extent that it can be observed in other developed countries that experienced a shift from an industrial economy towards a more service oriented economy. This process is generally found to be associated with smaller (absolute) values for q. Third, as shown by the confidence intervals for the East and West German q-coefficients, the difference in q between East and West Germany is significant. These confidence intervals also show that compared to the the pre-WWII situatuion, the change in q over time is probably more significant for the case of the west German cities. For the East German cities the confidence intervals for 1939 and subsequent years overlap.

[11] Carroll (1982) indicates that the Rank-Size Distribution has been discussed prior to Zipf (1949)

Figure 4 Evolution of the rank-size distribution

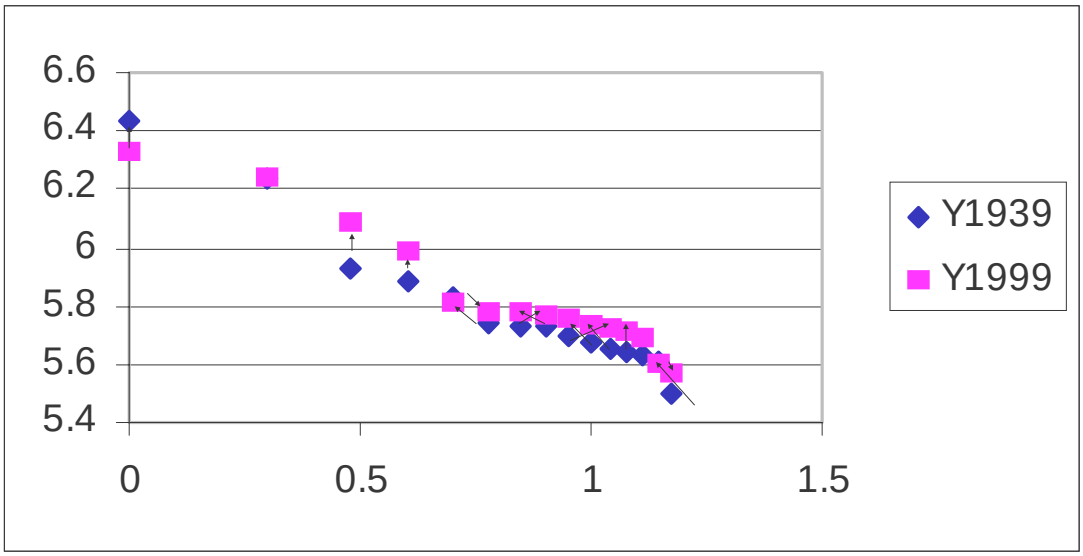


The figure gives values for -*q*. West German q's are obtained from the rank-size regression of the 75 largest west German cities in our sample, and the east German q from the rank-size regressions of the 22 largest east german cities. For Germany as whole (=west and east German cities) *q= -0.9* in the pre WWII period and then jumps to *q*= -0.85 in 1946 and thereafter gradually drops to *q*= -0.75 in the 1990s. The confidence intervals for $\hat{q}$ are indicated by the slashes in the figure; the upper band is defined as $\hat{q}+2\hat{\sigma}$ and the lower band as $\hat{q}-2\hat{\sigma}$, and $\hat{\sigma}$ is the estimate of standard deviation of q.

Simply inspecting values for *q*, however, does not give information on the position of *individual* cities. Figure 5 illustrates how rank-size curves can also be used to reveal the growth history of individual cities. The city size distribution can be very stable whereas at the same time the rank of individual cities can change dramatically.

Figure 5 Rank-size curve and the position of 15 largest cities in West Germany, 1939 and 1999

(rank (in logs) on horizontal axis, city size (in logs) on vertical axis)



notably by Auerbach and Lotka.

