A Search for Multiple Equilibria in Urban Industrial Structure

(Preliminary)

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September 5, 2002

Abstract

Theories of multiple equilibria (ME) 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. A key identifying test for multiple equilibria is the "ratchet effect": small shocks allow a full recovery while large shocks do not. We examine this theory for 114 Japanese cities in eight manufacturing industries. The data reject the existence of multiple equilibria. In the aftermath even of gargantuan shocks, a city recovers not only its population and its share of aggregate manufacturing, but even the specific industries it had before.

Keywords: Persistence, bifurcation, catastrophe
JEL Codes: D5, J1, N9, R1.

The authors want to thank Kazuko Shirono, Joshua Greenfield, and Heidee Stoller. We appreciate the financial support of the Center for Japanese Economy and Business at Columbia University. Weinstein also wants to thank the Japan Society for the Promotion of Science for funding part of this research, and Seiichi Katayama for providing him with research space and access to the Kobe University library.

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I. Multiple Equilibria in Theory and Data

The concept of *multiple equilibria* is a hallmark of modern economic thought, 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).[1]

The theoretical literature has now firmly established the analytic foundations for the existence of multiple equilibria. Theory, however, has far outpaced empirics. Virtually all of the existing empirical literature falls into a few genres: calibration studies; estimation contingent on acceptance of the base model; testing for propositions implied by the models (but possibly also by competing models); and testing hypotheses underlying the models. While such studies are important, they are inevitably incomplete.

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

[1] 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

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 due to a change in fundamentals 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 another reason. The theory of multiple equilibria relies on the existence of bifurcations that separate the distinct equilibria. In any real context, it is impracticable to identify such bifurcations or the location of unobserved equilibria. 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 bifurcation 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 begins to address the question of 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 clearly 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 applied what may be termed a “momentum test.” The premise was that if urban

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Small 1998, and Neary 2001). Recent major monographs in economic geography include Masahisa Fujita, Krugman and Venables (1998) and Fujita and Jacques Thisse (2002).

concentrations reflected circular forces of agglomeration, then sufficiently strong negative shocks should push them beyond the bifurcation and lead them to *unravel* further. And vice versa for cities that enjoyed unusually strong population growth – they should grow even faster in the aftermath. This was contrasted with a "locational fundamentals" theory that posits that temporary shocks will be entirely reversed in short order. Under the momentum test, the data strongly preferred the locational fundamentals theory. Even vastly destructive incendiary and nuclear bombs had little impact on relative city populations after a period of fifteen years.

The present paper goes beyond Davis and Weinstein (2002) in several dimensions: new and more detailed data; a new test; and new questions. In addition to the city population data of the earlier work, we employ economic data for cities' manufacturing in aggregate and at the city-industry level. In principle, it is perfectly possible that locational fundamentals determine the aggregate size of a city's population very rigidly, yet that the theories of multiple equilibria govern location of particular industries across cities. For example, Tokyo's location on the Kanto Plain may insure that its population or even aggregate manufacturing will be large, but we may need the theories with multiple equilibria to determine whether the machinery sector will be unusually large relative to textiles or vice versa. We can test these hypotheses directly with the city-industry data.

In addition, we implement a new test. The momentum test asks if it is a central feature of the data that those faced with a negative shock collapse further and those faced with a positive shock rise yet more in the aftermath. While finding such effects would be strong evidence of multiple equilibria, we can ask more subtle questions. One possibility is that some, but not all, cities are pushed past the relevant bifurcations. It could well be that those cities and industries faced with relatively weaker shocks return to their initial equilibrium, yet those faced with sufficiently strong shocks pass the bifurcation and fail to return. This gives rise to what we term the “ratchet test”: Is there evidence that those experiencing the strongest proportional shocks are less likely to return to their initial city-industry size than those suffering more modest shocks? This provides the data a second opportunity to signal the importance of multiple equilibria.

The present paper delivers a very clear message: We find *no* evidence of multiple equilibria. The economic data on aggregate city manufacturing strongly reject the hypothesis of momentum effects, just as the earlier data on population. City-industry panel data likewise strongly reject the hypothesis of momentum effects. Neither at the aggregate nor in the city-industry data can we reject the hypothesis that in the aftermath of shocks economic activity has a powerful tendency to return to its former relative size. Moreover, neither in the aggregate manufacturing nor in the city-industry data can we find evidence that those with proportionally larger shocks have less of a tendency to return to the initial equilibrium. That is, we find no evidence of the “ratcheting” that would indicate the existence of multiple equilibria. In short, faced even with shocks of frightening magnitude, there is a strong tendency for cities to recover not only their prior share of manufacturing in aggregate, but even the specific industries that they previously enjoyed. Every test we apply rejects the hypothesis of multiple equilibria.[2]

[2] 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. This underscores the fact 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 the various contexts.

These results are highly relevant for policy. 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 bifurcations 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.

Our results yield an important lesson for policy: The temptation to use limited and temporary interventions to select advantageous equilibria is a chimera. We confirm on city-aggregate manufacturing data that aggregate activity in cities is highly robust to temporary shocks even of gargantuan 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 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 – in the data – is utterly bankrupt.

II. Theory

Krugman (1991) provides theoretical inspiration for the empirical exercise we conduct. He 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 One, 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, $S = ½$ 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 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, a contest between centrifugal and centripetal forces 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 One, and $\dot{S}$ be its rate of change. Figure 2 exhibits three stable equilibria (indicated by *E*), as well as two bifurcations (indicated by *B*).

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 and consider the impact of shocks to *S*. If these shocks are small, i.e. do not shift *S* out of the range (B^-, B^+), 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 shocks that push *S* just past one of the bifurcations. In the case of a negative shock that pushes *S* just below B^-, we would thereafter see further unraveling in Region One's manufacturing share until it reached a new stable equilibrium at E^-. In the case of a positive shock that pushes *S* just above B^+, we would thereafter see further growth in Region One's manufacturing share until it reached a new stable equilibrium at E^+. In these cases, collapse is followed by further collapse; a rise is followed by a further rise. To the observer, the shock would appear to create *momentum* in cases where the share just passes a bifurcation (but does not initially pass the equilibrium to which it will settle). If it were possible to identify such momentum effects, this would be very clear evidence in favor of the model with multiple equilibria; these effects are inconsistent with a model of a globally unique equilibrium. In effect, it was precisely such a *momentum test* that Davis and Weinstein (2002) applied in their study of Japanese city populations.

It is important, though, to realize that while momentum effects would suffice to establish the existence of multiple equilibria, they are not necessary. Consider the consequences of shocks to S of such magnitude that they pass by the new equilibria. In the case of a negative shock that pushes S below E^-, we would not see further collapse. Instead, we would see a partial recovery (back to E^-). In the case of a positive shock that pushes S above E^+, we would not see yet more growth. Instead, we would see a partial retrenchment (back to E^+). This example illustrates two points. First, momentum is not a necessary consequence of multiple equilibrium. Second, when multiple equilibria exist, there is a *ratchet effect* – for sufficiently large shocks, you fail to return to the initial equilibrium.

