# Agglomeration Externalities and Productivity Growth: U.S. Cities, 1880-1930


**Alexander Klein**
University of Kent

and

**Nicholas Crafts**
University of Warwick


July 2018


Authors' Contact Details:

Klein is Senior Lecturer in Economics at the University of Kent: Postal address: School of Economics, Keynes College, University of Kent, Canterbury CT2 7NP, United Kingdom; email address: a.klein-474@kent.ac.uk

Crafts* is Professor of Economic History at the University of Warwick: Postal address: Department of Economics, University of Warwick, Gibbet Hill Road, Coventry CV4 7AL, United Kingdom; email address: n.crafts@warwick.ac.uk

*Corresponding author.



Acknowledgment: We are grateful to the editor Sara Horrell, four anonymous referees, and seminar participants at Stanford, UC Davis, UC Irvine, Oxford University, CEPR Economic History Conference in Dublin, University of Economics, Prague, and OWL Workshop for their comments. Alexander Klein is also affiliated with the University of Economics, Prague, The Faculty of National Economy. The paper was supported by a grant from the Grant Agency of Czech Republic 17-13296S.

# Agglomeration Externalities and Productivity Growth:
# U.S. Cities, 1880-1930

**Abstract**

We investigate the role of industrial structure in labour productivity growth in manufacturing in U.S. cities during the 'second industrial revolution'. We find that initially greater specialization was associated with faster subsequent productivity growth but that only the very high levels of diversity which obtained in some very large cities had a positive correlation. We interpret our results as demonstrating the existence of dynamic Marshallian externalities. The impact of industrial specialization in our sample of U.S. cities after 1890 is found to have raised the level of labour productivity in manufacturing by about 4 per cent by 1920.

**Keywords**: agglomeration externalities; diversity; manufacturing; productivity growth; specialization

**JEL Classification**: N91; N92; O18; R12

# I

In the last 20 years or so there has been a great revival of interest in the nature and extent of agglomeration economies that cities generate. The study of agglomeration externalities has developed so rapidly under the auspices of the new economic geography that major survey articles are frequently written.[1] Yet, remarkably little is known about the extent or nature of such externalities in U.S. cities during American industrialization.[2]

Filling in this gap becomes all the more important when it is recognized that American cities were growing fast and the urban system was evolving rapidly around the time at which the United States overtook the United Kingdom to become the world's leading economy during the so-called 'second industrial revolution'. Between 1880 and 1920, the percentage of urban population rose from 28.2 to 51.2. Cities became larger; in 1880 there were 41 cities with population of 50,000 or more accounting for 14.3 per cent of the population but by 1920 this had risen to 144 cities with 31.0 per cent of the population. This became the era of large industrial cities (Kim, 2000).[3] Cities also became more specialized as is epitomized by the examples of Akron, Ohio and Detroit.

In this paper, we examine the role of dynamic agglomeration externalities as a source of productivity growth in urban manufacturing. The idea is that the initial industrial structure of a city has impacts on subsequent productivity performance. This hypothesis has been supported in analyses of late-20th century American experience (Glaeser et al., 1992; Henderson et al., 1995).[4] Two aspects of industrial structure are highlighted in this literature, namely specialization and diversity. A specialized industrial structure may promote intra-industry sources of increased productivity as envisaged by Marshall while a diversified structure could be conducive to productivity improvement arising from interactions between industries as

---

1 For example, Rosenthal and Strange, 'Evidence' and Combes and Gobillon, 'Empirics'.
2 See Kim and Margo, 'Historical perspectives'.
3 Kim, 'Urban development'.
4 In particular, Glaeser, Kallal, Scheinkman, and Shleifer, 'Growth' and Henderson, Kuncor, and Turner, 'Industrial development'.

proposed by Jacobs.[5] An interesting permutation of these arguments was provided by Duranton and Puga who suggested a life-cycle pattern for industries which might benefit through inter-industry technological spillovers from location in diverse cities at an early stage but then at a later stage benefit from intra-industry externalities derived from location in specialized cities.[6]

The specific question that we address through a detailed analysis of data in the Census of Manufactures is the following: did dynamic Marshallian and/or Jacobian agglomeration externalities raise labour productivity growth in American cities in the period between 1880 and 1930? Our empirical strategy is to run regressions that relate labour productivity growth in manufacturing at the city-industry level during periods of between 20 and 50 years between 1880 and 1930 to measures of the degree of industrial specialization and diversity of urban economic activity while controlling for a wide range of variables relating to geography and state-level factor endowments. We have constructed a unique dataset derived from the Census of Manufactures for this purpose.

The main contribution of the paper is to establish the connection between specialization and diversity of industrial structure in early-20th century American cities and labour productivity growth. In particular, we report three main findings. First, we show that greater specialization was correlated with faster labour productivity growth in a city's industrial sectors. This effect is both economically and statistically significant. Second, we find less robust evidence that greater diversity of a city's industrial structure may have had a non-linear effect on productivity growth. For most levels of diversity, the effect is negative but when diversity is substantial, as it was in a few very large cities, the effect is positive. Third, we note that specialization in our sample of cities increased on average by about 25 per cent on our measure and that our regressions indicate that this would have had raised manufacturing labour productivity growth in our cities by 0.13 to 0.26 percentage points per year between 1890 and 1920.

[5] Marshall, *Principles*; Jacobs, *Economy of cities.*
[6] Duranton and Puga, 'Nursery cities'.

The paper proceeds as follows. Section II presents a detailed account of the literature on dynamic agglomeration externalities. Our approach to estimation is set out in Section III. Section IV describes and summarizes the data. In Section V, we present detailed econometric estimates. We discuss the economic significance of the results in Section VI. Section VII concludes.

## II

The sources of agglomeration externalities can be categorized as sharing, matching and learning mechanisms.[7] Sharing mechanisms include sharing indivisible facilities, sharing the gains from a wider variety of input suppliers, sharing the gains from a finer division of labour, or sharing risks. Matching mechanisms include better expected quality and/or higher probability of matches especially between employers and workers in a larger labour market. Learning mechanisms relate to the diffusion and accumulation of knowledge including tacit knowledge which is enhanced by the proximity of other producers. These benefits of agglomeration may occur within industries or across sectors. The former can be thought of as localization externalities which accrue from specialization and the latter as urbanization externalities which stem from diversity of production. Conventionally, external economies from specialization are described as Marshallian while those from diversity are termed Jacobian.

Dynamic agglomeration economies result when initial conditions have a persistent impact on productivity growth, for example as technological spillovers or learning effects accrue. The general idea can be stated formally along the following lines.[8] Consider the case where log labour productivity ($y_{s,c,t}$) in a sector in a city at time t is a function of a fixed effect ($\alpha$) and a static externality ($\beta_{s,c,t}$). Then

$$y_{s.c.t} - y_{s,c,t-1} = \beta_{s,c,t} - \beta_{s,c,t-1} \quad (1)$$

Dynamic externalities are introduced by assuming that for $t \geq 1$

[7] Duranton and Puga, 'Micro-foundations'.
[8] This exposition is based on Combes and Gobillon, 'Empirics'.

$$y_{s,c,t} - y_{s,c,t-1} = \beta_{s,c,t} - \beta_{s,c,t-1} + \mu_{c,s,t-1} \quad (2)$$

where μ represents the impact of initial conditions on productivity growth between time t – 1 and time t. It can then be hypothesized that initial conditions are located in industrial structure such that μ is a function of specialization and diversity where the former is measured by the sectoral share of city employment and the latter is captured by a Hirschman-Herfindahl index of sectoral employment shares. It should, however, be noted that city size per se may generate dynamic externalities and this needs to be taken into account when looking for evidence that industrial structure matters.

The pioneering empirical investigations of dynamic externalities in the new economic geography literature investigated the relationship between initial industrial structure and subsequent employment growth in U.S. cities in the later 20th century using long-difference regressions. In many but not all cases, employment growth at the city-industry level will be correlated with productivity growth. Glaeser et al. found that diversity of employment but not specialization promoted industrial employment growth while Henderson et al. found that past employment concentration generated employment growth in mature capital goods industries but for new high-tech industries both diversity and specialization had positive effects.[9] So there was some evidence in favour of both dynamic Jacobian and Marshallian externalities. If the data permit, it is preferable to examine the impact of industrial structure on subsequent productivity growth rather than employment growth as was done in later papers by Henderson (looking at US plants) and by Cingano and Schivardi (Italian firms).[10] Both these papers found evidence in favour of a positive impact from specialization in at least some industries but could not reject the null hypothesis for diversity.

