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A SEARCH FOR MULTIPLE EQUILIBRIA  
IN URBAN INDUSTRIAL STRUCTURE

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**ABSTRACT**

Theories featuring multiple equilibria are now widespread across many fields of economics. Yet little empirical work has asked if such multiple equilibria are salient features of real economies. We examine this in the context of the Allied bombing of Japanese cities and industries in WWII. We develop a new empirical test for multiple equilibria and apply it to data for 114 Japanese cities in eight manufacturing industries. The data provide no support for the existence of multiple equilibria. In the aftermath even of immense shocks, a city typically recovers not only its population and its share of aggregate manufacturing, but even the specific industries it had before.

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# A Search for Multiple Equilibria in Urban Industrial Structure

## I. Multiple Equilibria in Theory and Data

The concept of *multiple equilibria* is a hallmark of modern economics, one whose influence crosses broad swathes of the profession. In macroeconomics, it is offered as an underpinning for the business cycle (Russell Cooper and Andrew John 1988). In development economics it rationalizes a theory of the “big push” (Kevin M. Murphy, Andrei Shleifer, Robert W. Vishny 1988). In urban and regional economics, it provides a foundation for understanding variation in the density of economic activity across cities and regions (Paul R. Krugman 1991). In the field of international economics, it has even been offered as a candidate explanation for the division of the global economy into an industrial North and a non-industrial South, as well as the possible future collapse of such a world regime (Krugman and Anthony J. Venables 1995).<sup>1</sup>

The theoretical literature has now firmly established the analytic foundations for the existence of multiple equilibria. However theory has far outpaced empirics.<sup>2</sup> The most important empirical question arising from this intellectual current has almost not been touched: Are multiple equilibria a salient feature of real economies? This is inherently a difficult question. At any moment in time, one observes only the actual equilibrium, not alternative equilibria that exist only *potentially*. If the researcher observes a change over time, it is difficult to know if this change reflects a shift between equilibria due to temporary shocks or a change in fundamentals

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<sup>1</sup> A simple indication of the flood of work in these areas is that the *Journal of Economic Literature* has featured three surveys of segments of this literature in recent years (see Matsuyama 1995, Anas, Arnott and Small 1998, and Neary 2001). Recent major monographs in economic geography include Masahisa Fujita, Paul R. Krugman and Anthony Venables (1998), Fujita and Jacques Thisse (2002), and Richard Baldwin, et al. (2003).

<sup>2</sup> Cooper (2002) discusses issues of estimation and identification in the presence of multiple equilibria as well as surveying a selection from the small number of papers that seek to test empirically for multiple equilibria in specific economic contexts. We view these as welcome contributions to understanding a difficult problem, but also believe

that are perhaps not yet well understood by the researcher. If a cross section reveals heterogeneity that seems hard to explain by the observed variation in fundamentals, it is hard to know if this may be taken to confirm theories of multiple equilibria or if it suggests only that our empirical identification of fundamentals falls short.

Testing for multiple equilibria is also difficult for other reasons. The theory of multiple equilibria relies on the existence of thresholds that separate distinct equilibria. In any real context, it is difficult to identify such thresholds or the location of unobserved equilibria. In addition, a researcher may look for exogenous shocks, but these need to be of sufficient magnitude to shift the economy to the other side of the relevant threshold and they need to be clearly temporary so that we can see that we fail to return to the *status quo ante*. A researcher is rarely so blessed.

Donald R. Davis and David E. Weinstein (2002) initiated work that addresses the practical salience of multiple equilibria in the context of city sizes. The experiment considered was the Allied bombing of Japanese cities during World War II. This disturbance was exogenous, temporary and one of the most powerful shocks to relative city sizes in the history of the world. Hence it is an ideal laboratory for identifying multiple equilibria. That paper examined *city population data* and, in the context of the present paper, may be viewed as having answered two questions. Do the data reject a null that city population shares have a unique stable equilibrium? Do the data support a stated condition that would be *sufficient* to establish multiple equilibria in city population shares? In both cases, our answer was “no” – we could not reject a unique stable equilibrium nor could we establish the sufficient condition for multiple equilibria in city population shares.

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much remains to be done. Andrea Moro (2003) considers multiple equilibria in a statistical discrimination labor model.

The present paper goes beyond Davis and Weinstein (2002) in several dimensions. First we examine new and more detailed data. In addition to the city population data of the first paper, we consider data on *aggregate city manufacturing* and *city-industry* data for eight manufacturing industries. This is the first paper, to our knowledge, that tests whether the location of production is subject to multiple equilibria. Moreover, the detailed industry data is important because multiple equilibria may well arise at one level of aggregation even if not at another. For example, physical geography may act strongly to determine relative city populations or even relative sizes of city manufacturing, but multiple equilibria may yet arise in particular manufacturing industries. Subject to the level of detail in the available data, we can consider this question.

The second important advance over Davis and Weinstein (2002) is that we provide a sharper contrast between the implications of models of unique and multiple equilibria, one that naturally suggests empirical implementation in a framework of threshold regression. This new approach no longer requires that we treat unique equilibrium as the null, hence gives a greater opportunity for multiple equilibria to demonstrate their empirical relevance. Moreover, subject to the restrictions underlying our analysis, we now examine *necessary* (rather than *sufficient*) conditions for multiple equilibria. Hence a failure to find evidence of these conditions would be a more powerful rejection of the theory of multiple equilibria in this context. The methods developed in this paper to test for multiple equilibria may have application across a broad range of fields.

The present paper delivers a clear message: The data prefer a model with a unique stable equilibrium. Faced even with shocks of frightening magnitude, there is a strong tendency for cities to recover not only their prior share of population and manufacturing in aggregate, but

even the specific industries that they previously enjoyed. Our tests provide no support for the hypothesis of multiple equilibria.<sup>3</sup>

These results are highly relevant for policy analysis. Theories of multiple equilibria carry within them an important temptation. If multiple equilibria are possible, it is tempting to intervene to select that deemed most advantageous by the policymaker. If thresholds separate radically different equilibria, then the resolute policymaker can change the whole course of regional development or strongly affect the industrial composition of a region even with limited and temporary interventions. Implicitly, such views are at the base of regional and urban development policies in Europe, the United States, and elsewhere.<sup>4</sup>

Our results provide a strong caution against the idea that one may use limited and temporary interventions to select equilibria with large and permanent effects on city development. We confirm on population and city-aggregate manufacturing data that such aggregate measures of activity in cities are highly robust to temporary shocks even of immense size. Perhaps this is not so surprising given that natural geographic features may have a very strong influence on aggregate activity (Rappaport and Sachs 2001). However, it is much harder to believe that these visible features of geography impose the same direct constraints on the size of individual industries. Here the theory of multiple equilibria should emerge in full force. The fact that cities have a very strong tendency to return not only to the prior level of manufacturing activity but also to recover the specific industries that previously thrived there even in the

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<sup>3</sup> It is crucial to keep in mind that the broad structure of the models applied to the study of multiple equilibria rarely suffice for this phenomenon – multiple equilibria also depend on parameter values. Hence a rejection of multiple equilibria would not be a rejection of the underlying model of economic geography. Moreover, the fact that such models allow the possibility of multiple equilibria, but do not imply them, also underscores the idea that tests for the salience of multiple equilibria must be conducted directly in the context of interest. Our results are offered only as a contribution to what we hope will be a broader research effort to examine the salience of multiple equilibria in a wide variety of contexts.

aftermath of overwhelming destruction is very strong evidence that temporary interventions of economically relevant magnitude are extremely unlikely to alter the course of aggregate manufacturing or even to strongly affect industrial structure in a given locale. Small and temporary interventions to reap large and permanent changes in levels and composition of regional economic activity is an idea that does not find support in the data.

## II. Theory

Paul R. Krugman (1991) develops what has come to be known as the “core-periphery model,” which provides a theoretical framework for the empirical exercise we undertake. Krugman considers a country with two regions that are symmetric in all fundamentals. Each location has a fixed quantity of immobile factors dedicated to production of a constant returns, perfect competition, homogeneous good termed “agriculture.” There is also a labor force mobile between regions that produces an increasing returns, monopolistic competition set of differentiated varieties in what is termed “manufacturing.” There are costs of trade only in the manufactured good. With only two regions, symmetrically placed, the state of the system can be summarized by the share of the mobile manufacturing labor force in Region 1, which we can term  $S$ . Mobile labor is assumed to adjust between regions according to a myopic Marshallian adjustment determined by instantaneous differences in real wages in each of the regions.

By symmetry of the underlying fundamentals,  $S = 1/2$ , i.e. equal region sizes, is always an equilibrium (although it need not be stable). The symmetric equilibrium could be globally stable, as illustrated in Figure 1. However, the key novelty of Krugman’s paper concerns the possibility of asymmetric equilibria, ones in which manufacturing is concentrated in a single region. The

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<sup>4</sup> Baldwin, et al. (2003) provide a thorough and lucid analysis of the policy issues raised by the new economic

spatial equilibrium is viewed as a contest between centripetal forces pulling economic activity together and centrifugal forces pushing economic activity apart. The relative strength of these forces varies with  $S$ , the share of the mobile labor force in Region 1. The mobile labor force itself provides the source of demand for locally produced manufactured products that can make regional concentration self-sustaining.

Krugman found it convenient to focus on examples of equilibria either with perfect symmetry or complete concentration of manufactures. However, given that there are many potential types of centrifugal and centripetal forces, a slightly richer model is perfectly capable of admitting multiple stable equilibria without complete concentration. For our purposes, it is convenient to illustrate our approach in just such a case. As above, let  $S$  be the share of manufacturing in Region 1, and  $\dot{S}$  be its rate of change. Figure 2 exhibits three stable equilibria (indicated by  $\bar{\Omega} + \bar{\Delta}_1$ ,  $\bar{\Omega}$ , and  $\bar{\Omega} + \bar{\Delta}_3$ ), as well as two thresholds (indicated by  $\bar{b}_1$  and  $\bar{b}_2$ ).

We can now use Figure 2 to illustrate the key ideas underlying our empirical work. For concreteness, assume we are initially in the symmetric equilibrium ( $\bar{\Omega}$ ), and consider the impact of shocks to  $S$ . If these shocks are small, i.e. do not shift  $S$  out of the range ( $\bar{b}_1$ ,  $\bar{b}_2$ ), then local stability of the symmetric equilibrium insures that in the aftermath of the shocks, manufacturing shares return to their original magnitudes. This is why an empirical test of these theories requires that shocks be large: Small shocks mimic the effects of a globally stable equilibrium, making it difficult to know if we are in the world of Figure 1 or Figure 2.

Now consider, for example, a large negative shock that pushes  $S$  below the threshold  $\bar{b}_1$  in Figure 2. The manufacturing share of Region 1 will thereafter converge to a new lower

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geography. They refer to the possibility of spatial catastrophes as the “most celebrated” feature of Krugman’s core-periphery model (p. 35).

equilibrium at  $\bar{\Omega} + \bar{\Delta}_1$ . Similarly, a large shock that raises  $S$  above  $\bar{b}_2$  would lead  $S$  to converge to a new long run equilibrium at  $\bar{\Omega} + \bar{\Delta}_3$ . A key feature in these examples that has drawn attention to the new economic geography is the possibility of these spatial catastrophes. Small incremental movements that push an economy past a threshold can have large effects on the equilibrium. Similarly, this literature has emphasized the potential importance of hysteresis. Even if the initial shock is only temporary, once a threshold is passed, the change in equilibrium will be permanent.<sup>5</sup>

As a step in the direction of our empirical analysis, it is useful to translate the information in Figures 1 and 2 into the space of two-period growth rates. First, convert the units to log-shares (excluding a zero share, of course). Second, divide the time analytically into two periods. Period  $t$  is the period of an initial and temporary shock. Period  $t+1$  is the time interval of convergence from the initial shock to the new full equilibrium. Figure 3 illustrates this for the case of a unique stable equilibrium. In this case, the analytics are extremely simple. Whatever happens in the period of the shock is precisely undone in the period of the recovery. Accordingly, the only possible location for an observation is on a line of slope minus unity through the origin.

The analysis is only slightly more complicated in the case of multiple equilibria. This is considered in Figure 4. First, so long as the period  $t$  shock remains in the interval  $(b_1, b_2)$ , the

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<sup>5</sup> It is worth clarifying at this point the sense of “multiple equilibria” that we use. In the simple Krugman (1991) model, each starting value for  $S$ , Region 1’s share of the mobile labor force, converges to a unique equilibrium; however, multiple values of  $S$  are consistent with full equilibrium. This sense of multiple equilibria is perhaps closest to the experiment below focusing on city population and possibly aggregate manufacturing. Alternatively, as in Krugman and Venables (1995), a given division of immobile productive resources between locations may be consistent with multiple equilibria. In this case, the initial structure of production serves to pin down which equilibrium reigns. In the experiments below, this sense of multiple equilibria may pertain either to city-aggregate manufacturing or city-industry data, depending on the structure of input-output linkages. Neither approach rules out the possibility that expectations could help to coordinate on an equilibrium. Since we do not observe expectations of the mechanism by which they are formed, our approach implicitly assumes the same Marshallian expectations applied in the theoretical models that provide foundation for our work.

result is precisely as in the case of the unique stable equilibrium.<sup>6</sup> Within this interval, any observation in this space must lie on a line through the origin with slope minus unity. Now consider what happens if there is a negative shock sufficiently large to push the log-share below threshold  $b_1$ . It is simplest to begin by imagining that (by chance) the shock pushes the log-share all the way down to the new equilibrium at  $\bar{\Omega} + \bar{\Delta}_1$  ( $-\Delta_1$  log units below  $\bar{\Omega}$ ). In the following period, in this case, there would be no further change. If the initial shock had pushed the log-share below  $b_1$  but to some point other than the new full equilibrium, then the second period adjustment would simply undo the deviation *relative to the new full equilibrium at  $\bar{\Omega} + \bar{\Delta}_1$* . That is, in two-period growth space and for the domain below  $b_1$ , any observation must lie on a line with slope minus unity passing through  $\Delta_1$ . An exactly parallel discussion would be pertinent to shocks that push the initial log-share above  $b_2$ . Any observation must then lie on a line with slope minus unity passing through  $\Delta_3$ .