Thus while the momentum test applied by Davis and Weinstein (2002) provided an opportunity to demonstrate the existence of multiple equilibria, their inability to identify such effects on the population data does not exclude the possibility of multiple equilibria. Hence, in the present exercise, we will supplement the momentum test with a test designed to identify ratchet effects.

In preparation for our empirical exercises, it will be useful to translate these ideas into a space of two-period growth rates, the first reflecting the period of a shock and the second the aftermath. Graphically, it is useful to divide the space of two-period growth rates in half, quadrants 1 and 4 reflecting positive growth in the first period and vice versa for quadrants 2 and 3. Again, a model of unique stable equilibrium requires all data to lie on the line with slope minus unity through the origin, as in Figure 3. The model of multiple equilibria, as in Figure 4, requires the data to lie *on* this line (for small shocks) or *above* it (for large shocks) in quadrants 1 and 4, and to lie *on* this line (for small shocks) or *below* it (for large shocks) in quadrants 2 and 3.

This diagram allows us to see clearly the nature of the *momentum* and *ratchet* tests. The momentum test asks if the data lies in quadrants 1 and 3. An affirmative answer would suffice to establish multiple equilibria, but is not necessary for such equilibria. The ratchet test asks if the data is best represented by a simple line of slope minus unity (unique stable equilibria) or by the sum of a line with slope minus unity plus a cubic term with a positive coefficient.

III. Experimental Design

A. *The Experiment*

In searching for multiple equilibria in city-industry data, 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 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 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 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 antiaircraft 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.

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.[3] 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 actually *increasing* their share of 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 stone, glass, and clay 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 stone, glass, and clay 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 unbombed or lightly bombed cities. 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, stone, glass, and clay – which had risen in Nagoya – fell by 58

[3] These quantum indices are aggregated using value added weights.

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.

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 that the choice of US targets can safely be treated as exogenous.

The empirical exercise that we conduct has as an important element 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 required 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 electrode . . . . (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. 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. The second is aggregate city manufacturing. This is consistently available for 114 cities, which jointly accounted for 64 percent of Japanese manufacturing in 1938.[4] 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 order of size in 1938, they are Machinery; Metals; Chemicals; Textiles and Apparel; Processed Food; Printing and Publishing; Lumber and Wood; and Stone, Glass, and Clay (henceforth Ceramics).

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.

[4] 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].

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. Specification

We now develop a simple empirical specification capable of distinguishing the principal theoretical models of interest. The first theory is what may be termed *locational fundamentals*. This assumes that each city-industry share has a unique stable equilibrium. The second is the theory of *multiple equilibrium*, as in Krugman (1991). The third is the random walk theory of Gabaix (1999), which here can be considered a special case as the number of equilibria becomes large.

The basic distinctions between these theories are very simple. The locational fundamentals theory predicts that shocks are fully reversed, irrespective of the magnitude of the shock. The theory of multiple equilibrium predicts a full reversal in the case of small shocks, but not in the case of large shocks. If there is some recovery in the case of large shocks (those that pass over a bifurcation), it will be less than full. There is even the possibility that adjustment in the aftermath of a shock will be in the same direction as the shock itself (momentum). Finally, if there is no impetus to adjust irrespective of the magnitude of the shock, then we are in the Gabaix world of the random walk.

In terms of Figure 4, locational fundamentals holds that all the data should lie *on the 45° line*. The theory of multiple equilibria holds that the data will lie on the 45° line for small shocks only. For large negative shocks, the data will lie below the 45° line, and for large positive shocks it will lie above the 45° line. In the special case of *momentum*, the data would be further restricted to lie in the first and third quadrants.

Our empirical model posits adjustments to the wartime shocks in the simplest polynomial that captures these features. 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 n_{ci48} be the (typically large) shock to the city-industry share occasioned by the war and n_{ci69} be the (typically small) shock around the new postwar equilibrium. The simplest polynomial that captures the relevant features is a cubic in the shock. Hence we can let the postwar growth in city-industry share be given by

$$s_{ci69} - s_{ci48} = a_i + bn_{ci48} + gn_{ci48}^3 + n_{ci69} \tag{1}$$

We can interpret each of the theories as a restriction on the parameters of this equation. We begin with the simplest hypothesis, that of locational fundamentals. Theory implies that whatever shock occurs in the initial period will be reversed in the aftermath. In terms of Equation (1), this imposes the following restriction:

Locational Fundamentals: $b = -1$ and $g = 0$

The theory of multiple equilibria posits that for small shocks, there should be a complete recovery, hence the derivative evaluated at $n_{ci48} = 0$ should be minus unity, precisely as under locational fundamentals. The distinguishing characteristic of the theory of multiple equilibria is the role of the cubic term. Large positive shocks should not permit a retrenchment to the initial equilibrium; and similarly large negative shocks should not permit a full recovery. In the context of Equation (1), and in contrast with the theory of locational fundamentals, this requires the coefficient on the cubic term to be positive. Stated simply:

Multiple Equilibria (Ratcheting): $b = -1$ and $g > 0$

If city shares follow a random walk, as suggested by Gabaix (1999), then there will be no tendency for mean reversion, irrespective of the size of the shock. In the context of Figure 4, all data should lie on the horizontal axis. Hence this hypothesis can be stated as:

Random Walk: $b = 0$ and $g = 0$

Finally, there is one last possibility to contemplate. If the shocks were such that city shares just pass over the relevant bifurcation, then positive shocks are followed by further growth in share and negative shocks by further collapse. A simple test of this is:

Momentum: $b > 0$

We will consider each of these hypotheses in turn in Sub-Section C below.

In interpreting the regressions to follow, the most critical question is how to separate the theories of locational fundamentals and multiple equilibria (ratcheting). From above, they are distinguished by the prediction of $g = 0$ for locational fundamentals and $g > 0$ for multiple equilibria. This poses a potential problem, since even if the actual estimate of γ were precisely equal to zero, any confidence interval will also include positive values. What evidence would convince us that multiple equilibria are in fact a real feature of the world? We can consider a high standard and a low standard. The high standard would require that γ indeed be significantly greater than zero. The low standard would require that even if γ is not always significantly greater than zero, at least the point estimate should exceed zero across the specifications we examine. If the coefficient varies in sign and is consistently insignificant, we will interpret this as support for $g = 0$ and locational fundamentals. We will consider each of these hypotheses in turn in Sub-Section C below.

We now turn to measurement of the shock due to bombing, n_{ci48}. The growth rate of output in a city between 1938 and 1948 is a noisy measure of the bombing shock. In order to see this, we can rewrite equation (1) as

$$s_{ci48} - s_{ci38} = \left(a_i + bn_{ci38} + gn^3_{cit38}\right) + n_{ci48} \qquad (2)$$

Although n_{ci48} is not correlated with the terms in parentheses, these terms introduce classical measurement error into the analysis. This would lead us to biased and inconsistent results. An obvious solution is to find an instrument that is correlated with n_{ci48} but not past shocks. Since bomb damage is unlikely to be correlated with past shocks to industries in particular locations but is highly correlated with production in a location, we can use bombing data as an instrument to identify the effects of n_{ci48}.