When we turn to the era of the late 19th and the early 20th century, evidence about agglomeration economies is thin on the ground, as is evident from the survey article by Kim and Margo which suggested that Marshallian externalities may have been important in the rise of American cities but noted that quantitative

[9] Glaeser, Kallal, Scheinkman and Shleifer, 'Growth'; Henderson, Kuncor and Turner, 'Industrial development'.
[10] Henderson, 'Marshall's scale economies'; Cingano and Schivardi, 'Identifying'.

evidence on these externalities was then not available.[11] Kim showed that urban manufacturing firms had substantially higher wages, labour productivity and TFP than rural firms and that the wage premium increased considerably between 1850 and 1880.[12] Simon and Nardinelli found that cities with occupational structures intensive in the use of human capital at the start of the 20th century experienced stronger employment growth in the decades through to the 1980s and suggested that this may have reflected knowledge spillover effects but did not provide evidence of externalities.[13] On the other hand, Lee investigated static inter-industry spillovers using an empirical design based on the impact of the coming of the automobile on employment in supplier industries and found that they were very small while Bostic et al. found no evidence that variables designed to capture 'urbanization', 'specialization' or 'localization' had a positive effect on labour productivity growth in American cities in the 1880s.[14] However, research on 31 English cities in the period 1851 to 1911 has found evidence of dynamic inter-industry externalities in employment growth based on proximity to supplier industries and occupationally similar industries but not of dynamic intra-industry externalities.[15]

## III

The empirical literature on agglomeration economies has grown considerably over the past two decades, creating a pool of estimation techniques, regression specifications, and variables capturing the effects of agglomeration externalities.[16] We take advantage of this literature and choose an empirical specification which best suits our data. Specifically, we choose an estimation strategy linking labour productivity to measures of industrial specialization and industrial diversity used on numerous occasions to investigate the effect of dynamic Marshallian and Jacobian externalities on productivity growth. A simple model

[11] Kim and Margo, 'Historical perspectives'.
[12] Kim, 'Division of Labor'.
[13] Simon and Nardinelli, 'Human capital'.
[14] J. Lee, 'Measuring agglomeration: products, people, and ideas in U.S. manufacturing, 1880-1990', mimeo, Harvard University; Bostic, Gans, and Stern, 'Urban productivity'.
[15] Hanlon and Miscio, 'Agglomeration'.
[16] It is beyond the scope of this paper to provide a comprehensive review but one can be found in Combes and Gobillon, 'Empirics'.

motivating our estimation strategy and offering guidance for our reduced-form regression analysis is discussed in detail in Appendix I. In a nutshell, it is a model of city-industry growth which incorporates dynamic local spillovers within and across industries. Specifically, dynamic agglomeration spillovers are incorporated into a model of city-industry labour productivity growth which matches our data best since it operates with value-added per worker.[17]

We specify the regression equation as follows:

$$ln(y_{c,s,t+m}) - ln(y_{c,s,t}) = \alpha + \beta_1 SPEC_{cst} + \beta_2 DIV_{cst} + \beta_3 X_{cst} + \theta_c + \lambda_s + \epsilon_{cs} \quad (3)$$

where $y_{c,s,t}$ and $y_{c,s,t+m}$ is value-added per worker in industry *s*, city *c*, and time *t* and *t*+*m* respectively, $SPEC_{cst}$ and $DIV_{cst}$ are variables capturing specialization and diversity in industrial structure, and $X_{cst}$ is a vector of controls which include the initial period value added per worker of industry *s* in city *c*, and share of manufacturing employment in the state where the city is located. To avoid omitted variable bias, it is important to include a vector of industry dummies to control for unobserved industry effects ($\lambda_s$ in equation 3), and a vector of city dummies to control for unobserved city effects ($\theta_c$ in equation 3). The error term is expressed as $\epsilon_{cs} = \epsilon_{cst+m} - \epsilon_{cst}$. This regression specification thus expresses the growth rate of value-added per worker in an industry *s* in a city *c* in a period from *t* to *t*+*m* (for example between 1890 and 1920) as a function of specialization and diversity obtaining in industry *s* and city *c* in the initial period *t*, capturing thus the dynamic effect of *initial* industrial specialization (conducive to Marshallian externalities) and diversification (conducive to Jacobian externalities) in city *c* on subsequent productivity growth.[18]

---

[17] We do not use total factor productivity as our dependent variable because (i) US Census of Manufactures in 1930 did not report estimates of city-industry capital stock, and (ii) city-industry capital stock figures in 1880 and 1920 are of very low quality.

[18] We would like to stress that this is a reduced-form rather than a structural analysis.

Before discussing how we estimate equation (3) and estimation issues which arise, we define the variables to measure specialization and diversity.[19] The degree of specialization is defined as:

$$SPEC_{cs} \equiv (L_{cs}/L_c) \qquad (4)$$

where $L_{c,s}$ is employment in sector *s* and city *c*, and $L_c$ is the total employment in city *c*. Diversity is captured by the degree of industrial sector variety outside sector *s* in the city which is expressed using a Hirschman-Herfindahl index and defined as:

$$DIV_{\mathrm{CS}} \equiv \Sigma_{j \neq s} \left(\frac{L_{cj}}{L_c - L_{cs}}\right)^2 \qquad (5)$$

The value of the index is 1 if employment outside industry s is concentrated in a single sector, and $1/DIVc$ if employment outside industry s is uniformly distributed across other sectors.[20]

We investigate the evidence for dynamic agglomeration externalities using a long-difference period of 30 years. We present results in the main text for 1890-1920 and 1900-1930. We focus mainly on the results for 1890-1920 which are based on a much larger sample size. We also estimated equation (3) for shorter and longer periods within the 1880-1930 interval and report results in Appendix II. In the first instance, we estimate regression equation (3) by OLS but there are econometric issues to be addressed. First, the errors, $\epsilon_{cs} = \epsilon_{cst+m} - \epsilon_{cst}$, could be correlated within cities as well as industries. Therefore, we use the two-way clustering method of Cameron et al..[21] Second, unobserved factors contained in the error term, $\epsilon_{cs} = \epsilon_{cst+m} - \epsilon_{cst}$, may bias the estimates of Marshallian and Jacobian externalities. Two sorts of biases can be imagined. First, there might be other factors which influence Marshallian and Jacobian externalities, and are correlated with the value-added growth rates but which are not controlled for by $X_{cst}$. We believe

---

[19] In so doing, we are guided by Combes, ‘Economic structure’ and Cingano and Schivardi, ‘Identifying’.

[20] In the regression analysis, we use a logarithmic transformation of *DIV* which allows us a very useful measure of the percentage change in diversity. The literature sometimes uses the log of the diversity index and sometimes an index without logarithmic transformation. As a robustness check, we performed the regression analysis without the logarithmic transformation of the diversity index and the results (available from the authors upon request) were qualitatively similar.

[21] Cameron, Gelbach, and Miller, ‘Robust inference’.

that we control adequately for unobserved effects using industry and city dummies $\lambda_s$ and $\theta_c$ respectively.[22] Second, firms might partially predict $\epsilon_{cs} = \epsilon_{cst+m} - \epsilon_{cst}$ and relocate in anticipation. For example, if $\epsilon_{cs} = \epsilon_{cst+m} - \epsilon_{cst}$ includes specific long-run changes in technology, then a city that has an initial industrial structure which is more conducive to technological change might *systematically* attract firms. This would, as a result, make the initial industrial composition of cities – and our Marshallian and Jacobian externalities – potentially endogenous. While, the historical circumstances of the decades 1880-1930, the so-called 'second industrial revolution', make us believe that this was not the case, nevertheless, as a robustness check, we also estimate (3) using instrumental-variables methods which will be discussed in detail in section V.

## IV

We created a unique data set of city-industry pairs, and state-level employment. Specifically, the data set consists of SIC 3-digit city-industry real value added per worker, sectoral specialization, industrial variety, and U.S. state-level employment at SIC 2-digit level in the period 1880-1930. The data come from several sources. City-industry nominal value-added, number of workers, sectoral specialization, and industrial variety are drawn from the U.S. Census of Manufactures and the aggregation of individual industries at the three-digit level follows the standard industrial classification.[23] U.S. state-level employment at SIC 2-digit level in 1880-1920 comes from Klein and Crafts, supplemented by data from the 1930 U.S. Census of Manufactures.[24] The aggregation of individual industries at two-digit level again follows the standard

[22] The original empirical framework by Glaeser, Kallal, Scheinkman, and Shleifer, 'Growth', does not include city fixed effects. However, Glaeser, *Cities*, p.75 suggests that city fixed effects should be part of the empirical specification. The inclusion of geographical area fixed effects has been a standard approach in the agglomeration literature, for example Henderson, 'Externalities', Cingano and Schivardi, 'Identifying', or Greenstone, Hornbeck and Moretti, 'Identifying'.

[23] The assignment of individual industries into each SIC 3-digit level category is available from the authors upon request.

[24] Klein and Crafts, 'Making sense'.

industrial classification. We use the wholesale price index offered by the U.S. Historical Statistics Millennial Edition, series Cc-126 to calculate city-industry real value-added.[25]

The U.S. Census of Manufactures, while an excellent source of city-industry level data, is not without its challenges. First, the 1880 census reports the number of workers and not the number of employees which begins only in 1890. Therefore, we use the number of workers to be consistent over the entire period 1880-1930. Second, value added, as reported by the census in 1900, 1920, and 1930, does not exclude some of the costs.[26] Therefore, we calculated value added by subtracting all the costs from the reported gross value of output. Third, the number of cities included in the censuses changes over time.

Table 1 shows the distribution of the cities in our sample across time and U.S. regions. We see that the 1900 Census of Manufactures contains the most comprehensive information on U.S. cities. Most of the cities come from the New England, Middle Atlantic and East North Central regions, reflecting the dominant position of those regions in American economic development at the turn of the twentieth century. Table 2 presents the number of matched cities across the periods of our interest. Two points are worth mentioning. First, we see that the number of cities which can be consistently followed over time increased between 1880 and 1900. Second, there is a drop in the number of cities reported in the 1920 and 1930 Census of Manufactures resulting in fewer cities which can be followed up to 1920 and 1930, respectively.

There are two ways to deal with the changing number of cities. We can create a sample of only those cities for which the census consistently provides data in every period we analyse. This would give us a dataset with the same cities throughout. Alternatively, we can use all the cities provided by the census and have a different number of cities in each period we analyse. We do both. We do not think that the changing number of cities across periods is the result of sample selection. It is highly unlikely that the changing number of

[25] We have also used the wholesale price indices at SIC 2-digit level offered by Cain and Paterson, 'Factor biases'. Their indices, however, run only up to 1919, and so we use them as a robustness check for the regressions of 1880-1920, 1890-1920, and 1900-1920.

[26] Rents for offices are excluded in 1900 and 1920, value of fuel in 1930.

cities had anything to do with unobserved factors which might be correlated with labour productivity growth since decisions to include new cities in the census were driven by the capabilities and financial resources of the Census Bureau. However, it might be that there are some other sample selection mechanisms unobservable to us, therefore, as said above, we analyse the data using the data set with the same cities throughout.