The translation to the two-period growth space thus provides a very simple contrast between a model of a unique equilibrium versus one of multiple equilibria. In the case of a unique equilibrium, an observation should simply lie on a line with slope minus unity through the origin. In the case of multiple equilibria, we get a sequence of lines, all with slope minus unity, but with different intercepts. Because in this latter case these lines have slope minus unity, the intercepts are ordered and correspond to the displacement in log-share space from the initial to the new equilibrium. These elements will be central when we turn to empirical analysis.

The Krugman model features a ruthlessly simple environment – one in which there is a single state variable, the share of manufacturing in one region of a two-region world. In that

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<sup>6</sup> Note the change in notation. As we move from levels to log units, we remove the overstrikes above the variables.

world, the dynamics can be viewed as  $\dot{s} = \phi(s)$ , so that changes in a region's size depend on that region's size alone. When we turn to the empirics, our implementation of the Krugman model will impose strong assumptions.<sup>7</sup> For a wide class of new economic geography models, relative allocation is unaffected by the size of the aggregate economy, so that the dynamics could be written generically as a function of the shares,  $\dot{s}_{ct} = \phi(s_{ct}, \{s_{c't}\})$ . The first assumption is that the dynamics (hence thresholds) for a particular city may be written as  $\dot{s}_{ct} = \phi(s_{ct})$ , hence independent of the evolution of other city shares (and correlatively for the city-industry case). The second assumption is that, where relevant, the thresholds are common in log-share units across cities and industries. Hence, if it takes a 40 percent negative shock to move aggregate manufacturing in Tokyo past the threshold to a lower equilibrium, it likewise takes a 40 percent negative shock to do so in Osaka or Himeji. Similarly, when we consider pooled city-industry observations, we require that if it takes a 35 percent negative shock to move metals in Niigata to a lower equilibrium, it would take the same size negative shock to move machinery in Kyoto to a lower equilibrium. In short, we have assumed that movements across thresholds can be stated in terms of a city's (or city-industry's) own size alone and that these thresholds require a common proportional decline (rise) to pass a threshold (or thresholds). Under these assumptions, the two period model of adjustment in Figures 3 and 4 is not just a representation of changes for a single city (or city-industry), but is rather one in which we can place all relevant observations.

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<sup>7</sup> These assumptions should surely be revisited in future work. Nonetheless, we believe that the gains from having a structured look at the data are sufficient justification for imposing these assumptions at this stage of development of *empirical* research into multiple equilibria.

### III. Experimental Design

#### A. *The Experiment*

In searching for multiple equilibria in city-industry data<sup>8</sup>, an ideal experiment would have several key features. Shocks would be large, variable, exogenous, and purely temporary. In this paper, we consider the Allied bombing of Japanese cities and industry in WWII as precisely such an experiment.

The devastation of Japanese cities in the closing months of the war is one of the strongest shocks to relative city and industry sizes in the history of the world. United States strategic bombing targeted sixty-six Japanese cities. These include Hiroshima and Nagasaki, well known as blast sites of the atomic bombs. In these two blasts alone, more than 100,000 people died and major segments of the cities were razed. However, the devastation of the bombing campaign reached far beyond Hiroshima and Nagasaki. Raids of other Japanese cities with high explosives and napalm incendiaries were likewise devastating. Tokyo suffered over 100,000 deaths from firebombing raids and slightly over half of its structures burned to the ground. Most other cities suffered far fewer casualties. However, the *median* city among the sixty-six targeted had half of all buildings destroyed.

If anything, these figures *understate* the impact of the bombing campaign on production (see Figure 5). Wartime manufacturing production peaked in 1941, falling mildly through 1944 as the slowly-tightening noose of the Allied war effort made re-supply of important raw

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<sup>8</sup> The contrast between Figures 3 and 4 also helps in understanding the difference between the exercise on population data of Davis and Weinstein (2002) and the tests provided here. Note that observations in quadrants 1 and 3 represent regions with a positive (negative) shock in a first period followed by a further positive (negative) shock in the second (recovery) period. A comparison of Figures 3 and 4 shows that such observations cannot arise in the case of a unique stable equilibrium, but could well arise in the case of multiple equilibria. Davis and Weinstein (2002) asked whether such observations were a central tendency in the city-population data. If they had found a positive answer, that would have been sufficient to establish the existence of multiple equilibria. However, a finding that such observations are a central tendency is not a *necessary* consequence of multiple equilibria. Here we will use

materials more difficult and the early stages of Allied bombing began to bite. Manufacturing output plummeted in 1945 as the Allied bombing raids reached their height. From the peak in 1941 to the nadir in 1946, Japanese manufacturing output fell by nearly 90 percent. In short, it is fair to say these are large shocks.

While the magnitude of the shocks to city sizes and output was large, there was also a great deal of variance in these shocks. Our sample includes 114 cities for which we could obtain production data. The median city in our sample had one casualty for every 600 people; however those in the top ten percent had casualty rates ranging from 1 in 100 to one in five. By contrast, those cities in the bottom quartile lost less than one person in ten thousand. Capital destruction exhibits similar variability. The median number of buildings lost in a city was about one for every thirty-five people. But cities in the top decile of destruction lost more than one building for every nine people. And at the other end of the distribution, approximately a quarter of the cities lost fewer than one building for every ten thousand inhabitants. Reasons for this variance include not bombing for cultural reasons (e.g. Kyoto); preservation of future atomic bomb targets (e.g. Niigata and Kitakyushu); distance from US airbases (e.g. Sapporo, Sendai, and other Northern cities); evolving anti-aircraft defense capabilities (e.g. Osaka); the topography of specific cities (the relatively larger destruction in Hiroshima as opposed to Nagasaki); evolution of US air capabilities; the fact that early and incomplete firebombings created firebreaks that prevented the most destructive firestorms; and sheer fortune, as in the fact that Nagasaki was bombed only when the primary target, Kokura (now Kitakyushu), could not be visually identified due to cloud cover.

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the full structure of the contrast between Figures 3 and 4 to distinguish the cases of unique equilibrium versus multiple equilibria.

There was also substantial variation in the impact of bombing on different industries. Table 1 presents data on how quantum indices of output moved over the five years between 1941 and 1946.<sup>9</sup> Heavily targeted industries, such as machinery and metals, saw their output fall by over ninety percent while other sectors such as processed food and lumber and wood had declines that were half as large. This suggests that the bombing had a significant impact on aggregate Japanese industrial structure.

Even within cities, there was often considerable variation in the severity of damage by industry. This reflected variation in the type of bombing carried out (conventional ordnance, firebombing, or nuclear weapons), targeted production, errors in targeting, and sheer fate. Table 2 presents correlations between the growth rate between 1938 and 1948 of one industry in a given city with those of the other industries in the same city. Not surprisingly, these within-city correlations in growth rates are positive, indicating that having one's city bombed tended to be bad for all industries. More startling is the low level of these correlations: the median correlation is just 0.31. Even the highly targeted sectors of machinery and metals only exhibit a correlation of 0.60. This suggests that there was substantial variation in the relative shares of industries even within cities.

A more detailed look at the data bears this out. For example, incendiaries comprised ninety percent of the ordnance dropped on Tokyo and these attacks destroyed 56 square miles. As a result, output of all manufacturing sectors in Tokyo declined relative to the Japan average. Even so, there was substantial variation. Textiles and apparel fell only 12 percent relative to the national average, but metals and publishing fell 44 and 79 percent respectively. More surprising is the case of Nagoya, which received more bomb tonnage (14.6 kilotons) than any other Japanese city. It actually emerged from the war with some industries *increasing* their share of

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<sup>9</sup> These quantum indices are aggregated using value added weights.

national production. In part, this was due to the firebreaks discussed above and in part this was due to the high share of precision raids using high-explosive bombs, which left many untargeted factories untouched. In 1938, Nagoya supplied 12 percent of Japan's ceramics products and 11 percent of Japan's machinery. Over the next ten years, the machinery industry in Nagoya, a principal target of bombing raids, saw its output fall by more than 35 percent relative to the industry as a whole. By contrast, the output of ceramics in Nagoya *rose* by 21 percent relative to the national average. Similarly the metals sector in Nagoya saw its share of national output rise 64 percent.

It is interesting to compare these numbers to what happened to industrial sectors in cities bombed lightly or not at all. In Kyoto and Sapporo, machinery was the fastest growing sector, with output rising 75 percent and 186 percent faster than the national average. By contrast, ceramics – which had risen in Nagoya – fell by 58 percent in Kyoto (relative to the national average) and fell as a share of Sapporo's aggregate manufacturing output.

In sum, these data suggest that the allied bombing of Japan produced tremendous variation within and across cities in the output of Japanese industries.

Since our dependent variables will be city and industry growth rates, we need to address one potential selection issue. While there is evidence that the US targeted cities on the basis of population and industrial structure, there is no evidence that US picked industries on the basis of past or estimated future growth rates. We could find no references to targeting based on urban industrial growth in any source material. Moreover, the US Strategic Bombing Survey did not even cite the main data source on Japanese urban output data, raising the question of whether they knew the existence of these data. Even if they did, there is scant evidence that the US actually or inadvertently targeted on the basis of growth rates. For example the correlation

between prewar (1932 to 1938) manufacturing growth and casualty rates is only 0.07. Taken together, we believe that the choice of US targets can safely be treated as exogenous.

The empirical exercise that we conduct requires that we can appropriately identify the period of the shock, which should be temporary, as well as identifying the period of the recovery. The dramatic decline in output during the War provides a very natural periodization for the shock itself. In our central tests, our measure of the period of the shock is the change in output from 1938 to 1948, as is mandated by data availability. While peak to trough would take us from 1941 to 1946, the period available is proximate and hence should suffice. Even by 1948, Japanese manufacturing output levels remained barely 25 percent of their 1938 level. That the wartime shocks were temporary is obvious, but for this no less important. Deciding on the appropriate period of recovery is more difficult, since one has to decide whether to use an endpoint at which Japan reaches its pre-war peak level of manufacturing (which occurred in the early 1960's) or the point at which it resumes the prior trend (which would be near the end of the 1960's). We have opted for the latter, although the principal results are not affected by taking an earlier cutoff.

### ***B. Relevance of the Japanese Case***

One important concern is the relevance for modern economies of results on Japanese manufacturing industries, where our earliest data goes back to 1932 and the most recent is 1969. After all, the main body of the theoretical literature contemplates a modern industrial economy with differentiated products and a well-articulated web of intermediate suppliers (Fujita, Krugman and Venables 1999). If these conditions were not met, then this would be an inappropriate venue in which to test these theories. Violation of these conditions could arise, in

principle, either in large autonomous plants or small home-production plants, either of which failed to integrate in an essential way with other local producers.

An examination of the historical literature strongly points to the importance of producers tightly linked to a diverse set of intermediate suppliers, as suggested by theory. Indeed, the shift from precision bombing of large Japanese plants with high explosives to area bombing of Japanese cities was premised precisely on the need to disrupt the web of suppliers widely dispersed in the cities. However, the US Strategic Bombing Survey (henceforth USSBS) argues explicitly that these plants were not simply small cottage industries: “Before the urban attacks began, ‘home’ industry, in the strict sense of household industry (which by Japanese definition included plants with up to 10 workers), had almost disappeared.” (p. 29) In its place, the USSBS argued, was an elaborate system of specialized contractors which became the focus of the US air assault:

Part of the objective of the urban raids was the destruction of the smaller ‘feeder’ plants in the industrial areas. It was believed that the effect of such destruction would be immediately and seriously felt in the war economy.... It was discovered, however, that subcontracting in wartime Japan followed more or less the same pattern as it did in the Western countries, being widely distributed in plants of 50 to 10,000 or more workers. The effect of the urban raids on the great number of plants within that range was extensive. The ultimate effect of such destruction or damage varied considerably as among cities and industries. (p. 20-21)

This view was strongly supported by post-war surveys that considered the reasons for declines in production. A survey of 33 of the largest end product plants in Tokyo, Kawasaki, and Yokohama, corroborates the notion that it was the destruction of specialized components manufacturers. The USSBS writes:

Bomb damage to component suppliers was cited as the primary cause of component failure among the 33 customer plants. Next in order of importance was the shortage of raw materials as it affected these suppliers, and last was labor trouble. The latter two causes were in part induced, in part aggravated, by bomb damage. The impact of bomb damage on smaller component plants is illustrated

by the damage statistics for the Tokyo-Kawasaki-Yokohama complex, which revealed that plants of 100 workers and under were 73 percent destroyed. In Tokyo, the electrical equipment industry, particularly radio and communications equipment, was drastically affected by damage to its smaller component suppliers.... The Osaka Arsenal suffered a precipitous decline in production because of the destruction of the Nippon Kogaku plant... which supplied firing mechanisms for AA [Anti-Aircraft] guns, the Arsenal's chief item of output. The electric steel production of the Mitsubishi Steel Works at Nagasaki, was virtually stopped because of the destruction, in an urban attack, of its supplier of carbon electrodes . . . . (pp. 31-32)

A second feature important for verifying the relevance of the Krugman-type models is the *localization* of demand and cost influences on local production. One window on this is to compare declines in production across three types of plants: (1) Plants that are bombed; (2) Plants not bombed in cities that are bombed; (3) Plants in cities not bombed. By July 1945, plants that were bombed had their output reduced by nearly three-fourths from an October 1944 peak. Over the same period, plants that were not bombed located in cities that were bombed had output fall by just over half. Plants located in cities that were not bombed had output fall by a quarter (USSBS). A comparison between plant types (1) and (2) reveals that the *direct* impact of a plant's own bombing on plant output is surprisingly modest – only an incremental 25 percent in lost output. A comparison of plant types (2) and (3) reveals the importance of local factors. Even in comparing plants *not* bombed, simply to be in a city that is bombed costs the plant a quarter of its output. This is the same magnitude as the direct effect of bombing!