To avoid cluttering we have drawn the rank size curve only for the 15 largest West German cities for 1939 and 1999. The arrows in the graph connect the same city in 1939 and 1999 and show how the rank of that city has changed between 1939 and 1999. Visual inspection suggests that not only the rank-size distribution as such is rather stable but also that the rank of individual cities in 1999 is comparable to that of 1939. So, over a period of 60 years that includes i.c. WWII, the split of Germany in 1949 and the reunification in 1990 the ranking of the 15 largest West German cities in 1999 looks rather similar to that of 1939. Table 2 confirms this notion. In Table 2 rank correlations for the largest cities are given and they indeed show a clear persistence in the rank of individual cities; with the rank correlation increasing until the mid-1960s and decreasing somewhat afterwards.

Table 2. Rank correlation, with city size ranking for 1939 as benchmark

	W-50	**E-22**	**60**
1946	.860	.931	.875
1964	.953	.920	.946
1979	.867	.878	.856
1990	.850	.854	.847
1999	.855	.881	.841

W-50=50 largest cities in West Germany,
E-22=22 largest cities in East Germany,
60=60 largest cities in East and West Germany combined.

The summary statistics for Germany presented in this sub-section basically confirm the idea of (some degree of) stability of the city-size distribution over time. In this respect and despite WWII and other large shocks that hit Germany and its cities in the 20th century, Germany seems not very different from other developed countries. These summary statistics are, however, not able to answer our central question whether or not WWII and the ensuing split of Germany in 1949 had an impact on German city-growth. It is to this question that we now turn.

4. The WWII Shock and its Impact on City Growth in Germany

As a formal test of the WWII shock on German city growth, we follow the methodology employed by Davis and Weinstein (2001). 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):

(2) $$s_{it} = \Omega_i + \varepsilon_{it}$$

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:

(3) $$\varepsilon_{i,t+1} = \rho\varepsilon_{i,t} + v_{i,t+1}$$

where v_{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 (2) and by making use of (3) we get

(4) $$s_{i,t+1} - s_{i,t} = (\rho - 1)v_{i,t} + \left(v_{i,t+1} + \rho(\rho - 1)\varepsilon_{i,t-1}\right)$$

If ρ = 1, all shocks are permanent and city growth follows a random walk, if $\rho \in [0,1)$ than the shock will dissipate over time. With ρ=0 the shock has no persistence at all, and for 0<ρ<1 there is some degree of persistence but ultimately the relative city size is stationary an hence any shock will dissipate over time. As Davis and Weinstein (2001, p.21) 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 normally the innovation v_{it} cannot be identified. In our case, as with the case of Japan in Davis and Weinstein (2001), the innovation can be identified as long as we can come up with valid instruments for the war shock $(s_{i,1946} - s_{i,1939})$ that serves as v_{it} in our estimations.[12]

The basic equation (in logs) to be estimated is

(5) $$s_{i,1946+t} - s_{i,1946} = \alpha(s_{i,1946} - s_{i,1939}) + \beta_0 + error_i$$ [13]

where α=ρ-1.[14] So α=0 corresponds with the case of 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 (α=-1) or at most a temporary effect (-1<α<0) on relative city-growth in Germany. Equation (5) 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 urbanisation due to for instance changes in the industrial structure that might influence city growth.

[12] We did perform the Dickey-Fuller test for our sample of west German cities. For the majority of west German cities we can reject the hypothesis that city growth follows a random walk.

[13] 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).

[14] Note that the measure of the shock (or innovation) is the growth rate between 1939 and 1946, which (see equation (2) and (3)) is correlated with the error term in the estimating equation. This indicates that we have to use instruments.

Table 3 presents the results for the OLS estimations and, more importantly, the IV estimations. To estimate equation (5) we have to choose a *t* for the left-hand side variable $s_{i,1946+t}$ - $s_{i,1946}$. This choice is arbitrary and we present estimates for *t*=4 (indicating 1950), and *t*=17(18) (indicating 1963, 1964 respectively) in order to make a distinction between the start of the post-war reconstruction- and the long run (our idea of the long run corresponds with the time horizon used by Davis and Weinstein). Furthermore, and as has been explained in section 2, because of the very different post-war history of western and eastern Germany we mainly estimate equation (5) separately for both Germanies.

