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Abstract

The United States witnessed substantial growth in manufacturing and urban populations during the last half of the nineteenth century. To date, no convincing evidence has been presented to explain the shift in population to urban areas. We find evidence that capital intensity, particularly new capital in the form of steam horsepower, played a significant role in drawing labor into counties and by inference into urban areas. This provides support for the hypothesis that the locational decisions of manufacturers and their placement of capital in urban areas fueled urban growth in the nineteenth century.

Keywords: urbanization, capital intensity, regional population growth, technological change

JEL codes: J61, N11, O33

1. Introduction.

The second half of the nineteenth century in the United States was noted for both rapid urbanization and rapid growth in manufacturing. Manufacturing, using the new and highly mobile steam engine, was freed from the locational constraints imposed by watermill power to locate in urban areas offering abundant inputs. The shifts of manufacturing into urban areas presumably attracted still more workers and industrial activity to the cities. In this paper we use previously untapped county-level data for total steam horsepower and total capital invested in manufacturing for a test of the hypothesis that capital and/or steam horsepower played a pivotal role in influencing population location decisions during this time period.

Our paper is not the first attempt at finding empirical support for the impact of steam horsepower on population movements. Rosenberg and Trajtenberg (2004, hereafter RT) claimed to have found such evidence at the county level by using as a proxy for steam power the number of petitioners supporting an extension of a patent for one of the largest manufacturers, The Corliss Company. However, Abrams, Li and Mulligan (2008, hereafter ALM) find no support for RT's hypothesis after correcting for deficiencies in their data set and empirical approach.[1] For example, RT's proxy for the Corliss steam engine is the number of Corliss adopters in the county who had signed a petition seeking to grant the Corliss Company an extension of its patent rights. However, as ALM emphasize, the adopters of the Corliss steam engine who signed the petition constituted only 25 percent of actual Corliss-type engine adopters. In addition, Corliss-type engines represented only 15 percent of all steam horsepower extant in 1870. Thus, the number of

[1] Kim (2005) also questioned the effect of steam power on urbanization.

Corliss petitioners is a proxy for only about 4 percent of total steam horsepower in 1870. The Corliss engines would represent an even smaller percent of total physical capital, the factor arguably more closely linked to labor productivity and more instrumental in stimulating population relocations. Thus, the Corliss variable used by RT serves as a questionable proxy for total steam power or for physical capital in general.

An additional deficiency is the way that the Corliss proxy enters the RT empirical models. The Corliss variable is constructed as the total number of petitioners per county. It seems reasonable, however, to adjust this number for scale. For example, the adoption of a Corliss engine in a county with a small initial population would be expected to have a different effect on population growth than the adoption of a Corliss engine into a highly populated county. In other words, a proxy for capital measured on a per capita basis is a more appropriate specification for measuring the effect of capital on labor productivity, the factor likely to induce population flows. ALM show that once this correction is made, the statistical significance of the Corliss proxy disappears.

In this paper we avoid RT's problems by using U.S. Census data on steam horse power at the county level from eleven Eastern states to test the effects of aggregate capital and a highly important specific type of capital, steam horsepower, on county population growth in the 1870 to 1900 period.[2] In 1870, thirty-six percent of total U.S. population and sixty-six percent of total capital in manufacturing were in these eleven states. Focusing on these eleven capital-intensive "old" Eastern states, where agriculture

[2] The eleven states are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island and Vermont.

had already been well established, allows us to avoid dealing with problems of population growth due to land abundance—a factor largely responsible for Western migration.

We used two sample sizes. The largest sample includes all 242 counties of record in 1900 in our eleven states. Population growth for 34 of these counties had to be estimated due to reconfiguration of counties between 1870 and 1900.[3] As an alternative sample, we used only the 208 counties that remained unchanged over the thirty-year period. Since the empirical results did not depend on the sample selection, we report only the findings for the full 242-county sample.

2. Descriptive Evidence.

Figure 1 presents a scatter diagram for our 242-county sample plotting county population growth between 1870 and 1900 and capital in manufacturing per capita in 1870. The relationship is positive and significant. A simple regression explaining population growth using capital per capita yields a coefficient of 0.016 and a t-statistic of 6.15. This suggests that a $1 increase in capital per person at the mean would raise annual county population growth over the 1870-1900 by 0.00016 (0.016 percent). The adjusted R-square of the relationship, however, is only 0.13.

Figure 2 presents a scatter diagram for our 242-county sample plotting our other measure of county capital, steam horsepower per capita. Again, the relationship is

[3] Both of these samples correct another data problem in the RT study. RT did not account for the reconfiguration of several counties during this time. Thirteen new counties were drawn from twenty-one old counties over the time period under investigation. Ten new counties were formed by 1860, one in the 1860s, and two in the 1870s. We also estimate 1850 populations for both the new counties and the reduced-in-size contributing counties by assuming that the growth of the new counties and the reduced-in-size counties were the same as the growth of the contributing counties.

positive and significant with a coefficient of 20.45 and a t-statistic of 8.36 for the steam horsepower per capita variable. The adjusted R-square for the relationship is 0.23.

This preliminary evidence hints that capital abundance affected county population growth. We now provide increasingly richer tests of the hypothesis by adding other explanatory variables and controlling for the possible endogeneity of capital per capita.