Analysing the data set with all the cities provided by the census brings up the issue of how to compare the results across different periods. For example, the results for the period 1890-1920 can be different from 1880-1920 because, in addition to the cities which were in the 1880-1920 sample, we have 'new' cities entering the sample of 1890-1920 as well as cities exiting from the 1880-1920 sample. Therefore, it will be useful to see what kind of cities were entering and exiting the sample in the period of 1880-1900 and stayed there until 1920 and 1930, respectively. There was only one town which was present in 1880 but not after, namely, Saint Louise, Maine and two towns were present in 1880 but not in 1900, namely, Saint Louise, Maine, and Washington DC. As for 1890, there are only two towns present in 1890 but not in the 1900 census: Lincoln, Long Island, and Long Island City. The cities which entered the sample in 1890 and 1900, and stayed there until 1920 and/or 1930 were mostly small and medium size towns except for St. Louis, Akron (Ohio), Portland (Oregon), Seattle, and Los Angeles which entered the sample in 1890. As for the degree of industrial specialization and industrial diversity, cities entering the sample in 1890 are not, on average, different from the cities already in the sample. Cities entering the sample in 1900 are slightly more specialized and slightly less diversified. We believe, however, that this will not bias our results since there are only 9 new cities entering the sample for 1900-1920.

As we have seen in Table 2, it is a feature of the Census of Manufactures in 1930 that fewer cities were included in the census relative to the earlier censuses. As a result, our sample of cities in the period ending in 1930 drops relative to the one ending in 1920. Again, this was due to the resources of the US Census Bureau so that it is very unlikely that there would be any kind of systematic relationship between the change in the sample size and the growth of labour productivity of cities and we do not need to worry about sample-selection bias. The towns which dropped out of the sample (but were present until 1920) were mostly smaller towns with an average population of about 40,000, together with two large cities: Omaha and Milwaukee. As for the degree of industrial specialization and diversity, these towns are, on average, more specialized and less diversified than those which remained in the sample. Again, we believe that this will not materially affect the overall results; nevertheless, we conduct a series of robustness checks in Appendix II.[27]

Figure 1 graphs city populations on a log scale against their specialization index and to a first approximation this shows that the smallest cities were the most specialized. On a closer look, however, the relationship is a bit more complex. Indeed, at the lower end of the spectrum, with population up to about 50,000, there were both quite specialized as well as quite diversified towns. Then, as city population increases, the degree of industrial specialization declines rather rapidly in a curvilinear fashion, until specialization does not vary with the size of the cities. Figure 2 shows that there seems to be a positive relationship between the log of city size and industrial diversity. However, this relationship is also not linear but this time seems to be concave although the rank correlation is far from perfect. The very biggest cities were generally very diverse but there were outliers, notably Pittsburgh where the dominant industry was iron and steel.

Since this paper focuses on dynamic Marshallian and Jacobian agglomeration economies, it is interesting to see which industries were found in the most specialized and the most diversified industrial environments. We take the index of specialization for each city to be the average *SPEC* score for its industries and likewise the index of diversity to be the average *DIV* score for its industries. Table 3 presents the top five and the bottom five industries according to the average specialization and variety indices that they faced across all cities in 1880, 1900, and 1930.

[27] The share of total number of workers in our data set relative to the US total is large: 51% in 1880, 72% in 1890, 60% in 1900 and 53% in 1920.

We see in Panel A that traditional industries, such as textiles, were in cities of high specialization, though by 1930, this was also true of modern industries such as petroleum refining and motor vehicles, reflecting increased concentration of those industries in cities (e.g. motor vehicles in Detroit). On the other hand, modern industries such as chemicals and household appliances were located in cities with a diversified industrial structure. This is confirmed when looking at Panel B which shows that modern industries such as plastic materials or household appliances were in cities with the highest variety index while traditional industries such as textiles, food, or the leather industry were in locations with the lowest variety index. It is interesting to see, however, that by 1930, some of the modern industries such as aircraft were located in the cities with a low variety index, indicating that they had become highly specialized.

## V

The main results of the OLS estimation of equation (3) are presented in Table 4. In addition to the variables of interest — *SPEC* and *DIV* which capture aspects of industrial structure conducive to Marshallian and Jacobian externalities, respectively — the regression controls for city and industry fixed effects, beginning-of-period value-added per worker, and beginning-of-period share of state-level employment in the U.S. total for the corresponding SIC-2 digit level. This last is used to control for the presence of spatially correlated omitted variables operating at the state-level and also at the higher level of industrial aggregation. For example, there might be state-specific effects influencing city-industry productivity coming from state-specific factor endowments not controlled by city-industry dummies. Controlling for industry-specific effects at the higher-level industrial classification is important because there might be spillovers operating within industry groups. For example, labor productivity of industries producing transportation equipment could be influenced by unobserved industry effects specific to the transportation industry; hence our decision to control for industry employment at SIC 2-digit level. We have also estimated equation (3) with city latitude and longitude, access to waterways, lakes, and oceans, distance to New York City, temperature, share of state-level employment in mining, state-level prices, and share of state-level skilled occupations.[28] The results for the main variables of interest were unchanged, reassuring us that our estimates of Marshallian and Jacobian externalities are not affected by geography and state-level factor endowments.

Table 4, Panel A shows that average annual labour productivity growth is positively related to *SPEC* and negatively to *DIV*. The positive Marshallian relationship is statistically significant in both periods while the negative Jacobian relationship is significant only in 1890-1920. As for the remaining regressors, the share of state-level SIC 2-digit level employment is not significant whereas value-added per worker at the beginning of the period is significant and negative, indicating a β-type convergence among SIC 3-digit level industries.

Panel B of Table 4 adds $DIV^2$ to the estimating equation to investigate the possibility of a quadratic relationship between average annual labour productivity growth and diversity. The results show that the relationship is convex and that a positive effect is only found for some, but not all, large cities. For example, for 1890-1920 a *DIV* score above 2.54 is required and only 12 cities are in this category with Louisville (1890 population 161129) being the smallest.[29] *DIV* is below this cut-off for eight of the 20 largest cities including Baltimore (population 434439).[30] The estimated coefficients for *SPEC* remain very similar to those in Panel A.

It is important to distinguish the impact of industrial structure from that of city size. Table 5 attempts to address this issue. In that table we report results of the regression specification of Table 4 for cities with below- and above-median population size. The results are very similar for each of these samples, and also very similar to those already set out in Table 4. If anything, *SPEC* appears to have a slightly larger impact on labour productivity growth in smaller cities. The results for the cities below median in the period 1900-

[28] The results are available from the authors upon request.

[29] We have explored the issue of the required *DIV* score further using a semi-parametric technique which gave quite similar estimates; results available from the authors on request.

[30] The cities for which positive dynamic Jacobian externalities are predicted by this regression are in descending order of magnitude Philadelphia, Boston, St Louis, New York, Newark, Louisville, San Francisco, Milwaukee, Chicago, Buffalo, Cincinnati, and Detroit.

1930 are insignificant but this is largely due to a small sample size leaving us with only 96 city-industry pairs. The slightly larger impact of *SPEC* on labour productivity growth in smaller cities indicates that the net benefit of Marshallian externalities is larger in those locations. This suggests that the costs of agglomeration, which counterbalance the benefits, are higher in larger than in smaller cities. We have also looked at which industries gained most from agglomeration. Specialization promoted productivity growth most in textiles and apparel but the growth of labour productivity in machineries and transportation equipment also benefited considerably from agglomeration externalities in 1890-1920.

Overall, the OLS regressions provide strong evidence that *SPEC* had a positive impact on labour productivity growth in manufacturing in our sample of cities during the early 20th century. On balance, we believe that there is also some support for a positive impact of industrial diversity at high values of *DIV* but that this was most likely to be found in large cities whereas in smaller cities it is likely that diversity had a negative impact on productivity growth.

For OLS to be consistent and to bear a causal interpretation, there must be no link between factors which affect initial industrial structure and general improvements that affect future industrial productivity. We believe that the history of technological progress makes this a plausible assumption. Technological progress accelerated at this time but its progress was quite erratic and the development of new technologies and industrial locations was unpredictable. It took 40 years after the commercial generation of electricity to work out how to transform many American factories through electrification in the 1920s.[31] At the industry level, rank correlation coefficients between decadal rates of TFP growth were very low – 0.4 between the 1900s and 1910s, 0.0 between the 1910s and the 1920s, and 0.2 between the 1920s and 1930s and there were spectacular jumps in sectoral rankings; for example, chemicals rose from 33rd to 4th and petroleum & coal products from 35th to 1st between the 1910s and the 1920s.[32]

[31] David, 'Computer and dynamo'.
[32] Bakker, Crafts, and Woltjer, 'Sources of growth'.

A good example of unpredictability is provided by the history of the automobile and of its major supplier industry, rubber manufacture. Automobile registrations rose from 8000 in 1900 to 23 million in 1930 but at the start of the 20th century the future had appeared to be steam-powered cars rather than the internal combustion engine. Detroit would become the centre of the car-making industry and was home to more than 50 per cent of producers by the mid-1930s but, in the early years of the industry, none of 69 car manufacturers entering the market between 1895 and 1900 located in Detroit.[33] In 1900, rubber manufacturers did not see the production of tyres for cars as at all significant.[34]

Rather than rely solely on historical arguments, we also use instrumental variable estimation techniques to examine the endogeneity issue further. Finding suitable instruments is undoubtedly difficult but we have developed two strategies. First, we follow research in urban and regional economics and use a shift-share instrument introduced by Bartik. It is the most commonly used instrumental variable in this literature and has been applied in numerous studies.[35] The Bartik-type instrument constructs an exogenous source of variation of employment in a local geographical area based on national employment growth at the industry level to create an instrument for the industrial composition of cities. In so doing, it isolates the exogenous variation in local labour demand coming only from national shock in each manufacturing sector, thereby removing potentially endogenous local labour demand shocks that might be driving local employment levels (in our case city employment levels). The exogeneity of Bartik-type instruments rests on the assumption that the national employment growth at the industry level does not affect city-industry productivity growth. The character of the technological progress discussed previously suggests that the exogeneity assumption of Bartik-type instruments is reasonable.