One tempting alternative to the hypothesis of highly localized demand and cost effects on production through the web of intermediate suppliers is the possibility that the negative impact of being in a city that is bombed comes through the destruction of urban infrastructure. This would be a mistake. The USSBS categorically rejects the notion that infrastructure destruction was crucial, "Shipping and rail movements were maintained during the raid period with only slight interruptions, and the supply of water, gas and electric power to the remaining essential

consumers was always adequate . . . . At Hiroshima, target of the atom bomb, rail traffic was delayed only a few hours.” (p. 20) Japanese data bears this out. In Table 3, we present destruction of Japanese assets by asset class. A clear implication of this table is that public infrastructure, while obviously impaired, tended to be damaged far less seriously than other forms of capital. Hence infrastructure damage does not seem to be the primary culprit.

Taken together, these historical accounts and data draw a picture of Japanese industrial structure of the time for which the canonical models of the new economic geography may appear a good representation. There seems to have been a highly articulated web of intermediate suppliers to industry, the destruction of which was a primary factor determining US bombing strategy. Moreover, there seems to have been an importantly localized component of the effects of bombing, consistent with emphases within this literature.

## **IV. Empirics**

### ***A. Data***

Our data include three measures of economic activity. The first is a coarse measure – city population – previously employed in Davis and Weinstein (2002), which we include here for the purpose of comparison and because we apply new methods to the data. The second is aggregate city manufacturing. This is consistently available for 114 cities, which jointly accounted for 64 percent of Japanese manufacturing in 1938.<sup>10</sup> In the early periods, these data are available at infrequent intervals, namely 1932, 1938, and 1948; the last date we use is 1969. Our third and final measure of economic activity is city-industry data for eight manufacturing industries. In

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<sup>10</sup> This number was calculated by dividing the total manufacturing output of the 114 cities listed in the Nihon Toshi Nenkan by the total manufacturing output number in the Kogyo Tokei 50 Nenshi [50 Year History of Industrial Statistics].

order of size in 1938, they are Machinery; Metals; Chemicals; Textiles and Apparel; Processed Food; Printing and Publishing; Lumber and Wood; and Ceramics (Stone, Glass, and Clay).

The new data on manufacturing in aggregate and by industry is very important. First, it provides a more direct and precise measure of economic activity than the population data. Indeed, both the magnitude of the shocks and variability are much greater in the production than the population data. Second, a great deal of the theory has been developed specifically to capture features considered of particular importance in manufacturing. Finally, the ability to move down to the level of industries within manufacturing will allow us to see whether it is possible to identify multiple equilibria at any of a variety of levels of aggregation – since they could well be present at one level even if not at another.

In moving from theory to data, there will be an additional concern. Although the literature following in the wake of Krugman (1991) is often termed the “new economic geography,” real features of physical geography are rarely modeled. Yet in particular locations, physical geography may impose strong limits on city expansion. In particular, this could be an issue in a highly mountainous country such as Japan. Tokyo, lying on the large Kanto Plain, may naturally be larger in aggregate than Kyoto, nestled in a considerably smaller valley. Even if over half of Tokyo is destroyed in the war, with Kyoto nearly untouched, the grip of geography may imply that in aggregate Tokyo will return to a much greater size. This suggests the great advantage in the present paper of moving from the aggregate city data of Davis and Weinstein (2002) to the city-industry data of the present paper. While physical geography may impose strong restrictions on the aggregate expansion of a city, typically these do not constrain expansion of particular industries in particular cities. This point is underscored by the fact that across all cities and industries the median observation on city-industry output as a share of city

output is just 4.5 percent. For most city-industry observations, physical geography imposes no meaningful constraint on expansion of city-industry output.

We will also require direct measures of shocks to cities during the war. The first is *death* – the number killed or missing as a result of bombing deflated by city population in 1940. The second is *destruction* – the number of buildings destroyed per capita in the city in the course of the war. We can also divide cities according to whether or not they were bombed. In order to control for interventions by the government, as opposed to the consequences of private actions, we will also need a measure of regionally directed government reconstruction expenditures. This excludes subsidy programs that do not discriminate by location. The total expenditures of this type are small. These expenditures are divided by the city’s 1947 population to obtain a per capita variable *government reconstruction expenses*. Further details on the data are available in the Data Appendix.

## ***B. Specifications***

### 1. Unique Equilibrium

The next step, then, is to move from the theoretical discussion of Section II above to an empirical implementation. It is useful to break this discussion up into two parts, one in which we assume there is a unique equilibrium and the other in which we contemplate the possibility that there may be multiple equilibria.

We begin with the case of unique equilibrium, as represented in Figure 3. If we could partition time into two periods – the first the period of the shock and the second the period of the recovery – then the unique equilibrium model makes a very simple prediction: Starting from

equilibrium, whatever shock there is in period one will simply be undone in the second period.

As we can see in Figure 3, the data should lie on a line with slope minus unity through the origin.

This is the basis for the empirical specification employed by Davis and Weinstein (2002). Let  $S_{cit}$  be the share of output produced in city  $c$  in industry  $i$  at time  $t$ , and let  $s_{cit}$  be the natural logarithm of this share. Let  $v_{ci48}$  be the (typically large) shock to the city-industry share occasioned by the war and  $v_{ci69}$  be the (typically small) shock around the new postwar equilibrium. Suppose further that in each city, industry  $i$  has an initial stable equilibrium size  $\Omega_{ci}$  and is buffeted by city-industry specific shocks  $\varepsilon_{cit}$ . We can think about  $\Omega_{ci}$  as the result of all unchanging locational forces that affect an industry's size in a particular location. In this case we can write the share of an industry in any city in 1948 as,

$$s_{ci48} = \Omega_{ci} + \varepsilon_{ci48} \quad (1)$$

We can model the persistence in these shocks to industry shares as:

$$\varepsilon_{ci48} = \rho \varepsilon_{ci27} + v_{ci48} \quad (2)$$

where the parameter  $\rho \in [0,1)$  represents the rate at which shocks dissipate over time. Davis and Weinstein (2002) showed this gives rise to:

$$s_{ci69} - s_{ci48} = (\rho - 1)v_{ci48} + [v_{ci69} + \rho(1 - \rho)\varepsilon_{ci27}] \quad (3)$$

The term in square brackets is the error term and is uncorrelated with the wartime shock. An obvious proxy for the shock,  $v_{ci48}$ , is the growth rate between 1938 and 1948. Unfortunately, we cannot simply plug this variable into equation (3). The reason can be understood most simply by writing out the terms of the growth rate explicitly:

$$s_{ci48} - s_{ci38} = v_{ci48} + [(\rho - 1)v_{ci38} + \rho(1 - \rho)\varepsilon_{ci16}] \quad (4)$$

The terms in square brackets represent classical measurement error. The obvious solution to this problem is to instrument for the innovation using bombing data. The instruments we use to identify the magnitude of the shock,  $v_{ci48}$ , are “death” (the number of casualties and missing<sup>11</sup> in the city as a share of the 1940 population) and the interaction of “destruction” (buildings destroyed as a share of the 1940 population) with industry dummies.<sup>12</sup> This enables us to control for the fact that bombing is likely to have varying impacts on industries depending on whether the industry was targeted or not.

Importantly, under the null of a unique equilibrium, we expect the estimated value of  $\rho$  to equal zero so the coefficient on instrumented wartime growth will equal minus unity.

## 2. Multiple Equilibria

We now develop an empirical specification for the case in which there might be multiple equilibria. This case is complicated by the fact that *a priori* we know neither the number of equilibria nor the location of the thresholds. Our task is considerably simplified if we first abstract from this and assume that indeed we do know the number of equilibria and the location of the thresholds. We can then turn later to how we would determine these empirically.

Consider a case, for example, in which there are three equilibria. Assume there is an initial equilibrium log-share,  $\Omega_{ci}$ , a low equilibrium at  $-\Delta_1$  log-share units below (i.e. the first equilibrium is located at  $\Omega_{ci} + \Delta_1$  in log space), and third a high equilibrium at  $\Delta_3$  log-share units above the initial equilibrium. Assume that all city-industry shares are in full

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<sup>11</sup> Virtually all of the missing people disappeared following high intensity firebombings or nuclear attacks and therefore we believe them to be casualties.

<sup>12</sup> In principle we could have interacted our death instrument with industry dummies too. However, plots of the data and preliminary runs suggested that destruction had far more power as an instrumental variable. Hence, in the interests of conserving degrees of freedom, we only interacted the destruction variable.

equilibrium in the period prior to the shock (here 1938) so that the wartime innovation is the only shock that can push a city-industry observation past a threshold. Let the lower threshold be a shock  $b_1$  in log-share units and the upper threshold be at  $b_2 > b_1$  log-share units in the space of wartime shocks. We hypothesize that the log-share in 1969 then follows

$$s_{ci69} = \begin{cases} \Omega_{ci} + \Delta_1 + \varepsilon_{ci69}^1 & \text{if } v_{ci48} < b_1 \\ \Omega_{ci} + \varepsilon_{ci69}^2 & \text{if } b_1 < v_{ci48} < b_2 \\ \Omega_{ci} + \Delta_3 + \varepsilon_{ci69}^3 & \text{if } v_{ci48} > b_2 \end{cases} \quad (5)$$

The error terms change as we cross a threshold because shocks must be stated as relative to the new equilibrium. Formally, we have

$$\begin{aligned} \varepsilon_{ci69}^1 &= \rho(\varepsilon_{ci48} - \Delta_1) + v_{ci69} \\ \varepsilon_{ci69}^2 &= \rho\varepsilon_{ci48} + v_{ci69} \\ \varepsilon_{ci69}^3 &= \rho(\varepsilon_{ci48} - \Delta_3) + v_{ci69} \end{aligned} \quad (6)$$

If we subtract equation (1) from the equations presented in (5) we obtain our equations of motion:

$$s_{ci69} - s_{ci48} = \begin{cases} \Delta_1 + (\varepsilon_{ci69}^1 - \varepsilon_{ci48}) & \text{if } v_{ci48} < b_1 \\ (\varepsilon_{ci69}^2 - \varepsilon_{ci48}) & \text{if } b_1 < v_{ci48} < b_2 \\ \Delta_3 + (\varepsilon_{ci69}^3 - \varepsilon_{ci48}) & \text{if } v_{ci48} > b_2 \end{cases} \quad (7)$$

If we substitute in (2) and (6) into the above expressions we obtain

$$s_{ci69} - s_{ci48} = \begin{cases} \Delta_1(1-\rho) + (\rho-1)v_{ci48} + [v_{ci69} + \rho(1-\rho)\varepsilon_{ci27}] & \text{if } v_{ci48} < b_1 \\ (\rho-1)v_{ci48} + [v_{ci69} + \rho(1-\rho)\varepsilon_{ci27}] & \text{if } b_1 < v_{ci48} < b_2 \\ \Delta_3(1-\rho) + (\rho-1)v_{ci48} + [v_{ci69} + \rho(1-\rho)\varepsilon_{ci27}] & \text{if } v_{ci48} > b_2 \end{cases} \quad (8)$$

There are a few important features of the equations of motion described in equation (8). First, each of these equations differs only in the constant term. Second, if there is not much persistence in the shocks, then the coefficient on the innovation due to bombing,  $v_{ci48}$ , should be close to minus one. Finally, the error term, which is the set of variables that is enclosed in square brackets, is uncorrelated with the remaining variables on the right-hand side. It will be convenient for future reference to re-write equation (8) as:

$$s_{ci69} - s_{ci48} = (1 - \rho)\Delta_1 I_1(b_1, v_{ci48}) + (1 - \rho)\Delta_3 I_3(b_2, v_{ci48}) + (\rho - 1)(s_{ci48} - s_{ci38}) + [v_{ci69} + \rho(1 - \rho)\varepsilon_{ci27}] \quad (9)$$

where  $I_1(b_1, v_{ci48})$  and  $I_2(b_2, v_{ci48})$  are indicator variables that equal unity if  $v_{ci48} < b_1$  or  $v_{ci48} > b_2$  respectively, and we have substituted in the wartime growth rate as a proxy for the unobserved wartime shock  $v_{ci48}$ .