The instruments we use to identify the magnitude of the shock, n_{ci48}, are "death" (the number of casualties and missing[5] in the city as a share of the 1940 population), "destruction" (buildings destroyed as a share of the 1940 population), and a dummy that equals one if the city was bombed. In order to identify the cubic term, we used the cubes of death and destruction and the interaction between death and destruction as instruments. In addition, after regressing wartime growth on our instrument set, we cubed the predicted values and used these as instruments as well. We found this last instrument to have a lot of power.

There are two government interventions that may also affect the location of production in the war 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 them in our specification. In addition, since prewar growth rates may be correlated with postwar growth rates, we also include these in the specification. Hence our estimating equation is:

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[5] Virtually all of the missing people disappeared following high intensity firebombings or nuclear attacks and therefore we believe them to be casualties.

$$s_{ci69} - s_{ci48} = a_i + b\,(s_{ci48} - s_{ci38}) + g\,(s_{ci48} - s_{ci38})^3 + q\,RECONS_c + d\,(s_{ci38} - s_{ci32}) + n_{ci69} \tag{3}$$

where all Greek letters are parameters to be estimated and we instrument for the 1938-48 growth rate and its cube.

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 critical points 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. Let us measure the intensity of destruction by the number of buildings destroyed per inhabitant in 1940. And let us create a sample of the ten cities hit hardest according to this measure. In this sample, these 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 a quarter. If we now order the 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 city in this sample 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. This is precisely what the theory of locational fundamentals would predict. By contrast a momentum theory might predict that a negative shock this period would be followed by a positive shock the following period. In the pure mean reversion case, the data will be arrayed along a line with slope minus unity. In the momentum case, the data should lie on a line with positive slope. 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 reveals two 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. Secondly, there is a lot of dispersion among small cities. This may reflect a 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 hence 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.[6] This threatens to swamp the variation that arises among city-industry data that accounts for the vast bulk of output. We therefore decided to

[6] 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

restrict our attention to only those industrial locations that accounted for more than 0.1 percent of Japanese output in that industry. This collection of industrial locations represented at least 98 percent of Japanese 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 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 ratchet effects 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, does not appear to exhibit such curvature.

As a final check on the data we present the same 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 level of the shock during the war to that industry and the rate of growth in the postwar period. The behavior of outliers is particularly striking in these plots. If one believed in ratchet effects, one should not expect extreme points to lie 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.

D. *Regression Results*

particular plant in Maebashi or 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.

The theory of multiple equilibrium may operate at various levels of aggregation. At times it is used to describe the division of economic activity between North and South in the world economy (Krugman and Venables 1995); between cities or regions within a country (Krugman 1991); neighborhoods within a city (Fujita, Krugman, and Venables); and no doubt could be applied for activity even within a building or organization.

We are able to examine these questions at varying levels of aggregation. Davis and Weinstein (2002) looked for momentum effects in city populations. In this section, we replicate this work and go beyond it by looking for ratchet effects in city population. We also investigate the presence of both momentum and ratchet effects at two other levels of aggregation. The first is the city-manufacturing level and the second is the city-industry level. 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 describing the regressions in which we instrument for wartime growth and its cube. The instrumentation equations produced an R^2 of approximately 0.5 for each. The level of destruction was a statistically significant determinant of the wartime growth rate and the cubic terms significantly affected the cube of the growth rate. The results suggest that death and destruction were important determinants of both city growth between 1940 and 1947 as well as which cities received particularly heavy shocks.

In Table 4 we present the results of estimating Equation 3. In the first column we present results parallel to those of Davis and Weinstein (2002) for comparison purposes.[7] The coefficient on growth from 1940 to 1947 is -1.0 in base specification and significantly different from zero (*t*-stat = -6.3). Wartime reconstruction expenses, which Davis and Weinstein found mattered for growth rates up to 1960 see their effects become insignificant by 1965. As in the earlier work, city populations revert strongly to their initial shares of aggregate population.

The second column investigates the presence of ratchet effects by adding a cubic term. The cubic term is highly correlated with the growth rate (r = 0.8) which contributes to a decline in significance of the coefficient on wartime growth, even as there is an increase in its magnitude. Nevertheless wartime growth continues to exhibit a coefficient that is statistically smaller than zero and indistinguishable from minus unity, whereas the coefficient on the cubic term, while positive, is insignificant. Moreover the coefficient on the cubic term is of a very small economic magnitude. A one standard deviation movement in the cubic term would only change the slope coefficient by 0.06.

City populations do not exhibit multiple equilibria. We can reject momentum effects, ratchet effects and random walks – any of which would be consistent with multiple equilibria. We cannot reject the locational fundamentals view that in the aftermath of the shocks, city population shares simply return to the *status quo ante.*

We now turn to ask whether multiple equilibria are evident at the city-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

[7] The numbers are slightly different because we used a different instrument set in this paper.

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 Table 5. 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 (not reported) reveal death and destruction significantly affect the growth of production and the cubed instruments significantly affect the cube of production. The first column reports results without the cubic term. Reconstruction expenses have the correct sign 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. 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 temporary shocks. This time, however, the standard errors are larger. Very likely this results from the greater variability in manufacturing output relative to that of population.

When we introduce the cube of wartime growth, the coefficient on wartime growth falls to –0.85 and continues to be significantly negative and statistically indistinguishable from –1.0. Once again, while the cubic term has a positive sign, it is statistically insignificant. Dropping the wartime growth variable causes the cubic term to become negative and significant as we saw with the population data.

The results from looking at aggregate city-manufacturing strongly parallel those from city population data. The data reject the existence of multiple equilibria in the form of momentum effects, ratchet effects, or a random walk. We cannot reject the locational fundamentals hypothesis that aggregate manufacturing output returns to the same locations following large temporary shocks.

Finally, we consider the same question for individual industries within manufacturing. There are a number of reasons why this might allow a finding of multiple equilibria even where this was difficult to find 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. A second reason is that the prior focus at 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? While locational fundamentals may determine the size of a city, it is much less clear that they affect the relative output of machinery and metals.

In order to account for differences in industry growth rates, we include a set of industry fixed effects in the regressions and change the dependent variable to the growth rate of output of a particular industry between 1948 and 1969. Table 6 presents the results. Once again we find that wartime growth when entered alone has a coefficient that is negative and significantly different from zero but not from –1. This time, however, when we include the cube of growth it has the wrong sign, indicating that, if anything, industries that were hit harder came back faster!

Since it is possible that the same level of bombing presented each industry with a different shock, we change our instrument set to allow for this possibility. Instead of using destruction as an instrument we interact destruction with each of our industry dummies. This creates 8 new instruments and allows the same level of bombing to affect the growth of targeted sector, say, machinery, differently from the growth of an untargeted sectors such as processed food. We present the results in Table 7. Once again we find that the coefficient on growth is negative and significantly different from zero while the coefficient on the cubic term has the wrong sign and is insignificant. One potential problem with these results, however, is that in the specification without the cubic term the coefficient on prewar growth is sufficiently small in magnitude that we can reject a coefficient of –1 (but not –0.9). This result appears to be driven by some of the smallest industrial locations in our sample. In columns three and four, we repeat our regressions using only industrial locations that account for more than one percent of Japanese output in that industry.[8] The results are similar the previous ones except that the magnitude of the coefficient on growth rises and becomes indistinguishable from negative one. Hence we conclude that while we can accept the hypothesis that locational fundamentals determine industry size for locations that account for more than a trivial share of output, we cannot accept any of the hypotheses proposing multiple equilibria.