We construct this instrument in two steps. In the first step, we predict city-industry level of employment by interacting city industrial composition at time *t* with national industry-level employment growth over the

---

[33] Klepper, 'Origin'.
[34] French, US tire industry.
[35] Bartik, *Who benefits*; for an overview of studies using Bartik-type instruments, see Baum-Snow and Ferreira, 'Causal inference'.

period from $t$ to $t+m$. Specifically, we calculate the level of employment for industry $s$ in city $c$ in period $t+m$ as

$$l_{cst+m}^{predict} = l_{cst}\left(\frac{l_{st+m}}{l_{st}}\right) \qquad (6)$$

where the employment in city $c$ and industry $s$ at time $t$ – $l_{cst}$ – is multiplied by the employment growth of that industry at the *national* level between time $t$ and $t+m$. In the second step, we then use the predicted values of employment to calculate the instruments $IVSPEC_{cs}$ for initial specialization and $IVDIV_{cs}$ for initial diversity:

$$IVSPEC_{cs} \equiv (L_{cs}^{predicted}/L_{c}^{predicted}) \qquad (7)$$

$$IVDIV_{CS} \equiv \sum_{j \neq s}\left(\frac{L_{cj}^{predicted}}{L_{c}^{predicted} - L_{cs}^{predicted}}\right)^2 \qquad (8)$$

Unfortunately, the census does not provide city-industry employment in 1870 so we are unable to use this method for sample periods beginning in 1880. We can use an idea by Durbin who suggested that the instrument is created by ranking the city-industry values of *SPEC* and *DIV* nationally.[36] This allows us to conduct instrumental-variables estimation for periods starting in 1880 but we should note that unlike the Bartik method, this approach has not been widely used. [37]

Table 6 provides the results of estimation with the Bartik-type instrument. The instruments pass the weak instrument test in all cases. Endogeneity tests for *SPEC* and *DIV* variables indicate that, given the exogeneity of the instruments, *SPEC* and *DIV* are in most cases unlikely to be endogenous.

[36] Durbin, 'Errors'.
[37] We defer the discussion of this instrument and the presentation of the results to the Appendix.

Generally speaking, the pattern of statistical significance of the industrial structure variables in Tables 4 and 9 is similar to that for the OLS estimation in Table 5. In other words, the estimates in that table survive these robustness checks. An exception to this is the loss of statistical significance of $DIV^2$ with the Bartik-instrument. The absolute magnitude of the estimated coefficients on the industrial structure variables is smaller than the OLS estimates in the period 1900-1930 but larger in 1890-1920; however, the estimates in the online supplementary tables show that 2SLS estimates are typically larger.

Obviously, a question remains as to how confident we can be in interpreting the relationship between initial industrial structure and subsequent labour productivity growth as causal. We believe that this may well be justified in the context of the second industrial revolution. Nevertheless, if it is right to be cautious, at the very least we have revealed some interesting correlations which can stimulate research into the role that cities played in American productivity growth at the turn of the 20th century.[38]

## VI

The literature offers little guide to how productivity may vary with the degree of industrial diversity in a city. The only exception is a conjecture offered by Fujita and Thisse that small and medium size cities benefit mostly from intra-sectoral agglomeration economies while large cities benefit from both intra- and inter-sectoral agglomeration economies.[39] The implication is that in small and medium-size cities productivity advantages should result from Marshallian rather than Jacobian externalities while in large cities both types of externalities should have positive effects. This conjecture is consistent with the theoretical analysis of Duranton and Puga which proposes that diversified cities are a more costly place to produce than specialized cities.[40] Taken at face value, our empirical results are potentially consistent with these theoretical arguments. They imply that there is a diversity threshold below which the costs of

[38] Further robustness tests are presented in appendix II. They confirm the robustness of the results relating to *SPEC* but give some reasons to be cautious about those for *DIV*.
[39] Fujita and Thisse, *Economics of agglomeration*, p. 136.
[40] Duranton and Puga, 'Nursery cities', Lemma 4.

diversification are larger than the benefits, and above which the benefits begin to exceed the costs. At the turn of the 20th century, this threshold was only crossed in a subset of large cities in the United States. These might include 'nursery cities' in the sense of Duranton and Puga which were relatively attractive to modern industries (Table 3).[41]

These results have implications for the well-known analysis of American economic growth of Lucas which emphasized the importance of Jacobian externalities as an engine of growth.[42] To some extent, our findings provide support for this hypothesis during the period of the second industrial revolution. The key point that stands out is that dynamic externalities from diversity were not generated by urbanization generally but accrued in the really large cities of the United States. If Lucas's vision is correct, the basis for it would be the economic activity of Chicago, New York and Philadelphia rather than Akron, Ohio or Hartford, Connecticut. In any case, our evidence gives much stronger support to the importance of dynamic Marshallian externalities based on specialization as a contribution of cities to American economic growth. This is probably to be expected given the literature on agglomeration externalities.

Table 7 reports estimates of the impact of dynamic Marshallian externalities for labour productivity growth in American cities obtained by multiplying the value of *SPEC* at the start of each decade by its estimated coefficient in the OLS equation for 1890-1920 reported in Table 4.[43] The result is these externalities are estimated to have generated labour productivity growth at an average annual rate of 0.131 per cent per year during 1890-1920 which raised the level of labour productivity in this sample of cities by 3.93 per cent in 1920 compared with 1890.[44] Most of these productivity gains (about 80 per cent) would have been accrued with the degree of specialization existing already in 1890 but the remaining 20 per cent or so resulted from increased specialization during the period, as the counterfactual calculations in Table 7 reveal.

[41] Ibid.
[42] Lucas, 'On the Mechanics'.
[43] We disregard the contribution of diversity externalities which net out to approximately zero.
[44] If instead the calculations are based on the 2SLS estimates using Table 5, then the impacts are larger since the coefficient on *SPEC* is 0.046 compared with 0.031 in Table 4.

These results are a new finding but, even so, the productivity gains are quite small relative to the aggregate American economy. Total manufacturing output in our sample of cities was $16.272 billion in 1920 while U.S. GDP in that year was $91.5 billion. In the absence of the productivity boost from estimated dynamic agglomeration externalities during 1890-1920, manufacturing output in these cities would have been lower by $16.272 x .0393 = $0.639 billion which equates to 0.72 per cent of GDP which was $89.246 billion in 1920. If specialization had remained at the 1890 level, the reduction in manufacturing output would have been $16.272 x 0.0318 = $0.517 billion, i.e., lower by $0.122 billion = 0.14 per cent of GDP.

We find that specialization in cities facilitated labour productivity growth in manufacturing in the period 1890-1920. What underpinned this specialization? This is an important topic for future quantitative research but the traditional history literature provides a strong hypothesis. Pred stressed the role of falling railroad rates which he argued increased the practicability of serving national demands from a limited number of cities. [45] Likewise Chandler memorably saw the late 19th century as the point at which integration of the domestic market underpinned the beginnings of mass production together with mass distribution.[46]

## VII

Our analysis of productivity growth in early 20th-century U.S. cities has produced some interesting new results on the role of agglomeration externalities in raising labour productivity in manufacturing. We find that, on average, more specialized cities enjoyed higher labour productivity growth in manufacturing. This suggests that dynamic Marshallian externalities were an aspect of urbanization during the second industrial revolution. The impact of specialization within cities on labour productivity was both economically and statistically significant. We estimate that its impact over the 30 years from 1890 raised labour productivity in our sample of cities by about 4 per cent in 1920. An important task for future research will be to explore the sources of these agglomeration economies.

---

[45] Pred, *Spatial dynamics*.
[46] Chandler, *Visible hand*.

In contrast, the evidence for dynamic Jacobian externalities is less robust. It seems likely that dynamic Jacobian externalities were only realized in large cities such as Chicago, Philadelphia, and New York and played at most only a minor part in raising productivity. In smaller cities, increased diversity tended to reduce productivity growth. The nonlinearity of dynamic Jacobian externalities has not been found in the literature before, which offers an opportunity to investigate its causes in future research.

Our results are in contrast with the experience of the British cities, as shown in Hanlon and Miscio.[47] The differences could be driven by the fact that we investigate labour productivity growth whilst they focus on growth of city employment. However, given that their analysis includes only large cities, the finding that Jacobian externalities drive city-employment growth resonates with our finding that labour productivity is positively related to Jacobian externalities for the largest cities. There is certainly scope for the future research comparing the sources of agglomeration economies between the United States and Great Britain.

[47] Hanlon and Miscio, 'Agglomeration'.

## References

Bakker, G., Crafts, N., and Woltjer, P., ‘A vision of the growth process in a technologically progressive economy: the United States, 1899-1941’, *Economic Journal*, forthcoming.

Bartik, T., *Who benefits from state and local economic development policies?* (Kalmazoo, 1991).

Baum-Snow, N., and Ferreira, F. (2015), ‘Causal inference in urban and regional economics’, in G. Duranton, J.V. Henderson, and W.C. Strange, eds., *Handbook of regional and urban economics*, Volume 5 (Amsterdam, 2015), pp. 3-68.

Bostic, R. W., Gans, J. S., and Stern, S., ‘Urban productivity and factor growth in the late nineteenth century’, *Journal of Urban Economics*, 41 (1997), pp. 38-55.

Cain, L. P. and Paterson, D. G., ‘Factor biases and technical change in manufacturing: the American system, 1850-1919’, *Journal of Economic History*, 49 (1981), pp. 341-60.