Thus far we have simply assumed that we know the locations of the thresholds and so we must return to this question now. A standard approach within the literature on threshold regression would be to generate the likelihood function associated with equation (8) and then pick  $\Delta_1$ ,  $\Delta_3$ ,  $\rho$ ,  $b_1$ , and  $b_2$  to maximize its value. However, if we try to do this, we run into a thorny problem. For reasons described earlier, we will need to instrument the wartime growth rate with per capita death and destruction in the cities. The instrumenting equation, of course, will need to be run with all right hand side variables from (9), including the indicator variables. However, the indicator variables themselves are functions of the instrumented shocks, so will change with every different choice of thresholds. And the instrumented values themselves then also change with the thresholds. While this discussion may seem a bit convoluted, it has a simple bottom line. The likelihood function should be defined on the parameters alone, holding the data fixed. However, the need to instrument, combined with the fact that the instrumented values

themselves depend on the value of key parameters, means that it is not possible to hold all the “data” fixed. The likelihood function is not well-defined here.

In the face of this, we develop an alternative. If we assume that the periods we look over are long enough for non-contemporaneous shocks to dissipate, then we can impose  $\rho = 0$ . This then allows us to focus on the long difference between equations (9) and (3). We can then estimate

$$s_{ci69} - s_{ci38} = \Delta_1 I_1(b_1, v_{ci48}) + \Delta_3 I_3(b_2, v_{ci48}) + [v_{ci69} + \rho(1 - \rho)\varepsilon_{ci27}] \quad (10)$$

The key advantage of equation (10) is that it has a well-defined likelihood function because we no longer need to instrument. Once we have transformed the data in this way, we can proceed as if we were performing a standard threshold regression and pick the four parameters ( $\Delta_1$ ,  $\Delta_3$ ,  $b_1$ , and  $b_2$ ) that maximize the value of the likelihood function. In the general case where we have  $n$  thresholds, our estimates of the parameters answer a question of the following form: “Contingent on believing that there are  $n$  thresholds separating  $n+1$  stable equilibria, which parameters maximize the likelihood function?”

The mechanics of the threshold regression require us to maximize the likelihood function for all parameter values. This cannot be done analytically because the likelihood function will have flat spots when small movements in the threshold values cause no points to move from one equilibrium grouping to another and will jump discretely when infinitesimal movements in threshold values move points from one equilibrium to another. For computational ease, we focus on thresholds in which observations move from one equilibrium to another in clusters of five percent of the observations.

We implement this as follows. Theory indicates that the determinant of whether we cross a threshold is going to be monotonically related to the magnitude of the shock. By regressing industry growth between 1938 and 1948 on death, destruction, prewar growth, and postwar reconstruction expenses, we obtain a linear relationship of how bombing affects population or industry size.<sup>13</sup> If we multiply the magnitude of death and destruction by their respective estimated coefficients, we obtain an estimate of the magnitude of the shock to each location generated by the bombing. We can then use this shock variable in order to group the data according to how much the growth rate of each industry in each city was affected by the bombing. Bin 1 corresponds to the five percent hardest hit industrial locations, and Bin 20 contains the least damaged five percent. We then perform a grid search for the thresholds using a number of strategies.

First, if there is only one equilibrium, then there should only be one intercept. In this case we can run two specifications. First, we can use two-stage least squares to estimate  $\rho$ , and then test the reasonableness of restriction that it equals zero in the one stable equilibrium case. Second, we can estimate the constrained version so that we can obtain a likelihood function and calculate the Schwarz criterion under the maintained hypothesis that there is a unique equilibrium and  $\rho = 1$ .

We next consider the possibility of two equilibria. In order to test for this possibility, we first order the data according to our shock variable. We then set the threshold  $b_1$  to the level of the fifth percentile and pick the remaining parameters in order to maximize the likelihood function. We then repeat this exercise by calculating the maximum likelihood values of the parameters when  $b_1$  is set at the tenth percentile, the fifteenth percentile and so on. This process

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<sup>13</sup> We include postwar reconstruction expenses because they may have affected growth between 1945 and 1948.

is continued until we have a maximum likelihood value for each value of  $b_1$ . The parameters that maximize the likelihood across all values of the threshold become our estimates.

Our procedure in the case of three equilibria is analogous. In this case we divide the data into three groups based again on the shock variable. This time we allow the thresholds to occur at any percentile that we can factor by five (i.e. thresholds at (5,10); (5, 15); (5, 20); and so on until all possible combinations have been exhausted). Once again we calculate maximum likelihood parameters for each set of thresholds, and then pick the set of parameters and thresholds that generate the highest of these maximum values of the likelihood function. The maximum number of equilibria that we consider (in a correlative manner) is four.

Holding fixed the *number* of equilibria, the preferred selection of the thresholds is determined by the value of the likelihood function. For the selected specification to be admissible, we impose one further requirement. As we have set it up, the theory requires that locations suffering more negative shocks cannot arrive at a higher equilibrium. This then implies an ordering on the intercepts associated with the corresponding equilibria. Hence for a particular specification to be admissible, we require that the ordering of intercepts be in accord with the predictions of the theory of multiple equilibria.

Having obtained the preferred specification for each assumption regarding the number of equilibria, we can then apply the Schwarz criterion to identify which model is best supported by the data. The Schwarz criterion is defined to be:

$$\ln(L_t) - p/2*\ln(N)$$

where  $L_t$  is the maximized likelihood under hypothesis  $t$  (i.e. the number of thresholds),  $p$  is the number of parameters and  $N$  is the number of observations. The preferred specification is the one

with the largest Schwarz criterion. This criterion will asymptotically pick the correct model with probability one.

Before turning to the estimation, there are a few remaining technical issues that we need to address. First, we should correct for government policies to rebuild cities. Although Davis and Weinstein (2002) found that the effect of these policies became insignificant 20 years after the end of the war, we include them for completeness. There are two government interventions that we need to address. In the first few years after the end of the Second World War, the allies thought Japan should pay war reparations to other countries. Unfortunately, the abject poverty of Japan made this difficult, and so the allies began dismantling surviving Japanese factories and shipping the machinery abroad. This in combination with the fact that Japan had to pay for the US occupation explains why Japanese government transfers to the US exceeded US aid until 1948. Fortunately for us, since we are looking at growth after 1948, our results are unlikely to be biased by this policy.

In 1949, with the fall of China to the communists and the rise of a left-wing movement in Japan, US policy toward Japan changed, and a less punitive policy was adopted. US aid, although always small, began to exceed Japanese payments to the US. Moreover, the Japanese government made some small payments to rebuild particular cities. Since these may have some impact on the location of particular industries, we include these reconstruction expenses in our specification (RECON).

The second potential problem that we should correct for is that it is possible that  $\rho$  would not equal zero because there may be some other correlation between past and future growth rates that we do not model. In order to correct this, we include the prewar growth rate in the

regression. Finally, we include a constant term to allow for the fact that the error term might not be mean zero. Hence our estimating equation is:

$$s_{ci69} - s_{ci38} = \delta_2 + \delta_1 I_1(b_1, v_{ci4Z}) + \delta_3 I_3(b_2, v_{ci48}) + \beta \text{PREWAR}_{ci} + \gamma \text{RECON}_c + \mu_{ci} \quad (11)$$

where  $\delta_1$ ,  $\delta_2$ ,  $\delta_3$ ,  $\beta$ ,  $\gamma$ ,  $b_1$  and  $b_2$  are all parameters to be estimated, PREWAR is the prewar growth rate, and  $\mu$  is an iid error term. Here, one believes that stronger negative shocks push cities or industries to smaller equilibria, it should be the case that  $\delta_1 + \delta_2 < \delta_2 < \delta_2 + \delta_3$  or

$\delta_1 < 0 < \delta_3$ . It is important to note that  $\delta_2$  here represents only the second equilibrium from the left. As such, it is simply a normalization. Our work does not impose that  $\delta_2$  reflects the initial equilibrium point and so does not presume whether any or all of the multiple equilibria lie above or below the initial equilibrium.

### ***C. Data Preview***

Regression analysis will provide the key evidence in this paper. However, it is useful to get a feel for the data by considering some simple experiments and showing plots of the data. The key feature of the theory of multiple equilibria that we build on is the idea that big shocks will differ qualitatively from small shocks. Small shocks return to a (local) stable equilibrium. Big shocks pass a threshold and fail to return to the initial equilibrium. Hence a natural first place to look is to consider what happened to manufacturing in the cities that were hit hardest during the war. Measure the intensity of destruction by the number of buildings destroyed per inhabitant in 1940. Let us create a sample of the ten cities hit hardest according to this measure. In this sample, these cities lost at least one building for every eight inhabitants. If we now order our sample by the manufacturing growth rate between 1938-1948, the median city saw its share of

Japanese manufacturing fall by nearly 25 percent. If we now order these same cities by their growth in the subsequent period, 1948-1969, the median city in this sample *increased* its share of Japanese manufacturing by 40 percent. In other words, this simple view of the data offers no suggestion that the hardest hit cities failed to recover their shares of Japanese manufacturing. Indeed, as it turns out, the typical member in this sample of hard-hit cities actually *increased* its share of Japanese manufacturing in the period of recovery.

We can get a further feel for the data by looking at plots. For each city and each period, we can normalize the manufacturing growth rate by subtracting off the corresponding growth rate for all cities. There is mean reversion in the data if a negative shock in one period is followed by a positive shock of the same magnitude in the following period. In the pure mean reversion case, the data will be arrayed along a line with slope minus unity. By contrast, if there were multiple equilibria, one would expect to see the data for industries that were particularly hard hit arrayed along a line parallel and to the left of the data for less damaged sectors. Figure 6 summarizes the data on aggregate manufacturing, the size of each circle representing the size of manufacturing in that city in 1938. The data reveal three things. First, there is a clear negative association between the two growth rates. This strongly suggests some degree of reversion back to the initial share. Second, the data for the extreme points seems to be arrayed roughly along the same line as for more moderately affected industries. Finally, there is a lot of dispersion among small cities. This may reflect an underlying high degree of volatility in manufacturing growth rates in small cities.

One obvious concern with drawing conclusions from the previous graph is that manufacturing may be too large an aggregate to be meaningful. Geography may lock in city size and also aggregate manufacturing. It is less clear that geography should lock in a city's industrial

structure. One of the problems of using disaggregated data is that cities with infinitesimal shares of output in particular industries often have explosively large or small growth rates.<sup>14</sup> This threatens to swamp the variation that arises among city-industry data that accounts for the vast majority of output. We therefore decided to restrict our attention to only those industrial locations that account for more than 0.1 percent of Japanese urban output in that industry. This collection of industrial locations comprised at least 98 percent of Japanese urban output in 1938 in each of our eight industries.

In Figure 7, we repeat our experiment by plotting the normalized growth rates of industrial locations that account for more than 0.1 percent of Japanese urban output in 1938. Here we normalize each industry's growth rate in a city with the industry's growth rate in all cities and the size of the circle represents the share of that industry in the Japan total for that industry. Once again we see the clear negative relationship. When industries in cities suffer negative shocks, they appear to grow faster in subsequent periods. If multiple equilibria were prominent features of the data, one might expect to see industries with extreme shocks have less complete recoveries than those with smaller shocks. The data, however, do not appear to match this hypothesis.

As a final preview of the data we present the corresponding graphs for each of the eight industries in Figure 8. The plots are quite striking. In each industry there appears to be a clear negative association between the magnitude of the shock to that industry during the war and the rate of growth in the postwar period. The behavior of extreme points is particularly striking in these plots. If one believed in multiple equilibria, one should not expect extreme points to lie

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<sup>14</sup> For example, between 1932 and 1938 the share of Japanese printing and publishing in Maebashi (population 161,000) fell from one thousandth to 0.4 millionths, but by 1948 Printing and Publishing in Maebashi had returned to its 1932 share. Whether this dramatic evolution reflects the fortunes of a particular plant in Maebashi or

along the line defined by the other points. Instead they seem to lie more or less where one would predict based on a linear extrapolation of the less extreme points.

Indeed these plots demonstrate that even as we switch from population to output data and disaggregate from total city manufacturing to city-industry observations we find the same kind of mean reversion as Davis and Weinstein (2002, Figure 1) found in city population data.

#### ***D. Regression Results***

In this section we present our threshold regression results. Because it is possible that multiple equilibria arise at one level of aggregation even if not at another, we consider this at various levels of aggregation. We consider it first using the city population data considered in Davis and Weinstein (2002). The analysis of that data is augmented here by our new approach which sharpens the contrast between the theory of unique versus multiple equilibria and which also places the theories on a more even footing in our estimation approach. Thereafter, we consider the same questions using data on city aggregate manufacturing and city-industry observations for eight manufacturing industries. Since manufacturing is less than half of all economic activity within a typical city, it should be clear that even if population in a city were to recover from the shocks, this need not be true of aggregate city-manufacturing. The same point holds *a fortiori* for particular industries within manufacturing, which we also examine.