To make sure that no particular industry was driving the results we re-ran the regressions industry by industry. With an average of only 33 points per industry, statistical significance was difficult to achieve. Nevertheless, in specifications without the cubic term, the coefficient on wartime growth was negative in every sector except for

[8] In each of our industries the set of industrial locations that account for more than one percent of an industry's output accounts for at least 80 percent of the output in the sample.

Ceramics and was significantly negative in half of the sectors. Ceramics, the one sector where it was essentially zero (coefficient of 0.02, t-stat = 0.05), only had 21 observations, which may have been insufficient to establish a strong relationship. By contrast, in specifications with the growth rate and its cube, the cubic term had a negative sign in three-quarters of the industries and was never significantly positive or negative.

We should consider one alternative interpretation of our results. In some of our regressions, while we cannot reject that the coefficient on wartime growth is minus unity, the point estimate is of smaller magnitude. Might not this suggest that the model of multiple equilibria, as in Figure 4, generates the data? We would reject this interpretation. First, we should take seriously the fact that the data do not speak forcefully enough to reject a coefficient of minus unity. Second, and more importantly, we place the emphasis on the coefficient on the cube of wartime growth. What is crucial for the multiple equilibrium theory of Krugman (1991) is that large shocks differ from small shocks.[9] This should introduce curvature that would be captured by the cubic term. And we find no evidence of such curvature.

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 a strong tendency to return to their prior shares in the aftermath of large shocks. We find no evidence of the momentum effects, ratchet effects or random walks that would indicate the presence of multiple equilibria.

[9] The one exception would be the limiting case of a pure random walk, where there is no recovery from shocks, large or small. However, the data overwhelmingly reject the random walk.

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 asked. One reason for the absence of empirical work testing for the existence of multiple equilibria is that they are inherently difficult to identify. 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. Most importantly, it introduces what we term a *ratchet test* for multiple equilibria. It holds that in a world of multiple equilibria, large shocks should have less tendency to return to an initial equilibrium than small shocks because they are more likely to have crossed critical bifurcations. The paper examines this on Japanese city data on population, aggregate manufacturing, and 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.

Every test we consider rejects the model of multiple equilibria. We cannot reject what we term the model of *locational fundamentals* – the proposition that 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 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.

Finally, 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 regional production levels and structure obviously need not carry over to other contexts. However, 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

Two-Stage Least Squares Estimates of Impact of
Bombing on Cities with a Population over 30,000 in 1925

	Dependent variable is growth rate of population between 1947 and 1965	
Percent growth of population between 1940 and 1947	-1.03 (0.163)	-1.17 (0.452)
Cube of growth of population between 1940 and 1947		12.7 (11.2)
Percent growth of population between 1925 and 1947	0.617 (0.0923)	1.08 (0.301)
Government reconstruction expenses	0.392 (0.514)	0.298 (0.574)
Number of observations	303	303

Note: Standard Errors in Parentheses (Instruments: deaths per capita, buildings destroyed per capita, their cubes, interaction, the predicted growth rates cubed, and a bombing dummy (see text for details))

Table 5

Two-Stage Least Squares Estimates of Impact of Bombing on Manufacturing Output in Cities

	Dependent variable is normalized growth in urban manufacturing between 1948 and 1969	
Normalized growth in manufacturing between 1938 and 1948	-0.708 (0.203)	-0.848 (0.299)
Cube of normalized growth of manufacturing between 1938 and 1948		0.0392 (0.0617)
Normalized growth in manufacturing between 1932 and 1938	-0.275 (0.143)	-0.264 (0.143)
Government reconstruction expenses	21.7 (11.4)	21.0 (11.4)
Number of observations	98	98

Note: Standard Errors in Parenthesis (Instruments: deaths per capita, buildings destroyed per capita, their cubes, interaction, predicted growth rates cubed, and a bombing dummy (see text for details))

Table 6

Two-Stage Least Squares Estimates of Impact of
Bombing on Individual Industries in Cities

	Dependent variable is normalized growth in industry in city between 1948 and 1969	
Normalized growth in industry between 1938 and 1948	-0.727 (0.142)	-0.667 (0.164)
Cube of normalized growth of industry between 1938 and 1948		-0.0216 (0.0280)
Normalized growth in industry between 1932 and 1938	-0.149 (0.0510)	-0.170 (0.0586)
Government reconstruction expenses	-1.08 (7.84)	-4.01 (8.86)
Industry Fixed Effects	Yes	Yes
Allowing Bombing to Affect Industries Differently	No	No
Number of observations	325	325

Note: Standard Errors in Parenthesis (Instruments: deaths per capita, buildings destroyed per capita, their cubes, their interaction, the predicted growth rates cubed, industry fixed effects, and a bombing dummy (see text for details))

Table 7

Two-Stage Least Squares Estimates of Impact of
Bombing on Individual Industries in Cities

	Dependent variable is normalized growth in industry in city between 1948 and 1969			
Normalized growth in industry between 1938 and 1948	-0.675 (0.116)	-0.622 (0.144)	-0.731 (0.163)	-0.647 (0.184)
Cube of normalized growth of industry between 1938 and 1948		-0.013 (0.021)		-0.011 (0.011)
Normalized growth in industry between 1932 and 1938	-0.137 (0.047)	-0.145 (0.048)	-0.116 (0.107)	-0.153 (0.113)
Government reconstruction expenses	-1.178 (7.689)	-2.918 (8.185)	-40.736 (35.078)	-61.622 (40.935)
Industry Fixed Effects	Yes	Yes	Yes	Yes
Allowing Bombing to Affect Industries Differently	Yes	Yes	Yes	Yes
Industry Share Cutoff	0.001	0.001	0.01	0.01
Number of observations	325	325	113	113

Note: Standard Errors in Parentheses (Instruments: deaths per capita, buildings destroyed per capita interacted with industry dummies, their cubes, their interaction, the predicted growth rates cubed, industry fixed effects, and a bombing dummy (see text for details))