Table 3. Testing for a random walk of German city growth

	α	β_0	Instrument	Adj. R^2	Remarks
West, t=4	-0.34 (4.65)	0.03(1.2)	- (OLS)	0.209	79 cities, Wolfsburg (founded in 1938) Salzgitter (founded 1942) excluded
West, t=17	-0.48(7.23)	0.06(2.64)	- (OLS)	0.397	Idem
East, t=4	0.05(0.83)	0.007(0.47)	- (OLS)	<0	22 cities
East, t=18	0.05(0.33)	0.11(3.02)	- (OLS)	<0	22 cities
West, t=4	-0.42(4.03)	0.01(0.35)	Percentage of houses destroyed in 1945 relative to 1939	0.197	79 cities, Wolfsburg (founded in 1938), Salzgitter (founded 1942) are excluded
West, t=17	-0.52(5.47)	0.05(1.87)	Idem	0.395	Idem
East, t=4	0.05(0.88)	0.007(0.48)	Idem	<0	21 cities, no data on houses destroyed in Weimar
East, t=18	0.003(0.02)	0.11(2.53)	Idem	<0	Idem
East+West, t=4	-0.43(4.48)	0.04(0.5)	Idem	0.113	100 cities, Excluding Wolfsburg, Salzgitter, Weimar

t-values between brackets. Additional experiments (not shown), such as the inclusion of a pre-war trend between 1939 and 1933, did not change results significantly. Additional estimates of (5) without β of variants with an insignificant constant did not change the α notably and are not shown.

Before we turn to the estimation results we first briefly discuss our choice of the instrumental variables (IV). We can use the following 3 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 change in land tax revenues between 1939 and 1946. As we have already explained in section 3, the number of war casualties for each city is not a good instrument for the German case in our view. In order to test for the power of our three potential instruments we ran regressions in which the variable $s_{i,1946} - s_{i,\,1939}$ is to be explained by our instruments. It turns out that the instruments are highly significant with the right sign. In Table 3 we do, however, only show the IV-results with the housing stock as instrument. The reason to do this is twofold. First, we only have data on the rubble and the land tax variable for (a sub-set of) west-German cities and using these instruments would thus render a comparison between the results for West and East Germany difficult. Second, the results for West Germany do not depend on our choice of the instruments. In all cases we find results that are qualitatively the same as those for IV-estimation with only the housing stock destruction as instrument.

Furthermore, as an additional check on the validity of equation (5) we take a closer look at possible spatial dependencies. This is important because equation (5) estimates the evolution of city size through time, but does not reveal if there is a systematic bias in our estimates related to space. It could be the case, for example, that the α's we find systematically over- or underestimate the true value of α in specific regions. To this end we calculated Moran's correlation coefficient:

$$I = \frac{\sum_{i=1}^{R}\sum_{j=1}^{R} x_{i,t} x_{j,t} w_{i,j}}{\sum_{i=1}^{R} x_{i,t}^2},$$

where $x_{i,t}$,($x_{j,t}$) is the difference between the estimated share, s_i,(s_j) of a city i (j) and the actual share of city i (j) (in fact we are looking at residuals with zero mean), and $w_{i,j}$ a normalized spatial weight between i, and j. we choose $w_{i,j} = \frac{e^{-\theta . distance_{i,j}}}{\sum_{k}^{R} e^{-\theta . distance_{i,k}}}$,

where elements on the $w_{i,j}$ diagonal are set to zero: $w_{i,i}=0$.