We begin by considering city population data. Column 1 of Table 4 replicates the Davis and Weinstein (2002) results using population data. The IV estimate in column 1 tests a null of a unique stable equilibrium by asking if we can reject that the coefficient on the wartime (1940-1947) growth rate is minus unity. We cannot reject a coefficient of minus unity, hence cannot

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measurement error is hard to say, but these fluctuations of several thousand percent in tiny city-industry cases threaten to swamp the other variation in our data.

reject a null that there is a unique stable equilibrium. We also find that regionally-directed government reconstruction expenses following the war had no significant impact on city sizes twenty years after the war.

We next apply our threshold regression approach described above to testing for multiple equilibria. This places unique and multiple equilibria on an even footing. The results are reported in the remaining columns of Table 4. In column 2 of Table 4, we present the results for the estimation of equation (11) in the case in which there is a unique equilibrium. Given how close our previous estimate of  $\rho$  was to 0 (minus unity on wartime growth), it is not surprising that the estimates of the other parameters do not change much when we constrain  $\rho$  to take on this value.

Columns 3 through 5 present the results for threshold regressions premised on various numbers of equilibria.<sup>15</sup> In these regressions, the constant plus  $\delta_1$  is the intercept for the first equilibrium; the constant term is the intercept for the second equilibrium, the constant plus  $\delta_3$  is the intercept for the third equilibrium; and the constant plus  $\delta_4$  is the intercept for the fourth equilibrium. For each model of the number of equilibria, we calculate threshold values corresponding to how big a shock the city needs to receive to cross over into that new equilibrium. In order for the equilibria to be sensible in the sense that greater destruction does not cause a city to become larger, we require that the intercepts must be ordered as follows:  $\delta_1 + \delta_2 < \delta_2 < \delta_2 + \delta_3 < \delta_2 + \delta_4$  which can be simplified to  $\delta_1 < 0 < \delta_3 < \delta_4$ . Similarly, because it cannot be the case that an equilibrium is both stable and lies along a transition path to another equilibrium, it must be the case that the thresholds lie between the equilibria. Putting these together, we have the following condition:

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<sup>15</sup> In principle, we could have considered the possibility of more than four equilibria. However neither the data plots nor any of the regression results suggested that raising the number of potential equilibria was likely to improve the results.

$$\text{Intercept Ordering Criterion: } \delta_1 < b_1 < 0 < b_2 < \delta_3 < b_3 < \delta_4$$

In other words, in order to accept the hypothesis that a model of multiple equilibria describes the data, we require that the data selects the model and that the parameter estimates are consistent with the model.

The Schwarz criterion, presented at the bottom, slightly favors a multiple equilibrium model with two equilibria, but the parameter values associated with this model violate the intercept ordering criterion. In this case, the intercept for the low equilibrium has the wrong sign. Taken literally, the estimates would imply that cities that receive a negative shock of magnitude 0.1 percent or more would *increase* their size by 10 percent. This is inconsistent with the model underlying the exercise, hence we rule it out.<sup>16</sup> The data do let us draw a different conclusion. We can ask: Contingent on believing that multiple equilibria are possible, does the data suggest that negative shocks can move urban populations to lower equilibria? The answer to this question is “no.” Following enormous shocks there is no evidence that cities unravel further or fail to return to their former size.

We now examine whether multiple equilibria are evident at the city aggregate manufacturing level. Since manufacturing constitutes significantly less than half of all economic activity, it is quite possible that geography might lock in population but not aggregate city manufacturing. Indeed, a large class of theory about multiple equilibria in economic geography models is about the location of manufacturing. The results for city-manufacturing appear in Tables 5 and 6. The number of observations falls to 98 because the *Japan City Yearbook* only reports production data for the largest cities. As expected, the instrumentation equations

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<sup>16</sup> In principle, one could think about a more complicated model in which a negative shock might provide an opportunity for more than a full recovery. Perhaps this could be constructed as a variant of the model of Brezis, Krugman, and Tsiddon (1993). In any case, such an outcome is clearly inconsistent with multiple equilibria in the context of the model underlying our data exercise.

(reported in the first column of Table 5) reveal death and destruction significantly affect the growth of production.

Turning to our threshold regressions in columns 2-5 of Table 6, the Schwarz criterion clearly favors the model of one equilibrium. The model of multiple equilibria that fares best is the two equilibria model. Here the estimated intercept for the growth path for the lower equilibrium lies below the intercept for the higher equilibrium, although the intercepts are not statistically distinct. As we move to higher numbers of potential equilibria, the Schwarz criterion continues to reject these models ever more strongly and the parameters violate the intercept ordering criterion. For example in the three equilibrium case, the parameter estimates indicate that by increasing the magnitude of a negative shock from just under 0.3 percent to anything under 1.4 percent of output, would cause the equilibrium output to *rise* by 1.33 log units. Moreover, the closeness of the threshold values and volatility of the estimates suggests these results are being driven by a few outliers between thresholds that are very close together and probably do not reflect multiple equilibria.

Other parameter estimates seem to be precisely estimated and plausible in magnitude. Reconstruction expenses have the correct sign in most specifications and are significant at the 10 percent level. Interestingly, past growth rates of manufacturing seem to have, if anything, a negative correlation with future growth rates. This may suggest some degree of mean reversion over long time periods.

Given that our threshold regression has indicated that a unique equilibrium is the preferred model, it is reasonable to ask whether we obtain plausible estimates of  $\rho$  if we take as the null that the manufacturing output in each location is uniquely determined. In order to assess this, we estimate equation (3) using instrumental variables and report the results in column 1 of

Table 6. Most interesting for our purposes is the coefficient on wartime growth. It is negative, significant, and indistinguishable from minus unity even though the point estimate is of slightly smaller magnitude. Once again we cannot reject the hypothesis that manufacturing shares recover completely from these temporary shocks. This time, however, the standard errors are larger, in part due to the smaller number of observations and the greater variability in manufacturing output relative to that of population.

Although we cannot reject the hypothesis that  $\rho$  equals zero, the point estimate we obtain is 0.26. It is therefore reasonable to ask whether the assumption that  $\rho$  equals zero, imposed in the implementation of the threshold regression, might be biasing our results. If  $\rho$  is indeed greater than zero, it is straightforward to see that this would bias our estimates of  $\delta_1$  downward and the  $\delta_3$ 's upward. The reason is that if  $\rho$  is positive, the error term will contain  $\rho v_{ci48}$ , which is negatively correlated with the lower indicator variable and positively correlated with the higher indicator variable. This means that our tests will be biased in favor of finding multiple equilibria because the coefficient on the lower indicator is biased downwards and the coefficient on the higher one is biased upwards. The fact that we reject the model of multiple equilibria despite this potential bias strengthens the case for the unique equilibrium version.

We next consider the question of whether multiple equilibria matter for individual industries within manufacturing. There are a number of reasons why this might allow a finding of multiple equilibria even where it was difficult to find them at higher levels of aggregation. One reason is that the focus on individual industries goes a long way toward relieving purely geographical constraints that can bind more tightly on city population or even aggregate city manufacturing. Namely, if population equilibria are stable and shares of manufacturing are proportional to city population, it could be the case that manufacturing simply grew with

population. This view of the world does not find much support in the data. While there is no question that there is a strong positive correlation between city-size and the size of manufacturing (which in our data is 0.95), the correlation necessary to link population with manufacturing in our econometric specification is a correlation between the growth rates. The correlation between the growth rate of manufacturing between 1948 and 1969 with population between 1947 and 1970 is only 0.33.<sup>17</sup> This low correlation suggests that the growth rate of manufacturing is not easily explainable by the growth rate of population alone. Nevertheless, it may make sense to see if the results hold up on datasets that exhibit even lower correlations with population growth. For example, since the correlation between the growth rate of sectors within manufacturing and urban population is only 0.13, we can safely claim that the recovery of a city's population is largely uncorrelated with the growth rates of individual industries within the city.

A more compelling reason to examine disaggregated data is that the prior focus using higher levels of aggregation may have obscured a great deal of the heterogeneity across cities. As noted before, differences in bombing accuracy, which industries were targeted, geography, urban defenses, and just plain luck led to very different outcomes among industries in cities. If precision attacks savaged Nagoya's machinery industry but spared its metals sector, did this have a long-term effect on the structure of production in the city?

Working with the more disaggregated data enables us to exploit the fact that bombing is likely to affect industries differently. For example, sectors in cities that were principally targeted by high explosive bombs, such as machinery, were likely destroyed with relatively small amounts of collateral damage to other structures. Other sectors, such as textiles, were typically

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<sup>17</sup> The different start and end points correspond to the different years in which the manufacturing surveys and censuses were performed.

affected through area bombing that destroyed large numbers of structures. Hence by interacting our building destruction variable with an industry dummy and including industry fixed effects, we can exploit the variation generated by the varying correlations between building destruction and output reductions of particular sectors.

Results from this estimation are presented in Table 5. As one can see, building destruction has no discernible impact on machinery output, but the low fixed effect for this sector indicates that it was fairly uniformly targeted. At the other extreme is textiles, which was a fairly unconcentrated sector in prewar Japan, and which is extremely sensitive to area bombing. It is hard to give clear interpretations to the other coefficients except to say that the data strongly reject the notion that bombing affects all industries similarly.

If we multiply the coefficient estimates by death and the interaction of destruction with the industry dummies, we obtain a measure of the magnitude of the shock in each industry within a city that was due to the bombing. Once again we can use these estimates to calculate the shock values and perform the threshold regression. The results are presented in Table 7. Government reconstruction expenses cease to have any impact in these specifications probably because these expenditures did not target particular industries in particular locations and hence there is little correlation between these regionally-directed expenditures and the growth rate of particular industries. More interesting for our purposes, however, is the fact that the Schwarz criterion prefers the model in which there is a unique equilibrium. This implies that not only do population and aggregate manufacturing return to their prior level, but that even shocks to particular industries within those cities were reversed.

Of the specifications that entail multiple equilibria, the one featuring two equilibria again appears most plausible even though it is rejected by the Schwarz criterion. The estimated

threshold is at  $-0.67$  log units, which indicates that those industrial locations that saw their output fall 49 percent *more than the Japan average*. Given that the average industry in Japan fell by 87 percent as a result of the war, these locations saw output fall by around 93%. Indeed, the industrial locations that make up the data in this interval only include the 15 percent of the data that comprise the most bomb sensitive industries in the hardest hit locations. While one might want to interpret the point estimate of  $-0.425$  for  $\delta_1$  as evidence that these cities shifted to a new lower equilibrium, the point estimate violates the intercept-ordering criterion, because the new equilibrium point lies to the right of the threshold (at  $-0.672$ ). Hence the most sensible multiple equilibria model is rejected by the data and does not produce plausible point estimates.

To investigate the plausibility of the interpretation that a high  $\rho$  might be biasing the estimate for  $\delta_1$  downward, we estimated  $\rho$  in unique equilibrium case using instrumental variables. Since the Schwarz criterion indicates that this is the correct model, it seems appropriate to see what value for  $\rho$  we obtain. Our parameter estimate for  $\rho - 1$  is 0.655 (i.e.  $\rho$  is 0.34). Moreover, we can reject a  $\rho$  of 0 (but not 0.1) at conventional levels. One possible reason for this higher estimate of  $\rho$  is that it may be the case that places hit extremely hard take longer to recover. One of the features of the industry data is that the impacts of bombing were significantly more heterogeneous across industrial locations than across urban populations or aggregate manufacturing. For example, the standard deviation of our shock variable received for bombed cities was 0.09 when we use population data but 0.41 when we use industry data. This suggests that there were far more industries that received extreme shocks than populations. One reason why this might matter is that Davis and Weinstein (2002) found that it took Hiroshima's population, which had a casualty rate in excess of 20 percent, around half again longer than the typical city to recover.

Given that 10 percent of our data below the lower threshold comes from Hiroshima as well as our two most extreme points, it is reasonable to ask whether industries in Hiroshima are responsible for finding  $\rho > 0$ . Dropping Hiroshima does not qualitatively affect any of the threshold regressions (using any of the datasets), but it does drive down the estimate of  $\rho$  by 0.1 (as one can see in column 2 of Table 7) and makes it indistinguishable from zero. Hence we can conclude that the industry-level runs always support the model featuring a unique equilibrium, and we cannot reject the hypothesis that industries hit with non-nuclear ordnance returned to their prewar locations after 24 years.

In short, the conclusions above from city population and aggregate city manufacturing data are strongly reinforced when we turn to the disaggregated city-industry data. The population of cities, aggregate manufacturing, and even specific industries have no tendency to move to lower equilibria following large shocks.

One additional possibility that it is worth exploring is whether it is possible that manufacturing consists of some industries that exhibit multiple equilibria and others that do not. We have already presented plots indicating that in most industries the data suggests that there is a strong tendency for damaged industrial locations to recover. Unfortunately, we do not have enough observations to conduct tests of multiple equilibria for individual industries that have power to distinguish between hypotheses. One way around this problem is to test for multiple equilibria among the set of industries that are *a priori* most likely to exhibit them. It is often argued that concentrated industries are more likely to exhibit increasing returns and multiple equilibria. Thus, it is reasonable to ask whether we would obtain the same results if we restricted our estimation to sectors which are more geographically concentrated.