Figure 1

Globally Stable Unique Equilibrium

● Stable equilibrium
S: Region 1 Manufacturing Share

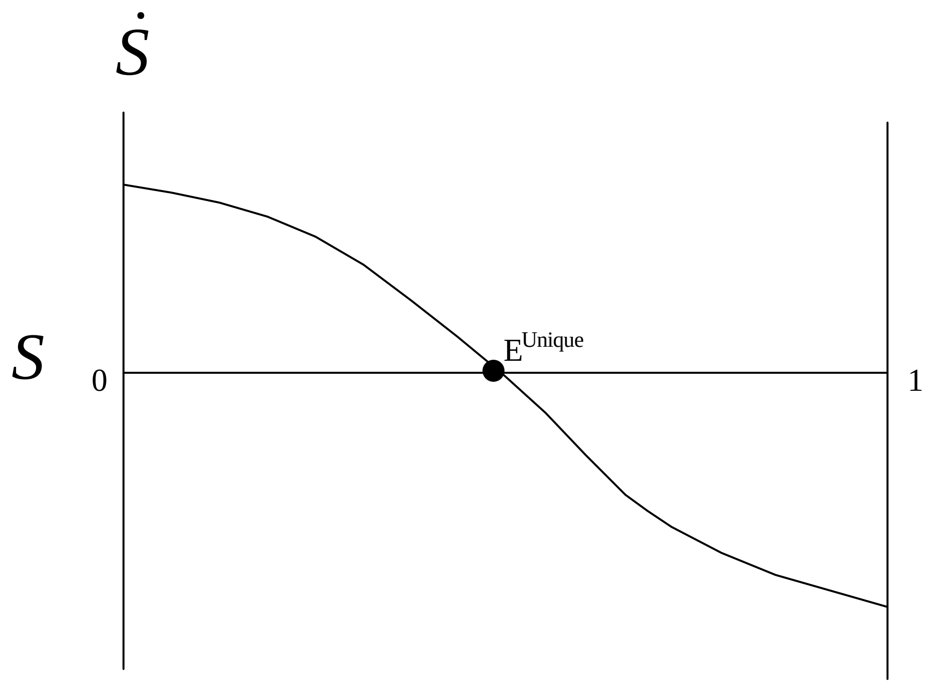


Figure 2

Multiple Equilibria in the Krugman Model

● Stable equilibrium
○ Bifurcation
S: Region 1 Manufacturing Share

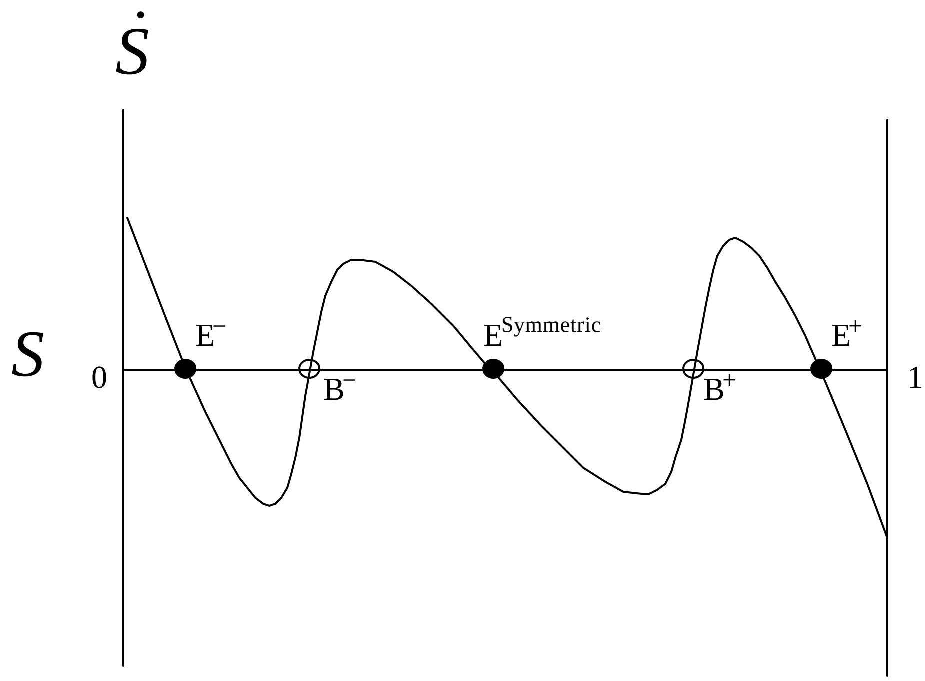


Figure 3

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

s: Region One Ln(Manufacturing Share)

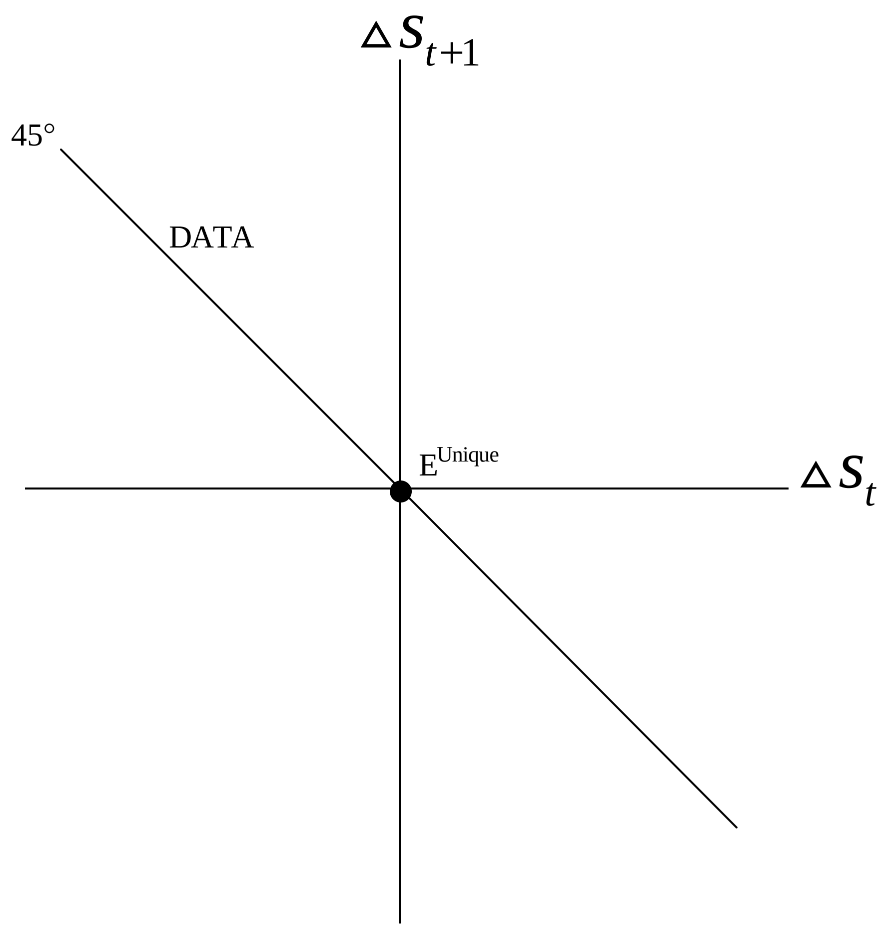


Figure 4

Two-Period Adjustment in the Model of Multiple Equilibrium

s: Region One Ln(Manufacturing Share)