The value of the corrrelation coefficient *I* thus gives a high weight to a similar misspecification of two cities if they are close to each other. In this way the statistic reveals possible spatial clusters of mis-specification.[15] We take the IV-estimates of table 3 with respect to West Germany as examples for both, t=4, and t= 17. We have to choose a value for θ, this is somewhat arbitrary and we take θ=0.1, and θ=0.2, as examples. If θ=0.1 then for t=4, *I*=0.009, and for t=17, *I*=0.053 and if θ=0.2, then for t=4, *I*=0.017, for t=17, *I*=0.08. These values for *I* are low and indicate that our estimates are not biased due to spatial dependencies (see also Anselin, 1988).

From Table 3 a number of observations follow. First, the estimation results for city growth in East and West Germany are very different. The values for α(=ρ-1) for western Germany are significantly smaller than zero, whereas for eastern Germany they are not significantly different from zero. This shows that city growth in western Germany is not a random walk, while city growth in eastern Germany does follow a random walk. In western Germany the WWII shock has a significant impact on post-war city growth but this impact is temporary. Still for west German cities not all of the shock was dissipated in 1950 (t=4) as well as 1963 (t=17). West German cities had partially recovered from the war shock in 1950 but also in 1963. This is a notable difference with the results found for Japan by Davis and Weinstein (2001). They find that α= -1 (and thus ρ=0) which means that on average Japanese cites had recovered completely from the war shock in 1960 (their cut-off year). In east Germany the shock of WWII via its destruction of German cities did, however, change the pattern of city growth and here we find evidence for the hypothesis that a large temporary shock can have permanent effects.

A second observation is that the OLS and IV regressions lead to similar conclusions but that one should focus on the IV-results for reasons explained above. Thirdly, in theory the strategic bombing campaign of the allied forces might have (systematically) targeted the rapidly growing cities, which could bias our results. Although the selection of targets was more or less random (see section 2), we controlled for this by adding a pre-war growth trend (relative size growth between

[15] A negative value means that there is less spatial clustering than might be expected from a random distribution; perfect negative correlation resembles a checker board.

1933-1939).[16] The results are almost identical confirming that the selection of targets was random. A fourth observation is that, as expected, the dissipation of the initial shock in western Germany is larger in the long-run than in the short-run, as the difference between the estimates for t=4 and t=17 illustrate.[17] For eastern Germany this difference is not relevant as city growth follows a random walk.

The last row of Table 3 shows the estimation results after we pooled the west and east German cities (for t=4). Given the greater number of west German cities in our sample (79 versus 21) it is not surprising that the results are rather close to those for the sub-sample of west German cities. One might argue that our estimation results are to some extent the combination of 2 shocks, the WWII shock and the division of Germany into the FRG and the GDR in 1949. It might be that the post-war growth of some German cities, for instance those located near the newly established FRG-GDR border (the so-called *Zonenrandgebiet*), is significantly influenced by this division. This would mean that the left-hand side variable in equation (5) not only depends on the war shock but also on the positioning of the city in post-1949 Germany. In order to check for this possibility, we re-ran equation (5) for west German cities while adding as an explanatory variable the minimum distance to the nearest east German city in kilometers. In all cases 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.

The difference in city growth between eastern and western Germany is remarkable. An obvious candidate to explain this difference is the difference in government policy

[16] As to the randomness of 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] Note that this finding is not inconsistent with the persistence of the ranking of individual cities as shown in section 3 (recall Table 2): if for $s_{i,t}>s_{j,t}$ than a sufficient condition for $s_{i,t+1}>s_{j,t+1}$ is that ρ=0 (and hence α= -1). In this case a shock cannot disturb the ranking of the city-size (in levels). For $0<\rho\leq 1$, which applies to west as well as east Germany according to table 3, the ranking of cities at *t+1* can (but need not) to be different from the ranking at *t*. To see this, suppose that two cities A and B have a size at time *t* of respectively 100.000 and 10.000 and suppose also that the growth process is characterized by a random walk (like in the case of east Germany) and after a shock has occurred cities A and B have at time *t+1* a respective size of 40.000 and 7.000. In terms of (negative) growth city A is worse off than city B but the ranking has not changed.