In order to determine which sectors are the most geographically concentrated, we constructed Herfindahl indices based on the share that each industry had in each location. Given that we had 98 or 99 observations in each industry, a Herfindahl of unity indicates perfect geographic specialization, while a Herfindahl of 0.01 indicates no specialization. In our sample, this procedure yields a plausible set of industries as candidates for increasing returns. The most concentrated sector is Printing and Publishing (Herfindahl = 0.28) followed by Machinery (0.19), Metals (0.18), and Chemicals (0.15). The least concentrated sectors were Processed Foods (0.08) and Textiles (0.05).

Our estimates using only data from the four most concentrated industries – Printing and Publishing, Machinery, Metals, and Chemicals – resulted in our dropping about two thirds of the data. The reason why our sample contains more points from less concentrated industries is that concentrated industries contain more zeros or industries of trivial size. Had we kept our bin sizes at 5 percent of the data this would have meant that we were trying to identify equilibria using only five or six points instead of the thirty-three points that we were working with earlier. Since this would make our procedure vulnerable to outliers, we increased our bin size to 10 percent of the data, which still meant that we were searching for equilibria that could encompass as few as eleven points.

Splitting the sample this way resulted in coefficients that were not qualitatively different from those reported in Table 7. The Schwarz criterion prefers the model of one equilibrium and the coefficient on wartime growth is negative and significant. As in Table 7, the estimate of  $\rho$  was just above zero for the full sample, but indistinguishable from zero if Hiroshima was dropped. As a result, we conclude that our results are robust to limiting our sample to the most concentrated industries.

## V. Conclusions

The concept of *multiple equilibria* is a powerful force in modern economic thought. In recent decades, it has been a central theoretical element in macroeconomics, development, urban and regional economics, and international trade. The theoretical developments have been inspired by puzzling features of the world for which these theories seem to offer an account. Yet theory has far outpaced formal empirics.

The most crucial empirical question – are multiple equilibria a salient feature of real economies – seems hardly to have been touched. One reason for the scarcity of empirical work testing for the existence of multiple equilibria is that they are inherently difficult to identify. In many contexts, one needs large, exogenous, highly variable, and temporary shocks. Such experiments are rare.

The present paper considers the Allied bombing of Japan during World War II as precisely such an experiment. The paper makes important advances over prior work. It provides the first test for multiple equilibria in the location of production. To do this, it develops simple analytics and an associated threshold regression framework for distinguishing the hypotheses of unique versus multiple equilibria. It then applies these tests to data on city population, aggregate city manufacturing, and city-industry data for eight manufacturing industries. The disaggregated industry runs are particularly important because they remove any obvious geographical limitations on the opportunities of particular city-industry observations to expand or contract.

The results of our experiments are clear: At all levels of aggregation examined, the data prefer a model of unique equilibrium. In the aftermath of a shock, there is a strong tendency for

city population, aggregate manufacturing and even the particular industries that existed prior to the shock to return to their former importance.

Our results are important for policy. Theories of multiple equilibria, explicitly or implicitly, are the foundation for a great deal of regional policy. Such policies promise to attain large and permanent impacts on regional industrial structure through small and temporary interventions at critical moments. Our findings that even wholesale destruction of cities and industries via incendiary, high explosive and nuclear bombs have little impact on the long-term level and structure of manufacturing should give pause to those for whom a small subsidy is the only arrow in their quiver.

We have emphasized that within the context of our analytic framework, multiple equilibria do not appear to be a salient feature. It is now time to provide a series of caveats. First, if one instead asked the question whether there are cases of cities or city-industry observations in which decline is followed by further decline, or a rise is followed by a yet greater rise, the answer would be in the affirmative. Is this not itself confirmation of the theory of multiple equilibria with its associated catastrophes? It's not clear how one could possibly rule out such a claim unless all of the data aligned neatly on a single line. Nevertheless, it would be a grand decline in ambition if the theory were to explain a few select points rather than a central tendency.

A second question concerns the particular restrictions we have imposed in structuring our tests. In particular, we have posited that the size evolution of cities and industries depends only on what happens in that city or city-industry. This is clearly an unrealistic assumption – one expects that what happens to a nearby city or city-industry affects its neighbors' opportunities. Two questions arise. Is there a more appealing alternative approach? Is there reason to believe

that the results will change appreciably? First, we will note, full generality is hopeless. We have data with as many as 114 cities and as many as eight industries. The state space for such a system will be incredibly complex and it is hard to imagine how one will identify potential equilibria or thresholds with any confidence. An alternative that we have not pursued here, but which might be feasible for future work, would be to use summary measures of supply and market access to condition the likelihood of reverting to the prior shares. While we believe that future work along these lines would be interesting, we conjecture that it would do little to alter our central results. In our view, the most striking feature of our results is the congruence between our threshold regression results and the simple plots of industry growth rates in the period of the shock and recovery. Both point to mean reversion as the central tendency.

A third issue concerns the nature of the experiment. Inherently, our experiment asks if industries and cities, once established, are robust even to enormous shocks. We answer in the affirmative. Yet it is a different question whether directed greenfield investment can permanently alter the course of regional development. Even where nuclear bombs fall, the land remains, as do particular claims to the land. A labor force specialized to particular industries may have largely survived (as did 80 percent of the population of Hiroshima). Infrastructure, as we emphasized earlier, largely survived the attacks. One could argue, then, that the prior pattern of economic activity acts as a focal point for reconstruction. We believe there is some merit in these observations and that further investigation is warranted. Still, our results strongly caution against taking literally the particular models in the literature on policy in an economic geography framework that rely crucially on high mobility of factors and industries. These models have been very important in discussions of European and regional integration. Our results still stress that small and temporary interventions are extremely unlikely to succeed in shifting existing patterns

of production. Hence, to insist on this path of defending the theories is also to say that, in policy terms, they can work only at the margins.

We hope that our paper will encourage further work by researchers in this and other fields to explore more deeply the empirical importance of multiple equilibria. The negative results for multiple equilibria in the context of city population and production structure obviously need not carry over to other contexts. We believe that the methods we develop to test for multiple equilibria are suitable for application in a broad range of fields. Moreover we hope that our paper has demonstrated that empirical examination of these issues is both feasible and worthwhile.

**Table 1**  
Evolution of Japanese manufacturing during World War II  
**(Quantum Indices from Japanese Economic Statistics)**

	1941	1946	Change
Manufacturing	206.2	27.4	-87%
Machinery	639.2	38.0	-94%
Metals	270.2	20.5	-92%
Chemicals	252.9	36.9	-85%
Textiles and Apparel	79.4	13.5	-83%
Processed Food	89.9	54.2	-40%
Printing and Publishing	133.5	32.7	-76%
Lumber and Wood	187.0	91.6	-51%
Stone, Clay, Glass	124.6	29.4	-76%

**Table 2**  
**Correlation of Growth Rates of Industries Within Cities 1938 to 1948**

	Machinery	Metals	Chemicals	Textiles	Food	Printing	Lumber
Metals	0.60						
Chemicals	0.30	0.36					
Textiles	0.12	0.35	0.25				
Food	0.32	0.65	0.31	0.49			
Printing	0.11	0.30	0.04	0.29	0.35		
Lumber	0.23	0.35	0.21	0.25	0.25	0.41	
Ceramics	0.13	0.53	0.36	0.38	0.50	0.41	0.23

**Table 3**  
**Inflation Adjusted Percent Decline in Assets Between 1935 and 1945**

	Decline
Total	25.4
Buildings	24.6
Harbors and canals	7.5
Bridges	3.5
Industrial machinery and equipmer	34.3
Railroads and tramways	7.0
Cars	21.9
Ships	80.6
Electric power generation facilities	10.8
Telecommunication facilities	14.8
Water and sewerage works	16.8

Source: Namakamura, Takafusa and Masayasu Miyazaki. Shiryo, Taiheiyo Senso Higai Chosa Hokoku (1995), pp.295-96.

**Table 4**  
Population Regressions

Dependent Variable is Growth rate Between	1947 and 1965	1940 and 1965			
	IV Estimate	1 Equilibrium	2 Equilibria	3 Equilibria	4 Equilibria
Population growth rate between 1925 and 1940	0.617 (0.0923)	0.627 (0.0671)	0.501 (0.0734)	0.514 (0.0738)	0.508 (0.074)
Population growth rate between 1940 and 1947	-1.03 (0.163)				
$\delta_1$			0.0978 (0.0256)	-0.0720 (0.0325)	-0.090 (0.036)
$\delta_3$				-0.127 (0.0272)	-0.055 (0.045)
$\delta_4$					-0.147 (0.040)
Gov't reconstruction expenses	0.392 (0.514)	0.412 (0.495)	-0.0358 (0.498)	0.236 (0.500)	0.203 (0.500)
Constant	0.215 (0.0407)	0.209 (0.0146)	0.196 (0.0146)	0.315 (0.0267)	0.335 (0.032)
<u>Thresholds</u>					
$b_1$			-0.001	-0.056	-0.056
$b_2$				0	-0.001
$b_3$					0
Intercept Ordering Criterion	N/A	N/A	Fail	Fail	Fail
Schwarz Criterion	N/A	75.6	77.1	74.9	69.9
Number of observations	303	303	303	303	303

Standard Errors are in Parenthesis Below Estimated Coefficient Value

**Table 5**  
**Instrumenting Equations**

Dependent Variable is Growth rate between 1938 and 1948				
	Total Manufacturing	standard errors	IRFE w/ Industry Shocks	standard errors
	(1)	(1a)	(2)	(2a)
Growth between 1932 and 1938	-0.368	(0.107)	-0.239	(0.049)
Deaths per Capita	1.54	(3.66)	-0.317	(2.13)
Buildings Destroyed Per Capita	-8.00	(1.64)		
Destruction * Ceramics			-4.38	(4.80)
Destruction * Chemicals			-7.70	(4.19)
Destruction * Processed Food			-4.03	(2.83)
Destruction * Lumber and Wood			-5.27	(2.55)
Destruction * Machinery			1.65	(4.12)
Destruction * Metals			-11.3	(4.97)
Destruction * Printing and Publishing			-2.39	(3.09)
Destruction * Textiles and Apparel			-11.7	(2.51)
Gov't Reconstruction Expenses	14.0	(10.3)	3.51	(9.81)
Constant	0.700	(0.111)		
Ceramics Constant			0.141	(0.371)
Chemicals Constant			0.884	(0.332)
Processed Food Constant			0.505	(0.200)
Lumber and Wood Constant			0.554	(0.191)
Machinery Constant			-0.039	(0.295)
Metals Constant			0.840	(0.378)
Printing and Publishing Constant			0.540	(0.236)
Textiles and Apparel Constant			0.439	(0.189)
R <sup>2</sup>	0.309		0.211	
Number of observations	98		325	

Standard Errors are in Parenthesis to the Right of Estimated Coefficient Value

**Table 6**  
**Aggregate Manufacturing**

Dependent Variable is Growth rate Between...	1948 and 1969	1938 and 1948 plus 1948 and 1969			
	IV Estimate	1 Equilibria	2 Equilibria	3 Equilibria	4 Equilibria
	(1)	(2)	(3)	(4)	(5)
Growth rate between 1932 and 1938	-0.287 (0.146)	-0.397 (0.131)	-0.376 (0.131)	-0.340 (0.127)	-0.360 (0.126)
Growth rate between 1938 and 1948	-0.737 (0.214)				
$\delta_1$			-0.306 (0.184)	-1.47 (0.434)	-1.47 (0.429)
$\delta_3$				-1.33 (0.452)	-0.954 (0.495)
$\delta_4$					-1.6990 (0.323)
Gov't reconstruction expenses	22.1 (11.6)	25.3 (12.8)	-4.01 (8.86)	21.3 (12.5)	21.3 (12.4)
Constant	0.291 (0.113)	0.376 (0.102)	-0.170 (0.0586)	1.77 (0.432)	1.76 (0.427)
<u>Thresholds</u>					
$b_1$			-0.0490	-0.014	-0.014
$b_2$				-0.003	-0.003
$b_3$					0
Intercept Ordering Criterion	N/A	N/A	Pass	Fail	Fail
Schwarz Criterion	N/A	-131	-134	-135	-137
Number of observations	98	98	98	98	98

Standard Errors are in Parenthesis Below Estimated Coefficient Value

**Table 7**  
**Individual Industry Runs with Industry Fixed Effects: Bombing Allowed to Have Different Industry Impacts**