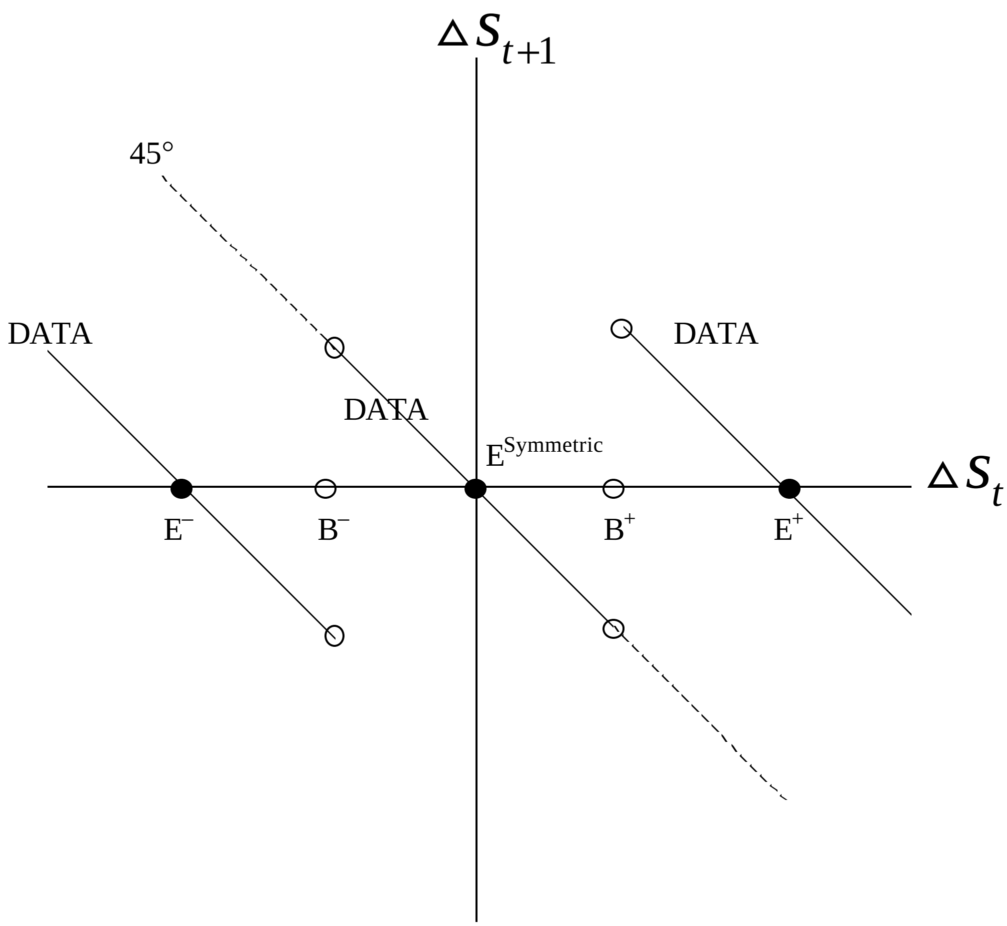


Figure 5

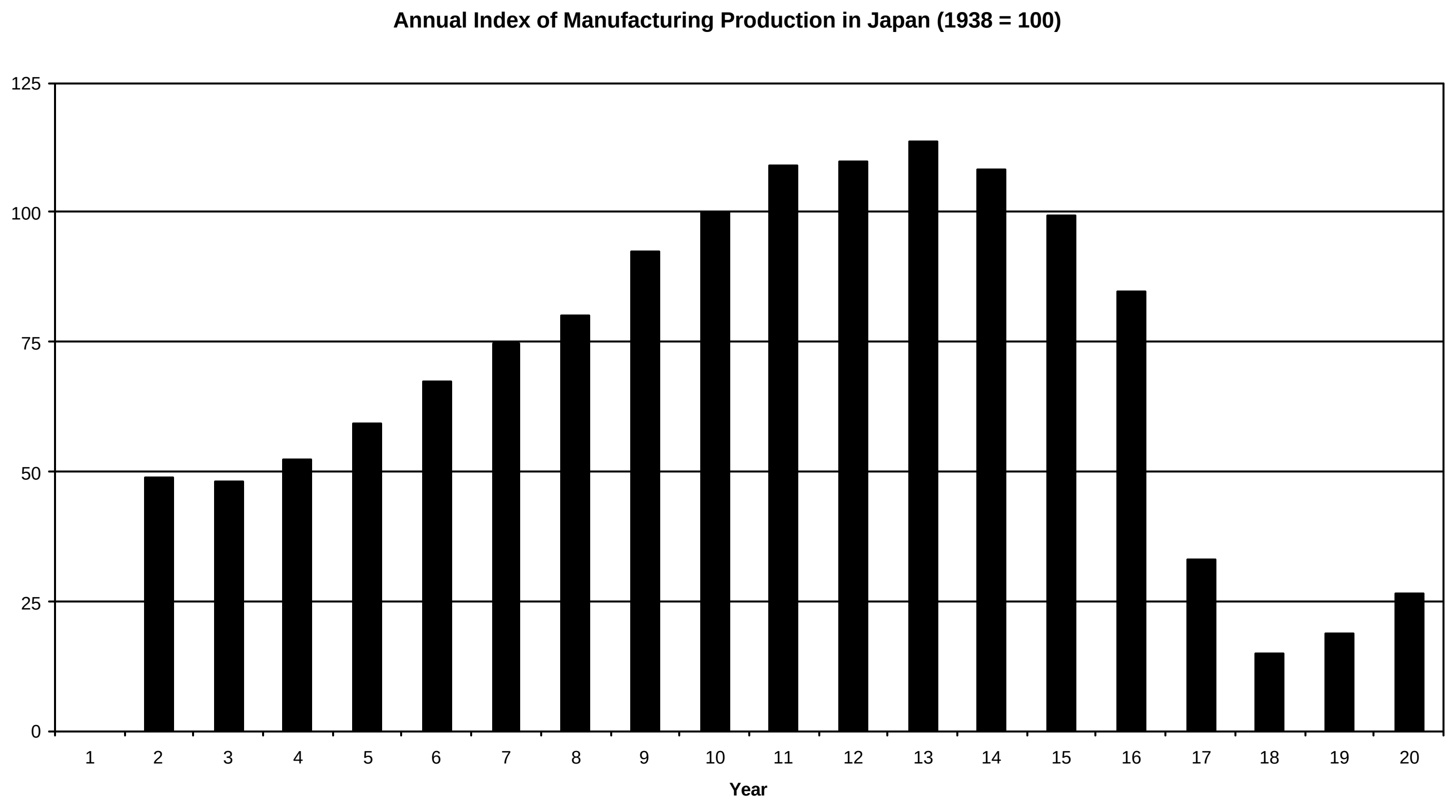

Annual Index of Manufacturing Production in Japan (1938 = 100)
125
100
75
50
25
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Year