between the two Germanies (see section 2). Government support on the city level is not available. For the GDR cities this is probably not a problem because, as we explained in section 2.2, government policies were not directed at the re-building of cities. However, for West German cities we can infer the following about government support (Diefendorf, 1993). For a very large part (due to the Federal Housing Law of 1950) support per state in the FRG was based on the following policy rule: support depended on the level of destruction (25%), the level of industrialization (25%) and population size (50%). The states distributed funds to cities according to a similar formula. The Federal Housing Law 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). Because data on the actual support received per city are lacking we constructed a support variable for West German cities that is based on the abovementioned distribution formula and in this way we can mimic the support policy as it was executed by the west German authorities:

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

Table 4 gives the estimation results of estimating equation (5) for West German cities when we add government support as an explanatory variable.

Table 4 Testing for a random walk in the presence of government policies, FRG

	α	β_0	Gov. support	Adj. R^2	Remarks
West, t=4	-0.49(4.30)	0.03(1.00)	-1.28(1.90)	0.214	77 cities, Wolfsburg (founded in 1938) Salzgitter (founded 1942) excluded, No rubble data for Saarbrucken, Oldenburg.
West, t=17	-0.58(5.89)	0.06(0.72)	-1.9(3.24)	0.447	Idem

T-value between brackets. Instrument: Percentage of houses destroyed in 1945 relative to 1939

Compared to Table 3, 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 1950 or 1963 west-German cities had only partially recovered from the WWII shock but ultimately the impact of the war shock is destined to be temporary.

Surprisingly, 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 (see section 2.2) 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 come to the fore. First, the support variable was not necessarily intended to grant relatively more funds to the cities that were relatively more 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),* cities not only consisted of "initial" (pre-WWII) inhabitants in 1950 or 1960 but also of refugees. In 1960 from the total amount of 11 million of these refugees about 3.1 million *Vertriebenen* were living in the 81 west German cities in our sample and we have data on the number of these refugees for each west German city in our sample. It turns out that these refugees were more inclined to go cities that were relatively *less* hit by the war. That is to say, higher values for $(s_{i,1946} - s_{i,1939})$ go along with a higher share of *Vertriebene* in the total population. This means that cities with relative more refugees ceteris paribus received more government support even though these cities had relatively a lower level of war destruction. The second reason why the government support variable does not foster city growth is that is biased in favor 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 confront our 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.

5. Evaluation

In section 3.2 we have provided some evidence that despite some large "shocks" the German city-size distribution is relative stable over time. In the introduction we

mentioned that various theoretical approaches (random growth, fundamental geography, increasing returns) can be called upon to explain this stability. The growth regressions in section 4 basically tested whether German city-growth follows a random walk using WWII as a large, temporary shock. Following Davis and Weinstein (2001) such a test enables us to make a first crude distinction between the three basic theoretical approaches. In this section we will briefly evaluate our findings against the background of these theories. Before we do so, it must be emphasized that we certainly do not want to claim that the analysis in this paper suffices for a conclusive test of these theories. Nevertheless, there are some interesting implications.

First, there are theories that emphasize fundamental geography or non-neutral space to explain (differences in) city-growth and the resulting city size distribution. The basic idea is that specific features in the landscape that favor certain cities. However, geographers typically stress the importance of fundamental geography. Gallup et al. (1998), for instance, stress that coastal regions, or regions linked to waterways are strongly favored in their development. Other regions that are landlocked or far from navigable waterways are hindered in their development. For city formation this means that cities near harbors, or coastal areas are favored over other regions. Fundamental geography thus influences city size distributions: the larger cities are located near the coast or navigable rivers.