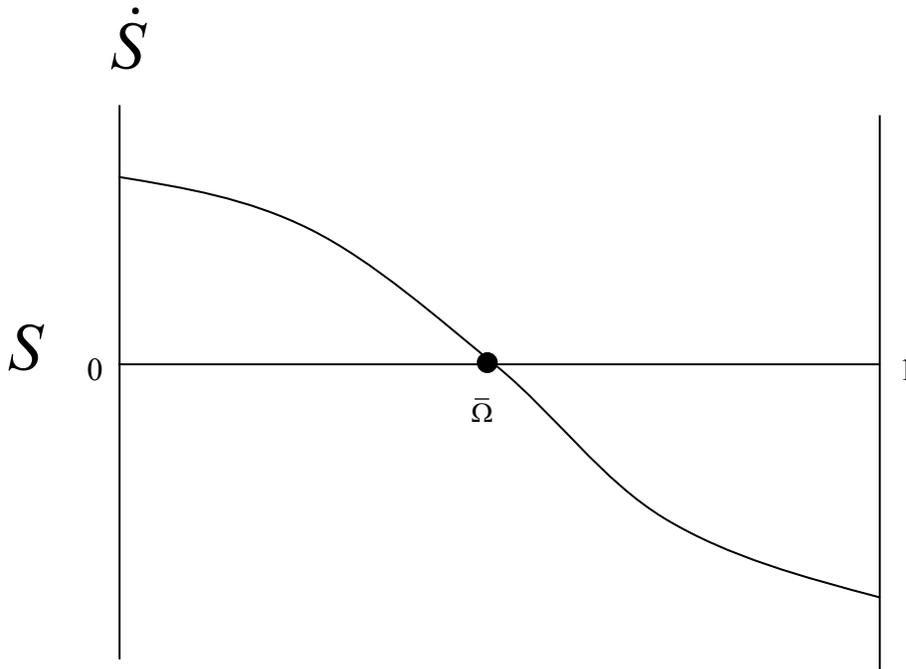
Dependent Variable is Growth rate Between...	1948 and 1969		1938 and 1948 plus 1948 and 1969			
	IV Estimate	IV Est. No Hiroshima	1 Equilibrium	2 Equilibria	3 Equilibria	4 Equilibria
	(1)	(2)	(3)	(4)	(5)	(6)
Growth rate between 1932 and 1938	-0.132 (0.0476)	-0.150 (0.0510)	-0.213 (0.0450)	-0.218 (0.0446)	-0.219 (0.0443)	-0.225 (0.044)
Growth rate between 1938 and 1948	-0.655 (0.124)	-0.747 (0.135)				
$\delta_1$				-0.425 (0.157)	-0.836 (0.0.240)	-0.389 (0.167)
$\delta_3$					-0.700 (0.248)	0.776 (0.240)
$\delta_4$						0.0310 (0.247)
Gov't reconstruction expenses	-1.22 (7.64)	-1.01 (7.92)	-0.543 (9.07)	0.133 (8.98)	-5.41 (9.10)	-5.20 (9.04)
<u>Thresholds</u>						
$b_1$				-0.672	-0.188	-0.672
$b_2$					-0.107	-0.187
$b_3$						-0.107
Intercept Ordering Criterion	N/A	N/A	N/A	Fail	Fail	Fail
Schwarz Criterion	N/A	N/A	-451	-453	-456	-459
Number of observations	325	319	325	325	325	325

Standard Errors are in Parenthesis Below Estimated Coefficient Value

# Figure 1

Globally Stable Unique Equilibrium

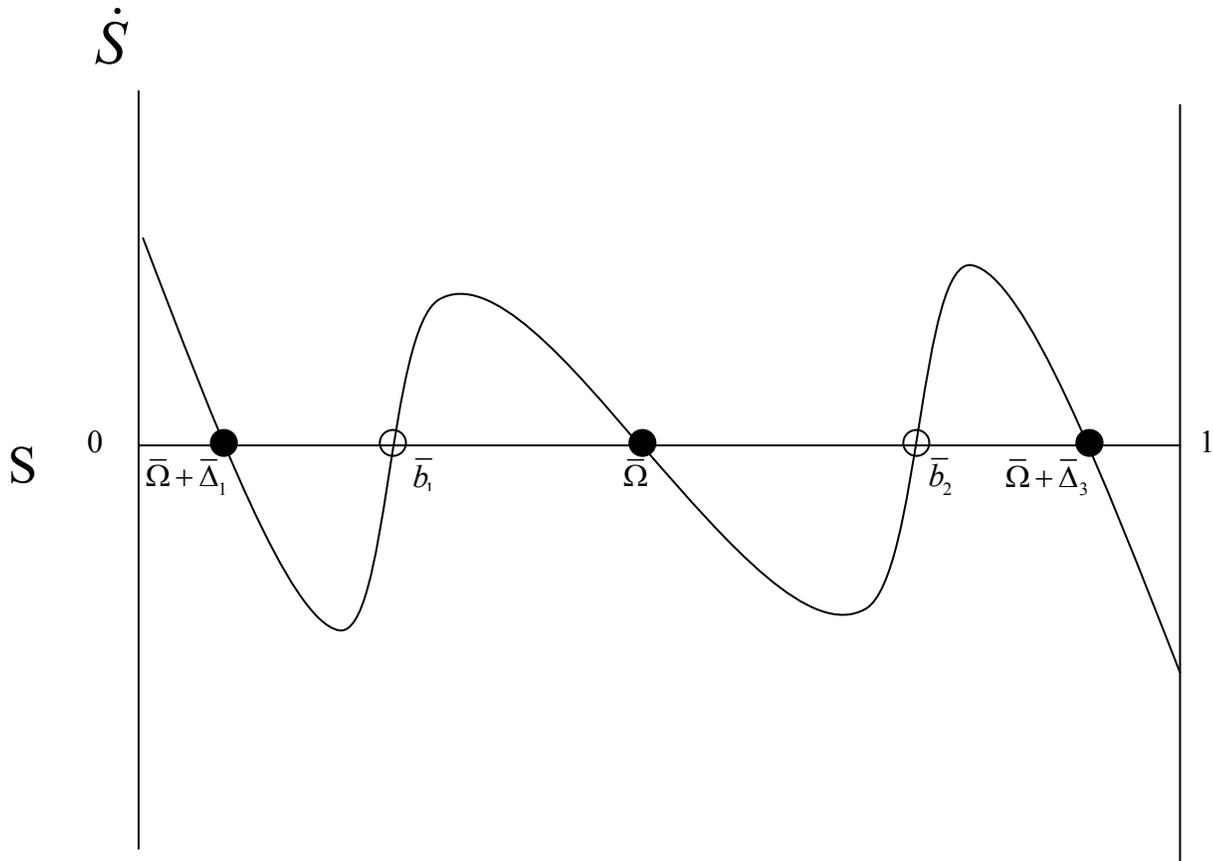
- Stable equilibrium
- S: Region 1 Manufacturing Share



**Figure 2**

Multiple Equilibria in the Krugman Model

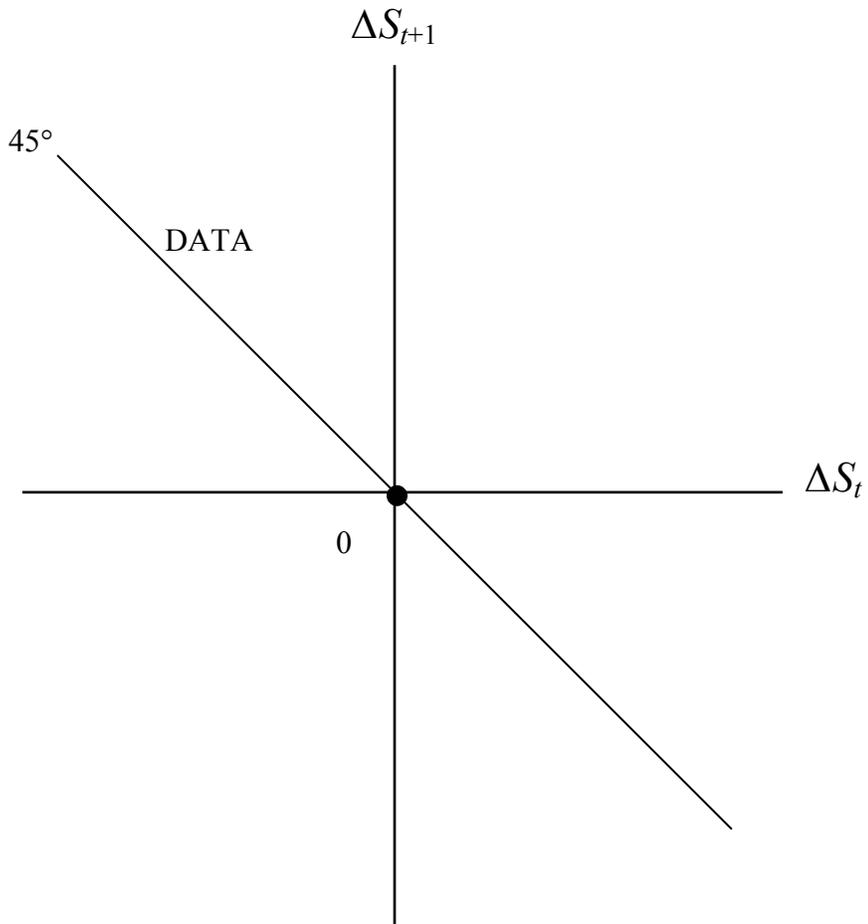
- Stable equilibrium
- Threshold
- S: Region 1 Manufacturing Share



**Figure 3**

Two-Period Adjustment in the Model of Globally Stable Unique Equilibrium

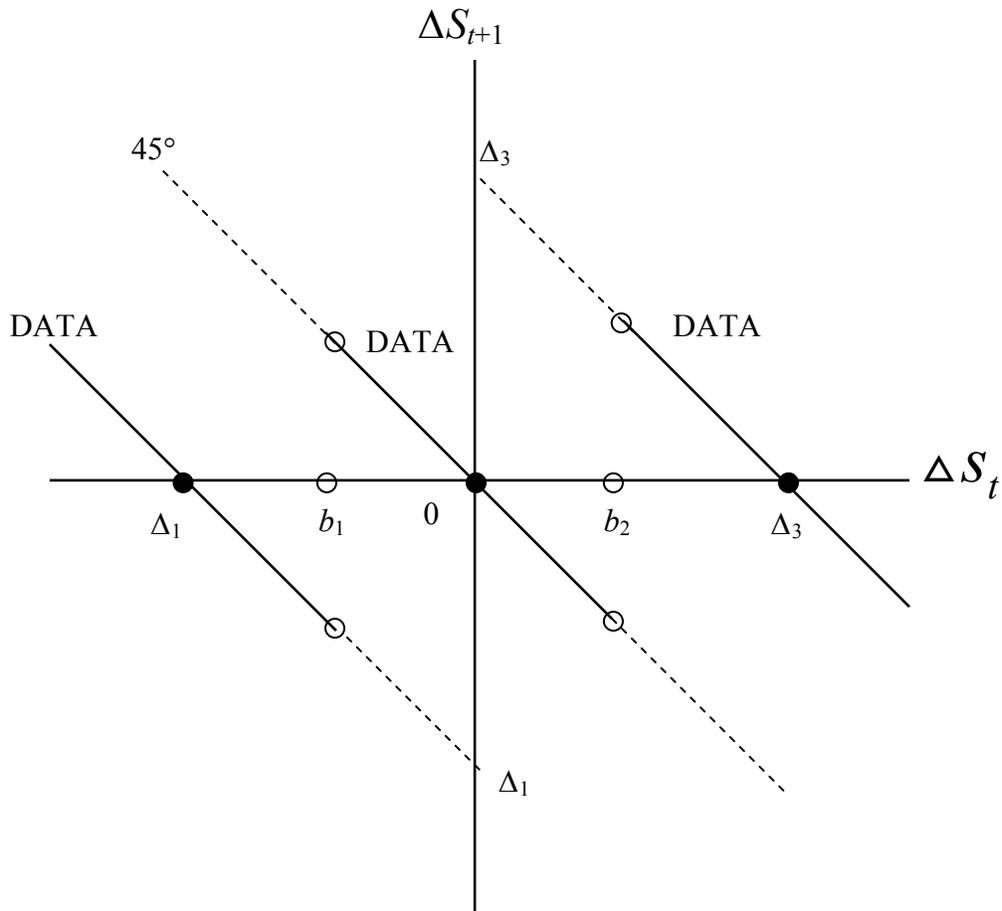
s: Region One Ln(Manufacturing Share)



**Figure 4**

Two-Period Adjustment in the Model of Multiple Equilibrium

$s$ : Region One Ln(Manufacturing Share)