Figure 6

Prewar and Postwar growth rates of manufacturing shares in bombed cities

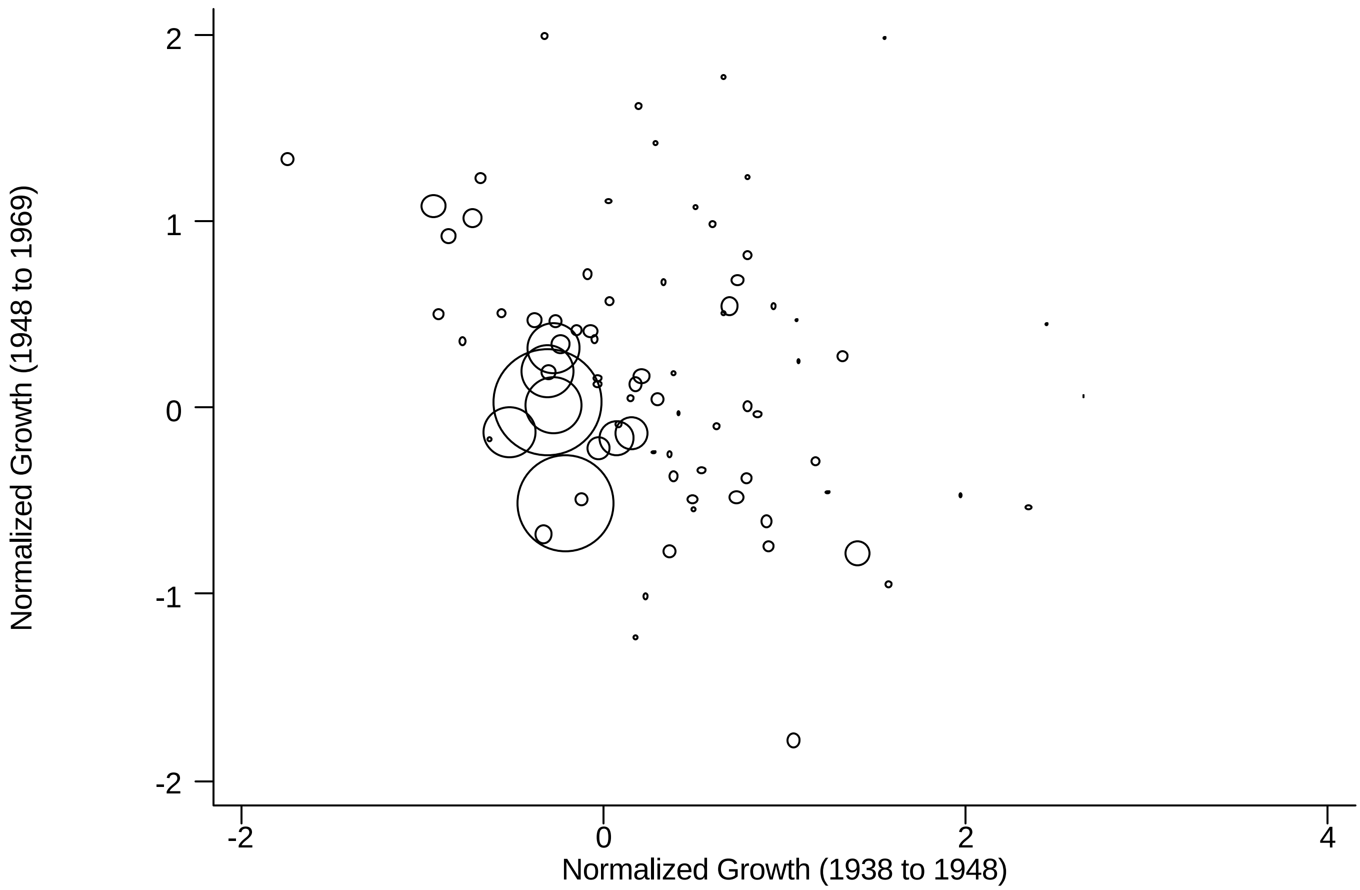
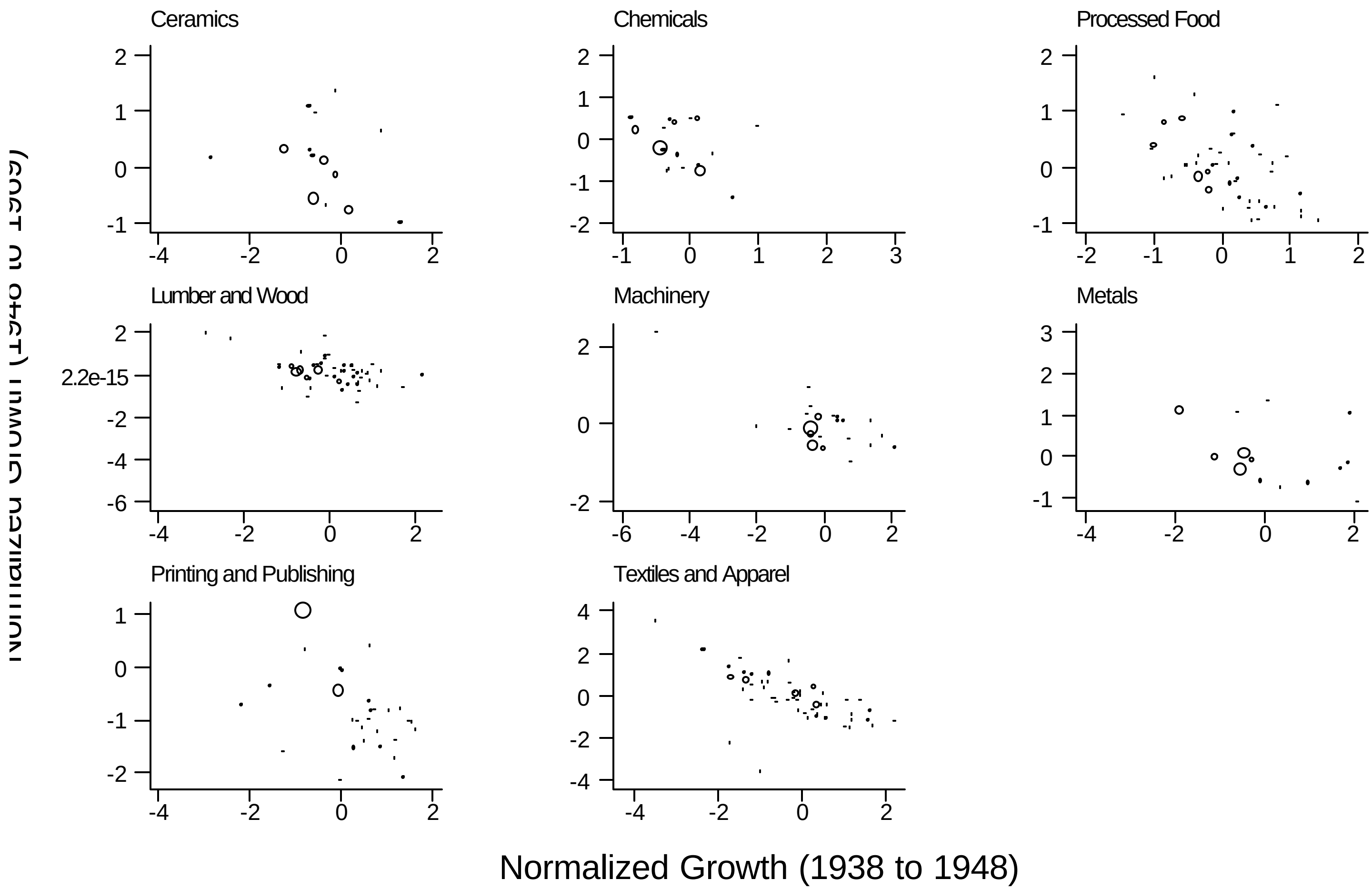
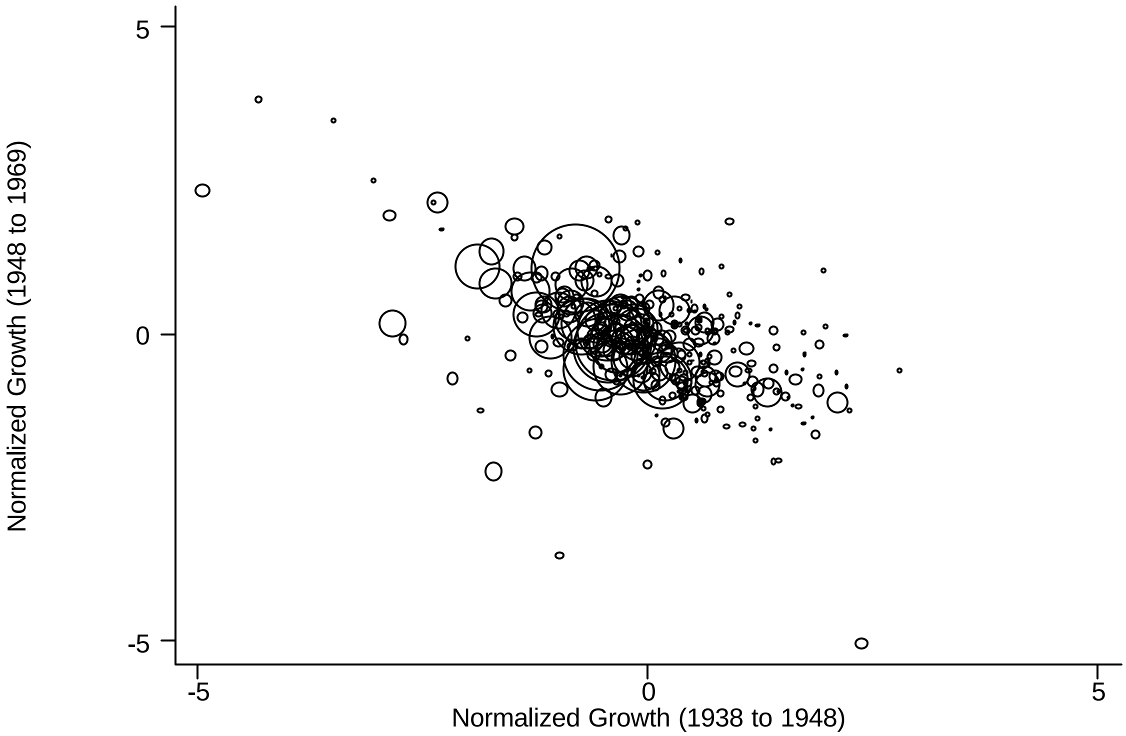