Cameron, A. C., Gelbach, J. B., and Miller, D. L., ‘Robust inference with multi-way clustering’, *Journal of Business and Economic Statistics*, 29 (2011), pp. 238-49.

Chandler, A. D., *The visible hand* (Cambridge, Mass., 1977).

Cingano, F. and Schivardi, F. (2004), ‘Identifying the sources of local productivity growth’, *Journal of the European Economic Association*, 2 (2004), pp. 720-42.

Combes, P-P., ‘Economic structure and local growth: France, 1981-1993’, *Journal of Urban Economics*, 47 (2000), pp. 329-55.

Combes, P-P. and Gobillon, L., ‘The empirics of agglomeration economies’, in G. Duranton, J. V. Henderson, and W. Strange, eds., *Handbook of regional and urban economics*, Volume 5 (Amsterdam, 2015), pp. 247-348.

Combes, P-P., Mayer, T., and Thisse, J-F., *Economic geography: the integration of regions and nations* (Princeton, 2008).

David, P. A., ‘Computer and dynamo: the modern productivity paradox in a not-too-distant mirror’, in OECD, *Technology and productivity: the challenge for economic policy* (Paris, 1991), pp. 315-47.

Duranton, G. and Puga, D., ‘Nursery cities: urban diversity, process innovation, and the life cycle of products’, *American Economic Review*, 91 (2001), pp. 1454-77.

Duranton, G. and Puga, D., ‘Micro-foundations of urban agglomeration economies’, in J. V. Henderson and J-F. Thisse, eds., *Handbook of regional and urban economics*, Volume 4 (Amsterdam, 2004), pp. 2063-2117.

Durbin, J., ‘Errors in variables’, *International Statistical Review*, 22 (1954), pp. 23–32.

French, M. J., *The US tire industry: a history* (Boston, 1991).

Fujita, M. and Thisse, J-F., *Economics of agglomeration: cities, industrial location and globalization* (Cambridge, 2013).

Glaeser, E. L., Kallal, H. D., Scheinkman, J. A., and Shleifer, A., ‘Growth in cities’, *Journal of Political Economy*, 100 (1992), pp. 1126-52.

Glaeser, E. L., *Cities, agglomeration, and spatial equilibrium* (Oxford, 2008).

Greenstone, M., Hornbeck, R., and Moretti, E., ‘Identifying agglomeration spillovers: evidence from winners and losers of large plant openings’, *Journal of Political Economy*, 118 (2010), pp. 536-98.

Hanlon, W. W. and Miscio, A., ‘Agglomeration: a long-run panel data approach’, *Journal of Urban Economics*, 99 (2017), pp. 1-14.

Henderson, J. V., Kuncor, A., and Turner, M., 'Industrial development in cities', *Journal of Political Economy*, 103 (1995), pp. 1067-90.

Henderson, J. V., 'Externalities and industrial development', *Journal of Urban Economics*, 42 (1997), pp. 449-70.

Henderson, J. V. (2003), 'Marshall's scale economies", *Journal of Urban Economics*, 53 (2003), pp. 1-28.

Jacobs, J., *The economy of cities* (New York, 1969).

Kim, S., 'Urban development in the United States, 1690-1990', *Southern Economic Journal*, 66 (2000), pp. 855-80.

Kim, S., 'Division of labor and the rise of cities: evidence from U.S. industrialization, 1850-1880', *Journal of Economic Geography*, 6 (2006), pp. 469-91.

Kim, S. and Margo, R. A., 'Historical perspectives on U. S. economic geography', in J. V. Henderson and J-F. Thisse, eds., *Handbook of regional and urban economics*, Volume 4 (Amsterdam, 2004), pp. 2981-3019.

Klein, A. and Crafts, N., 'Making sense of the manufacturing belt: determinants of U.S. industrial location, 1880-1920', *Journal of Economic Geography*, 12 (2012), pp. 775-807.

Klepper, S.,'The origin and growth of industry clusters: the making of Silicon Valley and Detroit', *Journal of Urban Economics*, 67 (2010), pp. 15-32.

Lucas, R. E., 'On the mechanics of economic development', *Journal of Monetary Economics*, 22 (1988), pp. 3-42.

Marshall, A., *Principles of Economics* (1890).

Pred, A. R., *The spatial dynamics of U. S. urban-industrial growth, 1800-1914* (Cambridge, Mass., 1966).

Rosenthal, S. S. and Strange,W. C., 'Evidence on the nature and sources of agglomeration economies', in J. V. Henderson and J-V. Thisse ,eds.,, *Handbook of regional and urban economics*, Volume 4 (Amsterdam, 2004), pp. 2119-71.

Sanderson, E. and Windmeijer, F., "A weak instrument F-test in linear IV models with multiple endogenous variables", *Journal of Econometrics,* 190 (2016), pp. 212-21.

Simon, C. J. and Nardinelli, C., 'Human capital and the rise of American cities, 1900-1990', *Regional Science and Urban Economics*, 32 (2002), pp. 59-96.

**U.S. Government Publications**

**1880:**

Report on the Manufactures of the United States at the Tenth Census, General Statistics. Department of the Interior, Census Office. Washington, Government Printing Office 1883.

Table VI: Manufactures of 100 Principal Cities by Specified Industries, pp. 381-455

**1890:**

Report on Manufacturing Industries in the United States at the Eleventh Census: 1890. Part II. Statistics of Cities. Department of the Interior, Census Office. Washington, D.C.: Government Printing Office. 1895.

Table 3: Manufactures in 165 Principal Cities by Specified Industries, pp. 21-611.

**1900:**

Twelfth Census of the United States, Taken in the Year 1900. Manufactures. Part II. States and Territories. (Volume VIII). United States Census Office. Washington, 1902.

Statistics of cities by specified industries are not reported in a separate section of the Census of Manufactures as in 1880, and 1890. Each US state has its own chapter with various statistics, including statistics of cities by specified industries. This makes providing detailed references to page numbers and table numbers for each city cumbersome. Therefore, we provide only a reference to the statistics of US states where the reader can find statistics of US cities used in this paper, usually in Table 8.

**1920:**

Fourteenth Census of the United States. Manufactures 1919. Reports for States, with Statistics for Principal Cities. (Volume IX). Department of Commerce, Bureau of Census. Washington, Government Printing Office, 1923.

As in 1900, statistics of cities by specified industries are not reported in a separate section of the Census of Manufactures but together with the statistics of US states. Therefore, again, we provide only a reference to the statistics of US states where the reader can find statistics of US cities used in this paper.

**1930:**

Fifteenth Census of the United States. Manufactures: 1929. Volume III. Reports by States. Statistics for Industrial Areas, Counties, and Cities. Department of Commerce, Bureau of Census. Washington, Government Printing Office, 1933.

As in 1900, and 1920, statistics of cities by specified industries are not reported in a separate section of the Census of Manufactures but together with the statistics of US states. Therefore, again, we provide only a reference to the statistics of US states where the reader can find statistics of US cities used in this paper.

**Appendix I**

We use a simple model of city-industry growth which incorporates local spillovers within and across industries to motivate the empirical framework discussed toward the end of this section. Specifically, we put the framework of dynamic agglomeration spillovers introduced by Glaeser et al. into the simple model of Combes et al. which we have chosen because it matches our data best as it operates with value-added per worker.[48] We consider an industry of sector *s*, in a city *c*, at time *t* with a Cobb-Douglas production function

$$y_{cst} = A_{cst} l_{cst}^{\mu} k_{cst}^{1-\mu} \qquad \text{(A1)}$$

where $A_{cst}$ is the Hicks-neutral factor-augmenting technology level, $l_{cst}$ is labor and $k_{cst}$ is the quantity of other inputs. The profit is given by

$$\Pi_{cst} = \sum_{c} p_{cst} y_{cst} - w_{st} l_{cst} - r_{st} k_{cst} \qquad (A2)$$

where $y_{cst}$ is the quantity exported to city c, $p_{cst}$ is the supply price in city *c* net of marginal costs of the intermediate inputs, $w_{st}$ is the wage rate and $r_{st}$ is the price of intermediate inputs other than labor. The profit function can be rewritten as

$$\Pi_{cst} = p_{st} y_{st} - w_{st} l_{cst} - r_{st} k_{cst} \qquad (A3)$$

where

$$p_{st} = \sum_{c} p_{cst} \frac{y_{cst}}{y_{st}} \qquad \text{(A4)}$$

[48] Glaeser, Kallal, Scheinkman, and Shleifer, 'Growth'; Combes, Mayer, and Thisse, *Economic geography*.

is the average unit value of the produced goods net of the cost of intermediate inputs. As a result, $p_{st}\, y_{st}$ is sector's *s* value added. The standard first order conditions plugged into the equation A1 yield the average labour productivity defined as value-added per worker

$$\frac{p_{st}y_{st}}{l_{cst}} = (1-\mu)^{(1-\mu/\mu)}\left(\frac{p_{st}^{1-\mu}\, A_{cst}}{r_{st}^{1-\mu}}\right)^{1/\mu} \qquad (A5).$$

Following the dynamic externalities framework of Glaeser et al., the growth rate of technology is given by

$$ln\left(\frac{A_{cst+m}}{A_{cst}}\right) \equiv E_{cst} \qquad \text{(A6)}$$

where $E_{cst}$ is the amount of localized spillovers in industry *s* in a city *c*. Theory does not offer us any concrete functional form linking the growth rate of technology with agglomeration externalities, hence, at this stage, we postulate that $E_{cst}$ is a linear function of Marshallian (Marshall-Arrow-Romer) externalities $MAR_{cst}$ and Jacobian externalities $JACOBS_{cst}$. We can use equation A6 to derive the growth rate of city-industry value-added per worker as a function of the growth of technology. Specifically, we transform equation A5 in logs, express it for period *t+m*, plug both log-equations for *t* and *t+m* into equation A6 to obtain

$$ln\frac{y_{cst+m}}{y_{cst}} = \frac{1}{\mu}E_{cst} + \left(\frac{1-\mu}{\mu}\right)\left[\left(ln\frac{p_{st+m}}{p_{st}}\right) - \left(ln\frac{r_{st+m}}{r_{st}}\right)\right] \qquad \text{(A7)}$$

where, for the sake of clarity in equation (A7), we abbreviate value-added per worker as *y*. This equation expresses the growth rate of value-added per worker in terms of (i) localized externalities which depends of MAR and Jacobian externalities, and (ii) the difference between the output prices and the prices of inputs. It motivates the regression equation.