Second, there are theories that stress increasing returns and externalities that arise when economic activity agglomerates in certain locations. Firms group together in a city because local demand is high and demand is high because firms have decided to produce in that city. This provides a rationale for agglomeration like in the core new economic geography model by Krugman (1991). In addition, this approach shows how additional externalities that are associated with specialization of cities on the one hand and/or the diversification of economic activity within the city on the other hand can lead to cities of different sizes and to differences in city-growth. The difference with the first approach is that the locational (dis)advantages of cities are man-made and not given by nature. The specialization/diversification distinction is referred to in the literature as one between so-called *Jacobs* externalities and *Marshall-Arrow-Romer* (MAR) externalities. Both externalities refer to knowledge spillovers between

firms. With MAR externalities, knowledge spillovers occur between firms that belong to the same industry. With Jacobs-externalities, knowledge spillovers are not industry-specific but take place among firms of different industries. Glaeser et al. (1992) conclude that Jacobs-externalities are the most important externalities for employment growth in U.S. cities. There is, however, also evidence in favor of MAR-externalities. Black and Henderson (1999) and also Beardsell and Henderson (1999) for instance find for the USA that MAR-externalities are to be found in the high-tech industries. Again, the point to emphasize here is that in the increasing returns approach the interaction between economic agents and not the actual geography that shapes the urban landscape. In this approach the actual space is typically assumed to be neutral.

Finally, there the approach that shows that under certain conditions a random growth process of cities can lead to stable city-size distributions. Simon shows that the random growth of the population will eventually result in Zipf's Law (Simon, 1955). Gabaix (1999) calls upon Gibrat's Law and proves that if every city, large or small, shares the same common mean growth rate, and if the variance of this growth rate is the same for every city, Zipf's Law follows. As opposed to the first two approaches, this approach focuses on the statistical properties of the city-growth process and does not go into the economics of city-growth nor does it pay attention to physical geographical differences between locations.

The prediction of these theories on the evolution of city growth following a large temporary shock, like our German WWII shock, is different. The most ambivalent theory is the theory based on increasing returns and externalities. Positive or negative externalities re-enforce each other once they come into existence; large cities will become larger and small cities will become smaller. This however does not imply that destructed but initially large cities will necessary return to their old size (or rank). It depends on whether or not the initial situation was an equilibrium in the first place, and if so, whether or not that equilibrium was stable or not. If the initial equilibrium was stable this might be consistent with the persistence of city size distributions and a temporary shock eventually dissipates. If the initial equilibrium was unstable the

evolution of city sizes might appear as a random walk.[18] Theories based on fundamental geography lead, however, to a clear-cut prediction: after a temporary shock the original city size distribution will re-emerge and the effects of a temporary shock on city-growth will dissipate over time. Finally, random growth theories predict, of course, that the evolution of city sizes follows a random walk and a large, temporary shock like the WWII shock will have permanent effects.

Do our findings in section 4 make it possible to choose between these theories? To some (limited) degree we think the answer is affirmative. For western Germany the random walk hypothesis is clearly rejected which is bad news for the random growth approach. In this respect our findings for western Germany are similar to those found by Davis and Weinstein (2001) for Japan even though we find that the war shock dissipates more slowly over time than in the case of Japan. The fundamental geography model is supported for western Germany by our findings. But what can we say about the theories based on increasing returns and externalities? Here, the answer can not be clear-cut because this theoretical approach comes up with an ambiguous prediction; both the acceptance and rejection of a random walk can be in accordance with this approach. Clearly more research is needed here. It is for instance interesting to observe (recall Figure 3), that that the evolution of the slope of the rank-size curve indicates that German city sizes have become more equal during the period 1925-1999. If only fundamental geography would matter, this is not easy to explain. The increasing returns approach is perhaps better placed to explain these changes and the possible link with shift in economic structure (de-industralization) in Germany. As has been stressed by Henderson (1974) city sizes differ because of the types of goods produced in certain cities differ. Each city has a size that optimally 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. Changes in the demand for the goods that are currently produced in a city will also change the distribution of urban concentrations. This process might be going on in Germany as the economy evolves from an industrial economy to a service economy. This is very much a topic for future research.