Figure 7



Prewar vs Postwar Growth Rate

Figure 8



5
0
-5
-5
0
5
Normalized Growth (1948 to 1969)
Normalized Growth (1938 to 1948)

References

Cohen, Jerome B. (1949) *Japan's Economy in War and Reconstruction*, Minneapolis: University of Minnesota Press.

Cooper, Russell; John, Andrew, "Coordinating Coordination Failures in Keynesian Models," *Quarterly Journal of Economics*, vol. 103, no. 3, August 1988, pp. 441-63.

David, Paul A. (2000) "Path Dependence, Its Critics, and the Quest for 'Historical Economics,' Stanford University Working Papers 00-011.

Davis, Donald R.; Weinstein, David E. (Forthcoming 2002) "Bones, Bombs, and Breakpoints: The Geography of Economic Activity," *American Economic Review*.

Fujita, M., P. R. Krugman, and A. J. Venables (1999) *The Spatial Economy: Cities, Regions, and International Trade*, Cambridge: The MIT Press.

Fujita M, Thisse JF (2002) *Economics of agglomeration*, Cambridge: Cambridge U. Pr.

Gabaix, Xavier (1999) "Zipf's Law for Cities: An Explanation" *Quarterly Journal of Economics*, 114 (3), August 1999, pages 739-67.

Gallup, John, Jeffrey Sachs, and Andrew Mellinger (1999) "Geography and Economic Development," *International Regional Science Review*, vol. 22, no. 2, August, pp. 179-232

Hammel, Eric (1998) *Air War Pacific: America's Air War Against Japan in East Asia and the Pacific 1941-1945 Chronology*, Pacifica: Pacifica Press.

Henderson, J.V. (1974) "The Sizes and Types of Cities," *American Economic Review* 64: 640-56.

Krugman, P. R. (1991) "Increasing Returns and Economic Geography," *Journal of Political Economy*, 99: 483-499.

Krugman, Paul R. (1991b) "History versus Expectations," *Quarterly Journal of Economics*, vol. 106, no. 2, May, pp. 651-67.

Krugman, Paul R; Venables, Anthony J, "Globalization and the Inequality of Nations," *Quarterly Journal of Economics*, vol. 110, no. 4, November 1995, pp. 857-80.

Lucas, Robert E , Jr. (2001) "Externalities and Cities," *Review of Economic Dynamics*, vol. 4, no. 2, April 2001, pp. 245-74.

Management and Coordination Agency of Japan, *Nihon Choki Tokei Soran* (Historical Statistics of Japan), Vol.1, 1987, pp.94-104.

Murphy, Kevin M; Shleifer, Andrei; Vishny, Robert W, "Industrialization and the Big Push," *Journal of Political Economy*, vol. 97, no. 5, October 1989, pp. 1003-26.

Nakamura, Takahide, and Masayasu Miyazaki. ed., *Shiryo Taiheiyo Senso Higai Chosa Hokoku* [Damage Survey Report of the Second World War] Todai Shuppankai, 1995.

Neary JP, (2001) "The spatial economy: Cities, regions and international trade by Fujita M, Krugman P, Venables AJ," *Journal of Economic Literature*, 39 (2): 536-561 June.

Rappaport, Jordan and Jeffrey D. Sachs (2001) "The US as a Coastal Nation," Mimeo.

Statistics Bureau of the Prime Minister's Office, *Nihon Tokei Nenkan* (Japan Statistical Yearbook), 1950, pp.154-155.

Simon, H. (1955) "On a class of skew distribution functions," *Biometrika* 42: 425-440.

Tokyo Shisei Chosakai. (Various Years) *Nihon Toshi Nenkan* [Japan City Yearbook] Tokyo: Daiichi Hoki Shuppan.

Toyo Keizai Shinposha. ed. (1991) *Kanketsu Showa Kokusei Soran* [Complete Showa Census Compendium] Vol.1, Tokyo: Toyo Keizai Shinposha.

Tsusan Sangyo Daijin Kanbo Chosa Tokeibu (1961) *Kogyo Tokei 50 Nenshi* [50 Year History of Industrial Statistics] Tokyo: Okurasho Insatsukyoku.

United States Strategic Bombing Survey (1947) *Effects of Air Attack on Japanese Urban Economy*Vol. 55, Washington, D.C.: Urban Areas Division.

Werrell, Kenneth P. (1996) *Blankets of Fire: U.S. Bombers over Japan during World War II*, Washington: Smithsonian Institution Press.