**Appendix II**

Here we report the results of three further robustness tests relating to the estimation of equation (3).

a) *Outliers*

We checked whether our results were driven by sectors which had an unusually strong impact of initial specialization on subsequent productivity growth. This entailed excluding sectors SIC22 (textiles) and SIC23 (apparel). OLS estimation results are reported in Table A1. If these are compared with our baseline estimates in Table 4, it is clear that they are very similar both in terms of statistical significance and size of the coefficients of interest.

b) *Balanced Sample*

As we discussed in section IV, the number of cities changes across periods under consideration. Even though the cities which enter our sample in 1890 and 1900 are not very different from the cities already in the sample, and the results are robust across all six periods, their inclusion might raise an issue of the comparability of the results between 1880, 1890, and 1900. Therefore, Table A2 presents the estimation results when we keep the number of cities constant over time. The first four columns show the results for the periods starting in 1890 and 1900 and only for the cities of the 1880 Census of Manufactures; the last two columns for the periods starting in 1900 and only for the cities of the 1890 Census of Manufactures. We see that the results are consistent with those in Table 4, and the only difference is for the period 1890-1920 in which $DIV^2$ loses conventional statistical significance, although the joint significance of the linear and quadratic terms is highly statistically significant.

c) *Twin Cities*

It might be argued that some of the observations in our sample should be twinned because today we might regard them as subsets of the same place. At the end of the 19th century when commuting was much less prevalent, this was probably less of an issue. For example, nowadays Oakland and San Francisco could possibly be thought of as a twin city following the opening of the Bay Bridge in 1936 and BART in 1972 but perhaps not with the transport of 1890. Nevertheless, we have re-estimated equation (3) with twin cities wherever this might be appropriate in the early 21st century. So Boston is combined with Cambridge, Dayton with Springfield, Minneapolis with Saint Paul, New York City with Hoboken and Newark, Oakland with San Francisco, and Philadelphia with Camden. The results are shown in Table A3.

Here there is an obvious difference from our baseline results in Table 4. While *SPEC* is still significant and has similar estimated coefficients, *DIV* and $DIV^2$ generally lose significance and $DIV^2$ has a negative coefficient in some cases. So while dynamic Marshallian externalities pass this test, dynamic Jacobian externalities do not. The proximate reason for this is that the combined cities generally have much lower diversity scores than each of their component parts measured separately; for example, in 1890 New York City-Hoboken-Newark has a *DIV* score of 0.7335 whereas New York City and Newark have *DIV* score of 3.0013 and 2.9994, respectively. In fact, 5 of the 12 observations with a *DIV* score high enough to imply a positive impact on labour productivity growth for 1890-1920 in Table 4 are removed from the sample. This could mean that, rather than inferring a complete absence of Jacobian externalities, we should regard the revised sample as not providing enough variance to allow them to be observed.

Taking all three additional robustness tests together, it seems that there is strong evidence for dynamic Marshallian externalities. Clearly, however, the evidence in favour of dynamic Jacobian externalities is much less robust.

**Table 1: Number of Cities by US Regions as Reported in the US Census of Manufactures 1880-1930.**

| Region/Number of Cities | 1880 | 1890 | 1900 | 1920 | 1930 |
|---|---|---|---|---|---|
| East North Central | 18 | 33 | 44 | 26 | 8 |
| East South Central | 6 | 11 | 11 | 8 | 1 |
| Middle Atlantic | 26 | 40 | 53 | 35 | 15 |
| Mountain | 2 | 3 | 4 | 1 | 1 |
| New England | 21 | 32 | 40 | 22 | 10 |
| Pacific | 3 | 7 | 9 | 11 | 8 |
| South Atlantic | 10 | 12 | 16 | 14 | 3 |
| West North Central | 8 | 18 | 23 | 14 | 6 |
| West South Central | 3 | 7 | 9 | 9 | 7 |
| DC | 1 | 1 | 0 | 0 | 0 |
| *US* | *98* | *164* | *209* | *140* | *59* |

*Sources*: US Census of Manufactures 1880, 1890, 1900, 1920, 1930

**Table 2: Number of Matched Cities 1880-1930.**

| Number of Cities/Time Period | 1880-1920 | 1880-1930 | 1890-1920 | 1890-1930 | 1900-1920 | 1900-1930 |
|---|---|---|---|---|---|---|
| Matched cities | 81 | 41 | 118 | 53 | 127 | 54 |
| Cities entering sample in 1890 and 1900 | | | 37 | 12 | 9 | 1 |
| Cities exiting the sample in 1930 | | 40 | | 65 | | 73 |

*Sources*: US Census of Manufactures 1880, 1890, 1900, 1920, 1930

**Table 3: Top five and bottom five industries by specialization and variety index.**

| 1880 | 1900 | 1930 |
|---|---|---|
| | **Panel A:** | |
| | *SIC 3 industries with the highest specialization index* | |
| Miscellaneous Manufacturers | Miscellaneous Manufacturers | Miscellaneous Manufacturers |
| Broadwoven Fabric Mills, Cotton | Broadwoven Fabric Mills, Cotton | Petroleum Refining |
| Iron & Steel Foundries | Petroleum Refining | Motor Vehicles & Equipment |
| Broadwoven Fabric Mills, Wool | Broadwoven Fabric Mills, Wool | Iron & Steel Foundries |
| Chewing & Smoking Tobacco | Iron & Steel Foundries | Blast Furnace & Basic Steel Products |
| | *SIC 3 industries with the lowest specialization index* | |
| Greeting Cards | Handbags & Personal Leather Goods | Miscellaneous Primary Metal Industries |
| Industrial Machinery, nec | Secondary Nonferrous Metals | Industrial Machinery, nec |
| Nonferrous Foundries (Castings) | Industrial Organic Chemicals | Refrigeration & Service Industry |
| Photographic Equipment & Supplies | General Industry Machinery | Watches, Clocks, Watchcases & Parts |
| Plastics Materials & Synthetics | Household Audio & Video Equipment | Miscellaneous Transportation Equipment |
| | **Panel B:** | |
| | *SIC 3 industries with the highest variety index* | |
| Plastics Materials & Synthetics | Handbags & Personal Leather Goods | Industrial Machinery, nec |
| Fabricated Rubber Products, nec | Office Furniture | Miscellaneous Primary Metal Industries |
| Toys & Sporting Goods | Photographic Equipment & Supplies | Miscellaneous Textile Goods |
| Leather Gloves & Mittens | Household Appliances | Knitting Mills |
| Special Industry Machinery | Nonferrous Foundries (Castings) | Carpets & Rugs |
| | *SIC 3 industries with the lowest variety index* | |
| Metal Forgings & Stampings | Leather Goods, nec | Aircraft & Parts |
| Broadwoven Fabric Mills, Wool | Newspapers | Special Industry Machinery |
| Iron & Steel Foundries | Metal Forgings & Stampings | Books |
| Paper Mills | Bakery Products | Bakery Products |
| Tobacco Stemming & Redrying | Men's & Boys' Furnishings | Iron & Steel Foundries |

*Sources*: US Census of Manufactures 1880, 1900, 1930.

*Note*: Specialization and variety indices are calculated as the average across all cities in the data set.

**Table 4: Agglomeration and Productivity Growth: OLS Regression.**

| | 1890-1920 | 1900-1930 | 1890-1920 | 1900-1930 |
|---|---|---|---|---|
| | **Panel A** | | **Panel B** | |
| *DIV* | -0.00798*** | -0.00499 | -0.02331*** | -0.03045*** |
| | [0.002] | [0.005] | [0.007] | [0.009] |
| $DIV^2$ | | | 0.00453** | 0.00689** |
| | | | [0.002] | [0.003] |
| *SPEC* | 0.02626*** | 0.02723*** | 0.03088*** | 0.02967*** |
| | [0.007] | [0.007] | [0.008] | [0.008] |
| Initial Value-Added per Worker | -0.00001*** | -0.00000** | -0.00001*** | -0.00000** |
| | [0.000] | [0.000] | [0.000] | [0.000] |
| Initial State Manuf Empl (% from US) | 0.00001 | 0.00003 | 0 | 0.00001 |
| | [0.000] | [0.000] | [0.000] | [0.000] |
| Constant | 0.01528*** | 0.02197*** | 0.02685*** | 0.04297*** |
| | [0.006] | [0.007] | [0.008] | [0.008] |
| *Joint significance* | | | | |
| $DIV$ & $DIV^2 \neq 0$ | | | 23.54*** | 10.77*** |
| City Dummies | YES | YES | YES | YES |
| Industry Dummies | YES | YES | YES | YES |
| $R^2$ | 0.525 | 0.508 | 0.526 | 0.51 |
| N | 1,954 | 1,157 | 1954 | 1,157 |

Sources: US Census of Manufactures 1890, 1900, 1920, 1930.