[18] This is also when summarizing the predictions of these 3 theories w.r.t. to the impact of allied bombing on Japanese city-growth, Davis and Weinstein (2001, Table 4) put a question mark behind the increasing returns approach.

In eastern Germany, city growth follows a random walk. Here our findings in section 4 do seem to lend some support to the random growth approach. At the same time theoretical approaches like the fundamental geography approach or (depending on the precise assumptions) the increasing returns approach look less relevant. In our view eastern Germany is, however, a rather special case and one could doubt whether the period of the GDR could be used to test these 3 theoretical approaches 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 made that the rebuilding of houses was relatively easy after 1949. With additional government support this created incentives to rebuild the destructed housing stock. In East Germany this was not the case.[19] To some extent property was nationalised, and to another (larger) extent property was still in private hands, however, 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 implied that the incentives for reconstruction were lacking in East Germany. Furthermore, the state gave priority to rapid industrialisation that used up the scarce investment funds. In addition, the communist party wanted to destroy the remnants of the old Germany, and blew up old castles, stately homes and churches, and left old streets to natural decay. The switch from a market economy to a planned economy implied that economic forces caused by fundamental geography or increasing returns, 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 permanent impact on east German city growth may not only or not even in the 1st place be caused by the war itself but by the

[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 tot depend *negatively* on the same growth rate during the early days of the GDR in 1946-1964. We ran the following simple regression for our 21 East German cities $s_{i,1999} - s_{i,1981} = \varphi\left(s_{i,1964} - s_{i,1946}\right) + \text{constant} + error_i$. The φ coeffcient 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.

'blackboard' planning of the socialist economy that characterized east Germany after WWII.

6. Conclusions

In this paper we compiled a unique data set on German cities to analyze the impact a large, temporary shock on city-growth and the resulting city-size distribution. Inspired by Davis and Weinstein (2001), we have opted for the destruction of German cities during WWII as our 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 on not only the size of cities but also on the extent of war damage and the subsequent government policies enable us to determine the impact of WWII and its aftermath on post-war city-growth. We first establish that despite the WWII and other (political) shocks the city-size distribution of both Germany as a whole and of the former FRG and GDR separately display a considerable degree of stability for the period 1925-1999. Taking the relevance of the division of Germany into the FRG and GDR into account, we then perform what is essentially a random walk test to analyze the impact of the WWII related destruction on German city growth. For Germany as a whole we find that this impact is significant but temporary. More importantly, this conclusion also holds for West German cities but not for the smaller group of East German cities. For the latter we find evidence in favor a random walk, which implies that for these cities WWII and the ensuing establishment of the GDR had a permanent impact on city-growth. Our results for west Germany provide tentative support for those theoretical approaches, most notably the fundamental geography approach, that predict that large, temporary shocks will at most have temporary shocks on city-growth. The results for east German cities seem to provide support for theories, like the random growth theory, that emphasize that shocks like WW II will permanently change the relative size of cities. It must be kept in mind, however, that the change in East Germany from a market economy to a centrally planned economy renders this conclusion inevitable.

City-size distributions are found to be relative stable over time and the German case is thus no exception. In addition we find that large temporary shocks have temporary effects. These findings do give support to those growth theories that predict mean reversion after a shock. At the same time, it is not true that there is no change at all.

For the German case this is for instance illustrated by the changes in the rank-size distribution in the course of the 20th century. Germany is changing from an industrial towards a more service-oriented economy. In this respect both the fundamental geography and the random growth approach may be too extreme in its predictions and we may have to call upon the third approach, the increasing returns approach to get a firm grip on the facts. In order to be able to do so, more data are needed and it may in particular be fruitful to look into the changes in the production structure of cities over time.

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