**Figure 5**

**Annual Index of Manufacturing Production in Japan (1938 = 100)**

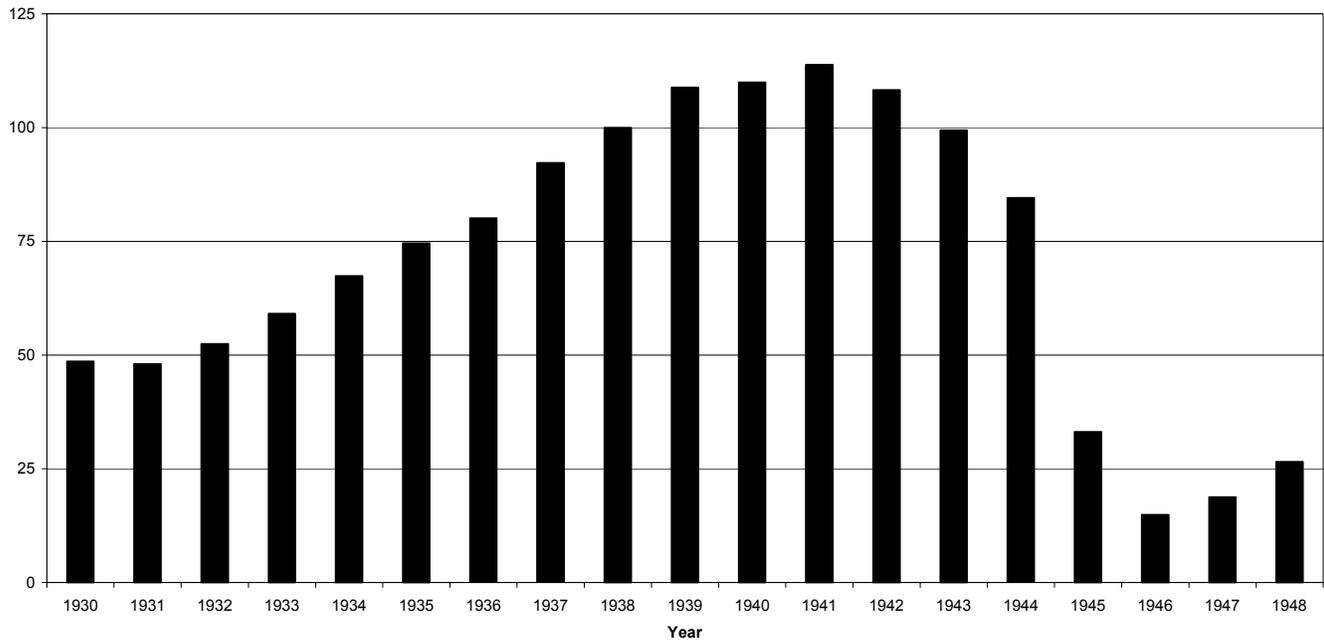


Figure 6

Prewar and Postwar growth rates of manufacturing shares in bombed cities

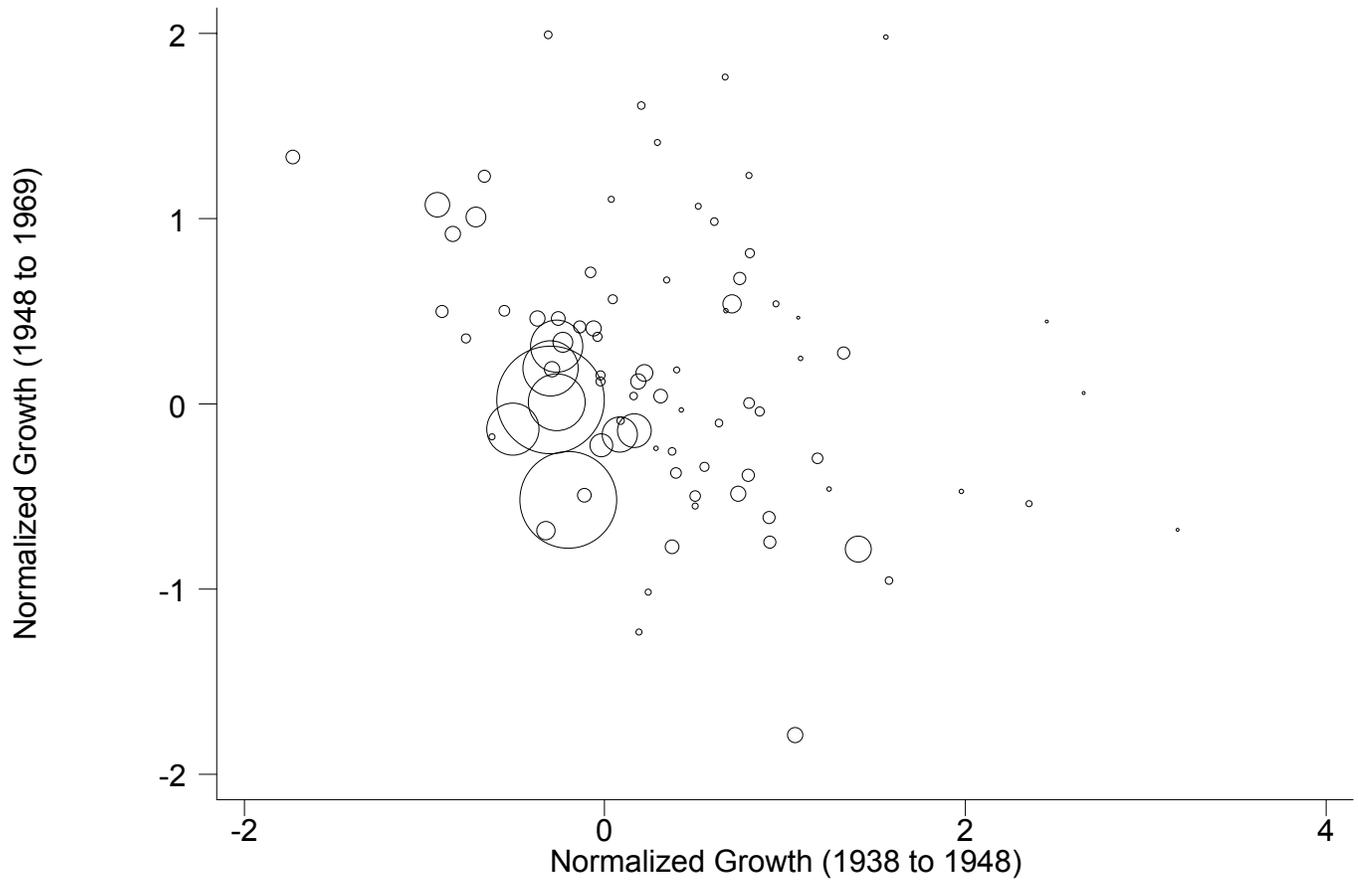


Figure 7

Mean-Differenced Industry Growth Rates

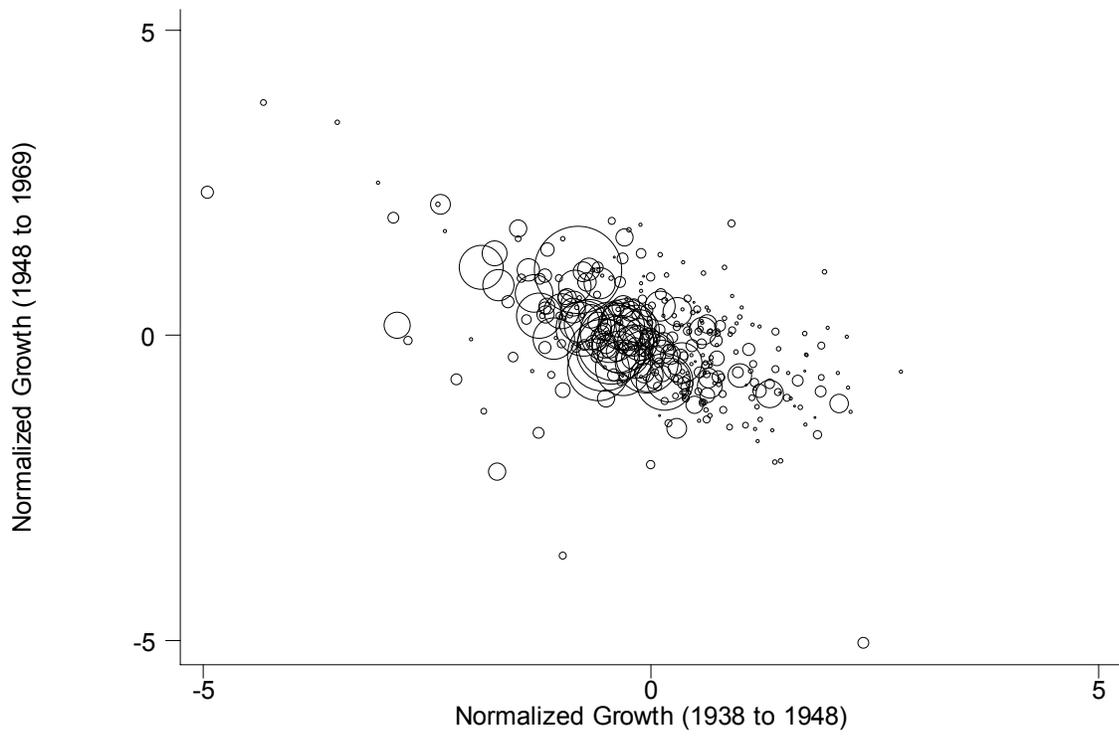
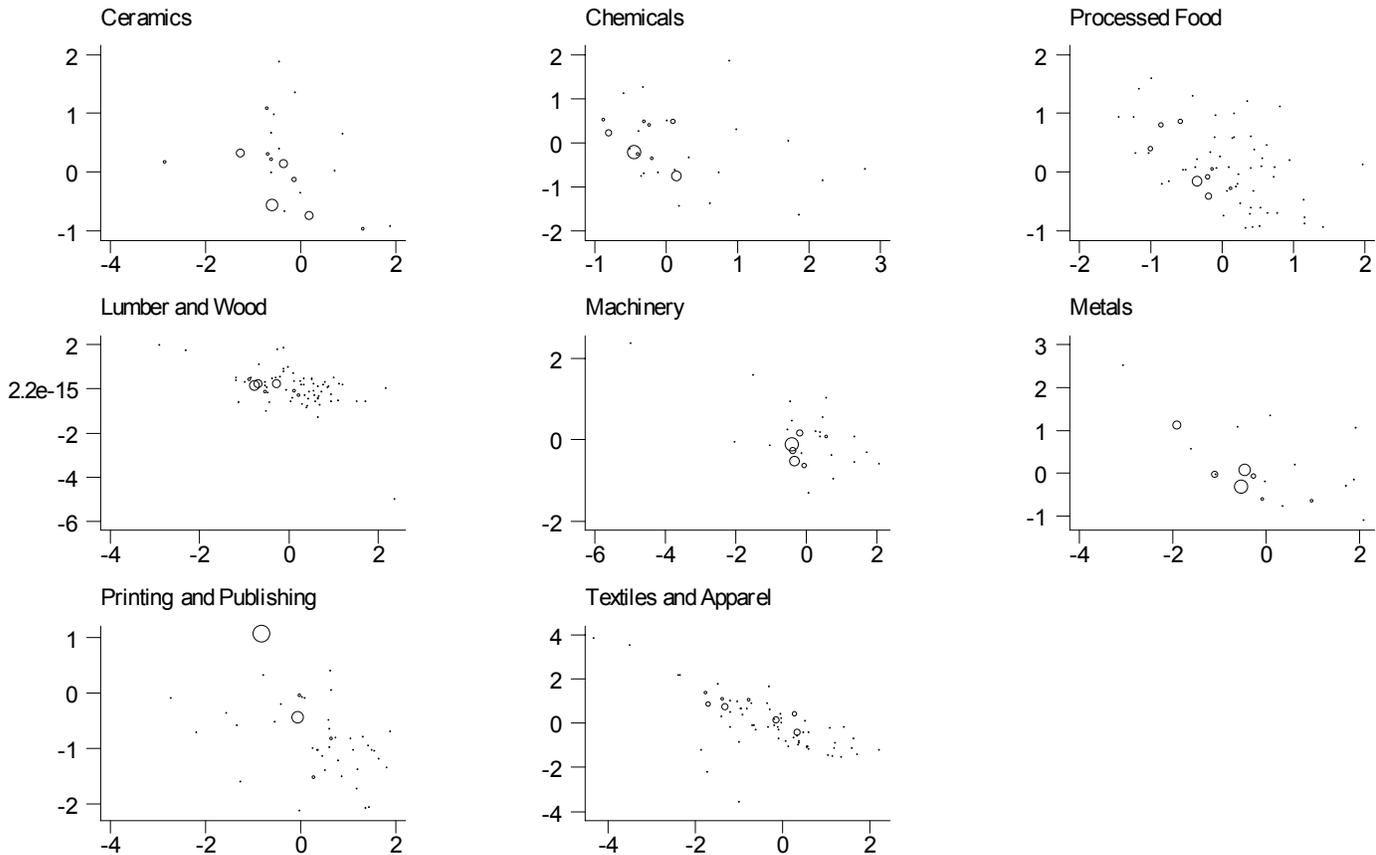


Figure 8

Industry Growth Rates



Normalized Growth (1938 to 1948)  
Prewar vs Postwar Growth Rate

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## Data Appendix

There are two principal sources of information on death and destruction caused by World War II in Japan: the US Strategic Bombing Survey (USSBS) (1947) and Nakamura and Miyazaki (1995). This latter source is basically a reprint of “The Report on Damage and Casualties of World War II” compiled by The Central Economic Stabilization Board (CESB) in 1949 and reprinted in Nakamura and Miyazaki (1995). The US source is particularly good for matching death and destruction to particular US air operations, while the Japanese source is a far more complete 600-page census of all death and destruction that occurred within Japan proper. As such, we use Nakamura and Miyazaki (1995) as the source for all death and destruction data presented in our tables, figures, and regressions.

Urban population data were taken from the *Kanketsu Showa Kokusei Soran*. This data source reports urban populations for several hundred cities based on censuses every five years.<sup>18</sup> The only exception is 1945. The 1945 census of cities was not performed until 1947 due to the war. This is actually fortunate for us. Japanese ground transportation was largely unaffected by the war. This means that by 1947, anyone who had fled due to the fear of air strikes could have returned provided that housing and employment existed there.

Urban manufacturing data was taken from the *Japan City Yearbook*, and reconstruction expense data was taken from the *Japan Statistical Yearbook*.

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<sup>18</sup> We dropped the city of Kure from our data. Kure became the site of a major Japanese naval arsenal. As a result its population rose 50% between 1925 and 1940 as Japan built up its fleet. Kure was heavily bombed during the war and then returned to its prewar size as demand for naval warships approached zero after the war.