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%
standard errors are clustered at city and industry level

**Table 5: Agglomeration and Productivity Growth: OLS Regression with Nonlinearities by City Size.**

| | 1890-1920 | 1900-1930 | 1890-1920 | 1900-1930 |
|---|---|---|---|---|
| | *City Size Below Median* | | *City Size Above Median* | |
| *DIV* | -0.03*** | -0.00078 | -0.024*** | -0.026*** |
| | [0.01] | [0.055] | [0.008] | [0.008] |
| *$DIV^2$* | 0.0066*** | 0.0057 | 0.004* | 0.006** |
| | [0.002] | [0.014] | [0.0025] | [0.003] |
| *SPEC* | 0.04*** | 0.0018 | 0.03*** | 0.017*** |
| | [0.01] | [0.011] | [0.01] | [0.006] |
| Initial Value-Added per Worker | -0.000007*** | -0.000002*** | -0.00001*** | -0.00001*** |
| | [0.000002] | [0.0000004] | [0.000001] | [0.000001] |
| Initial State Manuf Empl (% from US) | 0.000002 | 0.002 | 0.000004 | 0.00001 |
| | [0.00015] | [0.003] | [0.00009] | [0.00008] |
| Constant | 0.023** | 0.00039 | 0.05*** | 0.06*** |
| | [0.008] | [0.055] | [0.008] | [0.007] |
| *Joint significance* | | | | |
| *DIV* & *$DIV^2$* $\neq 0$ | 10.96*** | 1.94 | 18.52*** | 10.18*** |
| City Dummies | YES | YES | YES | YES |
| Industry Dummies | YES | YES | YES | YES |
| $R^2$ | 0.64 | 0.74 | 0.51 | 0.64 |
| N | 428 | 97 | 1526 | 1060 |

Sources: US Census of Manufactures 1880, 1890, 1900, 1920, 1930.

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%

standard errors are clustered at city and industry level

**Table 6: Agglomeration and Productivity Growth: 2SLS Instrumental Variable Regressions.**

| | 1890-1920 | 1900-1930 |
|---|---|---|
| *DIV* | -0.04106** | -0.01747* |
| | [0.018] | [0.010] |
| $DIV^2$ | 0.0071^ | 0.00517** |
| | [0.005] | [0.003] |
| *SPEC* | 0.04601*** | 0.01679** |
| | [0.011] | [0.008] |
| Beginning of Period Value-Added per Worker | -0.00001*** | -0.00001*** |
| | [0.000] | [0.000] |
| Beginning of Period State Manuf Empl (% from US) | -0.00002 | 0.00002 |
| | [0.000] | [0.000] |
| City Dummies | YES | YES |
| Industry Dummies | YES | YES |
| *Weak Instrument Tests* | | |
| *DIV (F-stat from first-stage)* | 43.07 | 33.29 |
| $DIV^2$ *(F-stat from first-stage)* | 67.23 | 30.04 |
| *SPEC (F-stat from first-stage)* | 22.2 | 300.64 |
| *Anderson-Rubin chi-square test* | 26.25 | 9.528 |
| *Anderson-Rubin chi-square test p-values* | 8.45E-06 | 0.023 |
| *Endogeneity Test* | | |
| *Endogeneity test chi-square* | 2.104 | 3.097 |
| *Endogeneity test chi-square t-test* | 0.551 | 0.3768 |
| $R^2$ | 0.295 | 0.387 |
| N | 1,190 | 1,003 |

Sources: US Census of Manufactures 1880, 1890, 1900, 1920, 1930

Note: ^ significant at 12%; * significant at 10%; ** significant at 5%; *** significant at 1%

Standard errors are clustered at city and industry level; in 1880-1920 and 1880-1930, 2SLS is based on Bartik instruments.

Weak IV test as in Sanderson and Windmeijer, 'Weak Instrument F-test.'

**Table 7: Economic Significance of Specialization, US Cities 1890-1920.**

| | | 1890-1900 | 1900-1910 | 1910-1920 |
|---|---|---|---|---|
| 1 | Beginning of Period Average Specialization (%) | 3.42 | 3.44 | 5.83 |
| 2 | Predicted Average Annual Growth Rate (%) (row 1* OLS estimates 0.031) | 0.106 | 0.107 | 0.181 |
| 3 | Predicted Decadal Cumulative Growth Rate (%) (row 2 * 10) | 1.060 | 1.066 | 1.807 |
| 4 | Predicted Cumulative Growth Rate 1890-1920 (sum row 3) | 3.934 | | |
| 5 | Average Labour Productivity Growth 1890-1920 (% per year) (row 4/30) | 0.131 | | |
| | *Counterfactual: Specialization Remains as in 1890* | | | |
| 6 | Average Specialization in 1890 (%) | 3.420 | 3.420 | 3.420 |
| 7 | Predicted Average Annual Growth Rate (%) (row 6* OLS estimates 0.031) | 0.106 | 0.106 | 0.106 |
| 8 | Predicted Decadal Cumulative Growth Rate (%) (row 7 * 10) | 1.060 | 1.060 | 1.060 |
| 9 | Predicted Cumulative Growth Rate 1890-1920 (sum row 8) | 3.181 | | |
| 10 | Counterfactual Average Labour Productivity Growth 1890-1920 (% per year) (row 9/30) | 0.106 | | |

Sources: US Census of Manufacturers 1890, 1920. Estimated coefficients of OLS from Table 4, Panel B.

**Table A1: Agglomeration and Productivity Growth: OLS Regression with Nonlinearities. Excluding Textiles, and Apparel.**

| | 1880-1920 | 1880-1930 | 1890-1920 | 1890-1930 | 1900-1920 | 1900-1930 |
|---|---|---|---|---|---|---|
| *DIV* | -0.008 | 0.007 | -0.018*** | -0.0003 | -0.024*** | -0.02** |
| | [0.0078] | [0.01] | [0.004] | [0.0059] | [0.006] | [0.01] |
| $DIV^2$ | 0.0013 | -0.002 | 0.0026** | 0.0006 | 0.0005 | 0.005* |
| | [0.0024] | [0.003] | [0.001] | [0.0017] | [0.002] | [0.003] |
| *SPEC* | 0.018*** | 0.007 | 0.029*** | 0.005 | 0.054*** | 0.02*** |
| | [0.005] | [0.005] | [0.007] | [0.008] | [0.013] | [0.007] |
| Initial Value-Added per Worker | -0.00002*** | -0.000012*** | -0.000008*** | -0.000007*** | -0.000008* | -0.000004** |
| | [0.000002] | [0.000003] | [0.000001] | [0.000001] | [0.000004] | [0.000002] |
| Initial State Manuf Empl (% from US) | -0.00003 | -0.00012* | 0.00002 | -0.00001 | -0.000014 | 0.00004 |
| | [0.0001] | [0.00007] | [0.00009] | [0.00006] | [0.00017] | [0.00008] |
| Constant | 0.038*** | 0.03*** | 0.023*** | 0.016*** | 0.039*** | 0.038*** |
| | [0.006] | [0.009] | [0.0055779] | [0.005] | [0.008] | [0.008] |
| *Joint significance* | | | | | | |
| $DIV$ & $DIV^2 \neq 0$ | 6.76** | 0.65 | 21.45*** | 0.44 | 21.82*** | 6.82** |
| $DIV$ & $DIV^2$ & $SPEC \neq 0$ | 13.48*** | 5.91^ | 21.71*** | 3.6 | 22.22*** | 15.37*** |
| City Dummies | YES | YES | YES | YES | YES | YES |
| Industry Dummies | YES | YES | YES | YES | YES | YES |
| $R^2$ | 0.60 | 0.63 | 0.52 | 0.69 | 0.43 | 0.50 |
| N | 1134 | 653 | 1763 | 933 | 1976 | 1035 |

Sources: US Census of Manufactures 1880, 1890, 1900, 1920, 1930.

Notes: ^ significant at 11%, * significant at 10%; ** significant at 5%; *** significant at 1%

standard errors are clustered at city and industry level

**Table A2: Agglomeration and Productivity Growth: OLS Regressions, Balanced Samples of Cities**

| | 1890-1920 | 1890-1930 | 1900-1920 | 1900-1930 | 1900-1920 | 1900-1930 |
|---|---|---|---|---|---|---|
| | Sample of Cities in 1880 | | Sample of Cities in 1880 | | Sample of Cities in 1890 | |
| | *Basic specification* | | | | | |
| *DIV* | -0.00943*** | 0.00255 | -0.01575*** | -0.00302 | -0.01505*** | -0.00193 |
| | [0.002] | [0.004] | [0.005] | [0.004] | [0.005] | [0.004] |
| *SPEC* | 0.03406*** | 0.01756** | 0.04331*** | 0.01966*** | 0.03842*** | 0.01372** |
| | [0.008] | [0.009] | [0.013] | [0.006] | [0.011] | [0.006] |
| Value-added/Worker | -0.00001*** | -0.00001*** | -0.00002*** | -0.00001*** | -0.00002*** | -0.00001*** |
| | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] |
| State Manf. Empt. (% US) | 0 | -0.00003 | -0.00003 | 0.00001 | -0.00004 | 0.00003 |
| | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] |
| Constant | 0.02552*** | 0.02003*** | 0.05971*** | 0.04893*** | 0.05131*** | 0.03944*** |
| | [0.004] | [0.005] | [0.007] | [0.008] | [0.006] | [0.005] |
| *Joint significance* *DIV* & *SPEC* $\neq 0$ | 24.89*** | 5.63* | 11.97** | 9.57** | 12.12*** | 6.45** |
| City Dummies | YES | YES | YES | YES | YES | YES |
| Industry Dummies | YES | YES | YES | YES | YES | YES |
| $R^2$ | 0.528 | 0.663 | 0.56 | 0.642 | 0.553 | 0.634 |
| N | 1,581 | 876 | 1,693 | 935 | 2,138 | 1,148 |
| | *Nonlinearities* | | | | | |
| *DIV* | -0.02282*** | -0.00263 | -0.01462* | -0.02660** | -0.01977*** | -0.02642*** |
| | [0.009] | [0.010] | [0.008] | [0.013] | [0.007] | [0.008] |
| $DIV^2$ | 0.00394 | 0.0014 | -0.00034 | 0.00616** | 0.00144 | 0.00663*** |
| | [0.003] | [0.003] | [0.002] | [0.003] | [0.002] | [0.002] |
| *SPEC* | 0.03651*** | 0.01756** | 0.04319*** | 0.01823*** | 0.03946*** | 0.01617** |
| | [0.008] | [0.009] | [0.013] | [0.006] | [0.011] | [0.006] |

| | | | | | | |
|---|---|---|---|---|---|---|
| Value-added/Worker | -0.00001*** | -0.00001*** | -0.00002*** | -0.00001*** | -0.00002*** | -0.00001*** |
| | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] |
| State Manf. Empt. (% US) | | | -0.00003 | 0.00001 | -0.00004 | 0.00002 |
| | | | [0.000] | [0.000] | [0.000] | [0.000] |
| Constant | 0.03574*** | 0.02374*** | 0.05878*** | 0.07085*** | 0.05486*** | 0.05964*** |
| | [0.008] | [0.007] | [0.009] | [0.015] | [0.007] | [0.007] |
| *Joint significance* | | | | | | |
| *DIV* & $DIV^2 \neq 0$ | 33.25*** | 0.73 | 11.75*** | 4.21^ | 10.89** | 9.85* |
| *DIV*, $DIV^2$ & $SPEC \neq 0$ | | 6.27* | | | | |
| City Dummies | YES | YES | YES | YES | YES | YES |
| Industry Dummies | YES | YES | YES | YES | YES | YES |
| $R^2$ | 0.529 | 0.663 | 0.56 | 0.643 | 0.553 | 0.635 |
| N | 1,581 | 876 | 1,693 | 935 | 2,138 | 1,148 |

*Sources*: US Census of Manufactures 1890, 1900, 1920, 1930.

*Notes*: ^ significant at 12%, * significant at 10%; ** significant at 5%; *** significant at 1%

standard errors are clustered at city and industry level

**Table A3: Agglomeration and Productivity Growth: OLS Regression with Nonlinearities. Twin Cities.**

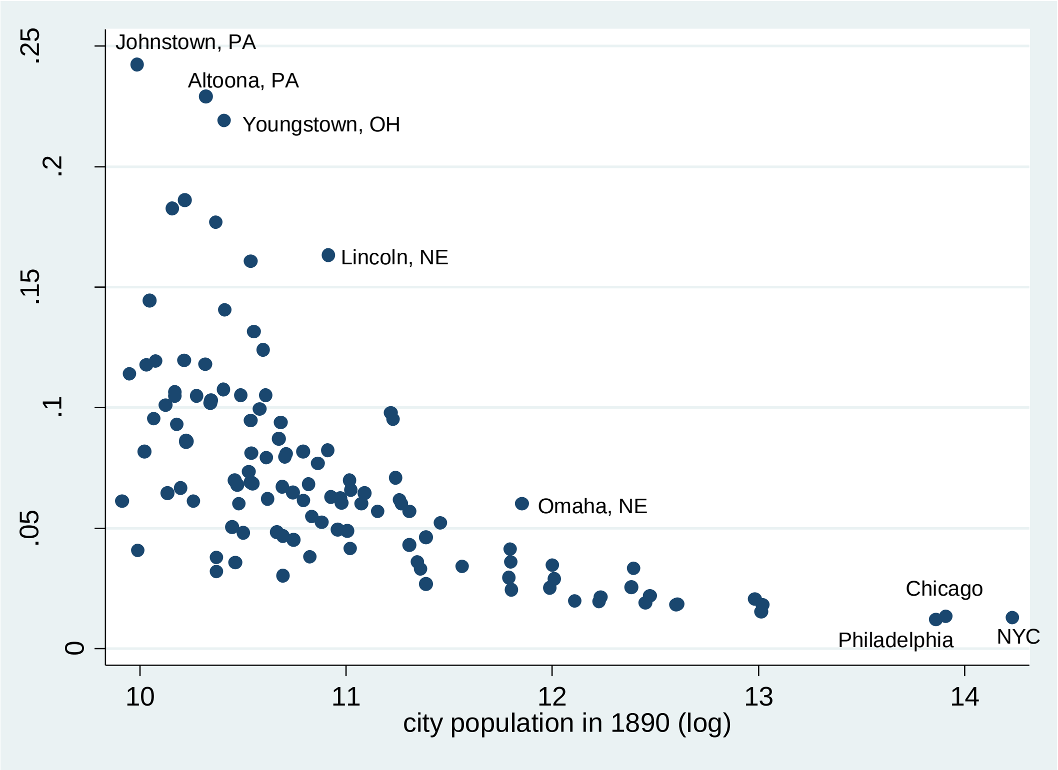
| | 1880-1920 | 1880-1930 | 1890-1920 | 1890-1930 | 1900-1920 | 1900-1930 |
|---|---|---|---|---|---|---|
| *DIV* | 0.0004 | 0.003 | -0.0012 | 0.0006 | -0.01*** | -0.01 |
| | [0.001] | [0.007] | [0.003] | [0.006] | [0.003] | [0.009] |
| $DIV^2$ | -0.001* | -0.0013 | -0.001 | 0.0002 | -0.001*** | 0.002 |
| | [0.0005] | [0.002] | [0.001] | [0.002] | [0.0004] | [0.002] |
| *SPEC* | 0.016** | 0.01** | 0.02*** | 0.012 | 0.03** | 0.026*** |
| | [0.006] | [0.006] | [0.006] | [0.008] | [0.01] | [0.008] |
| Initial Value-Added per Worker | -0.00002*** | -0.00001*** | -0.00001*** | -0.000007*** | -0.000008* | -0.000004* |
| | [0.000002] | [0.000003] | [0.000001] | [0.000001] | [0.000004] | [0.000002] |
| Initial State Manuf Empl (% from US) | -0.000005 | -0.00006 | 0.000009 | -0.00002 | -0.00006 | 0.00001 |
| | [0.00009] | [0.00007] | [0.00008] | [0.00005] | [0.0001] | [0.00006] |
| Constant | 0.03*** | 0.03*** | 0.012 | 0.02** | 0.039** | 0.046** |
| | [0.003] | [0.008] | [0.006] | [0.007] | [0.014] | [0.015] |
| *Joint significance* | | | | | | |
| $DIV$ & $DIV^2 \neq 0$ | 5.31* | 0.69 | 3.55 | 0.18 | 10.04*** | 3.24 |
| $DIV$ & $DIV^2$ & $SPEC \neq 0$ | 6.37* | 3.31 | 12.64*** | 2.65 | 10.06** | 12.4*** |
| City Dummies | YES | YES | YES | YES | YES | YES |
| Industry Dummies | YES | YES | YES | YES | YES | YES |
| $R^2$ | 0.61 | 0.63 | 0.54 | 0.68 | 0.43 | 0.52 |
| N | 1172 | 689 | 1792 | 967 | 1989 | 1065 |

Sources: US Census of Manufactures 1880, 1890, 1900, 1920, 1930.

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%

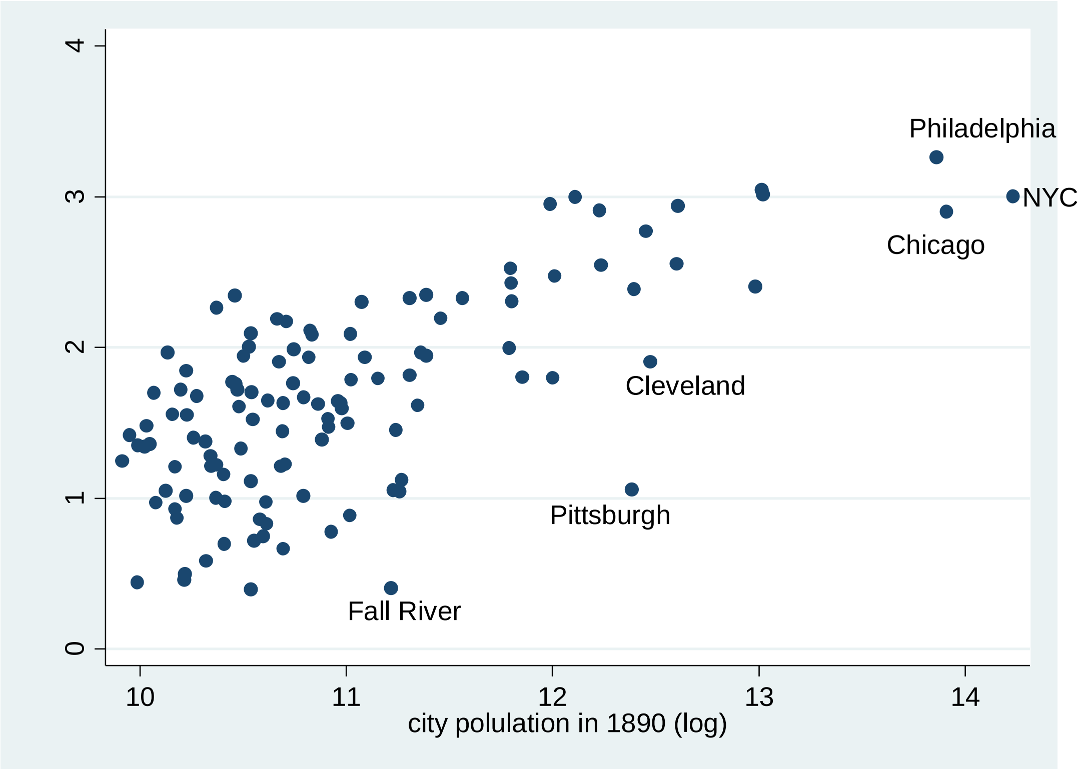
standard errors are clustered at city and industry level

**Figure 1: City Population vs Specialization in 1890.**




*Source*: derived from U. S. Census of Manufactures 1890.

**Figure 2: City Population vs Variety in 1890.**




*Source*: derived from U. S. Census of Manufactures 1890.