3. The OLS Model.

We now present an OLS model that controls for several other possible causes of population growth in the period 1870-1900. We borrow variables extensively from Rosenberg and Trajtenberg (2004), but enter variables, where appropriate, in per capita terms. In our OLS model, we again attempt to explain population growth with various measures of capital intensity at the beginning of the time period, 1870. An appendix provides descriptive statistics for all variables entering the models. We now add combinations of the following explanatory variables to the estimating equations:

Capital per capita in manufacturing in 1870:[4] Presumably the more capital per capita, other things equal, the higher labor productivity and wages. We expect a positive sign for the coefficient on this variable indicating that higher levels of capital per capita increased post-1870 county population growth.

Steam horsepower per capita in 1870: This variable serves as an alternative measure for capital intensity, but one that focuses on the new energy technology.

[4] All 1870 data are obtained from the U. S. Department of the Interior, Ninth Census.

Number of watermills per capita in 1870: This provides a measure of capital intensity for another specific type of capital, but an old capital technology that is location dependent and in decline during this time period.[5]

County taxes per capita in 1870: This variable measures the extent of government involvement and provision of services in the county in 1870. On the one hand, public provision of services can enhance the attractiveness of a county. On the other hand, tax burdens can act as a deterrent to migrate into the county. We make no prediction for the sign on the coefficient for this variable.

State tax revenues per capita: This variable controls for state-specific effects of taxation and the size of state government (1870 data). We have no prediction for the sign on the coefficient for this variable.

State dummy variables: These variables control for state-specific effects and serve as an alternative to state tax revenues per capita.

Capital per establishment in 1870: This variable controls for average manufacturing firm size in the county at the start of the period. Presumably larger-sized firms may be benefitting from economies of scale that provide greater job growth.

Prior county population growth, 1850-1870: This variable controls for growth factors not picked up by other variables.[6]

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[5] Although we use the number of watermills per capita in 1870 for comparison to RT, we also estimated the models using water horsepower per capita with essentially identical results for the coefficients of all the other variables. RT actually used the number of watermills in 1880, since they were unaware of the availability of the 1870 data. However, both the 1880 and 1870 data yield essentially the same results.

[6] We also experimented with entering population in 1850 in the estimations. It's inclusion had little effect on the estimated coefficients and significance of the other variables.

4. OLS Findings.

Table 1 provides findings for various specifications of the single-equation OLS model explaining growth between 1870 and 1900 (models 1-5) and between 1880 and 1900 (models 6-7). However, we find that capital per capita and capital invested in manufacturing per establishment are highly collinear (a simple correlation of 0.77), so we avoid simultaneously entering these two variables into the model. Before discussing the specific models, we note that our OLS findings generally support the hypothesis that capital and steam horsepower per capita induced labor flows into counties. We also find that counties that had larger-sized firms also experienced faster population growth.

Some collinearity problems, however, may remain with the data. The simple correlation between capital per capita and steam horsepower per capita is 0.39 and the simple correlation between capital per establishment and steam horsepower per capital is 0.45. Collinearity warns of inaccurate estimates and makes it difficult to separate their independent effects.

But the OLS evidence implies that capital seems to matter and that steam power, the most technologically advanced form of capital introduced in the second half of the nineteenth century, likely played a role in the growth of population in counties. Another important and consistent finding is that counties relying upon watermills as a power source experienced reduced population growth after 1870, ceteris paribus. Production and employment using the old technology, water power, appear to have been crowded out in the age of steam power.

Regarding the other variables in the models, we find that prior population growth positively affects population growth and is uniformly statistically significant; the number of watermills per capita in the county exerts a negative influence on population growth, but with marginal significance at best; state and county taxes per capita appear to play no role on population growth, *ceteris paribus*.

Specifically, Model 1 includes all variables less state dummies and capital per capita. The key variable of interest, total steam horsepower per capita, has the expected sign and is marginally significant (t = 1.64). Model 2 drops capital per establishment and steam horsepower per capita becomes statistically significant (t = 2.54). As noted earlier, come collinearity exists between steam horsepower per capita and capital per establishment. Dropping either of these variables raises the significance of the variable remaining in the model. When both enter the model, they usually become statistically insignificant.

Model 3 substitutes total capital per capita for capital per establishment. Steam horsepower per capita and capital per capita are both marginally significant (t = 1.91 and t = 1.93). Again, the simple correlation between these two variables is 0.39 and the inclusion of both simultaneously lowers their statistical significance. In model 6, explaining growth from 1880 to 1900, steam horsepower per capita enters the model alone and is statistically significant (t = 2.42).

Models 4, 5 and 7 substitute state dummies for state tax per capita. As a general rule, inclusion of the state dummies reduces the significance of steam horsepower per capita as well as all the other explanatory variables except prior population growth. In models 5 and 7, all explanatory variables except prior population growth become insignificant.

5. Robustness Checks and Controls for Endogeneity.

Although the OLS results support the hypothesis that steam horsepower and total physical capital contributed to county population growth, our measures for capital intensity may suffer from endogeneity. Some uncontrolled for factors may be responsible for affecting capital intensity in 1870 and also for affecting subsequent population growth. To control for possible endogeneity, we first estimate a predicted value for steam horsepower per capita and then use this predicted value in a second equation to explain population growth after 1870. Due to our concern about collinearity between capital per capita and steam horsepower per capita, we focus on the specific contribution of just one capital variable, steam horsepower per capita, in the two-stage analysis.

The first-stage equation used to predict steam horsepower per capita includes an intercept term plus the following variables:

Capital invested in manufacturing per establishment in 1870: Atack, Bateman and Margo (ABM, 2008, p. 185) report that “[l]arge establishments … were much more likely to use steam power than smaller establishments.” To control for this effect we use capital invested in manufacturing per establishment, a measure of firm size, as an instrumental variable.

Library books per capita in the county in 1870: The number of library books per capita provides a measure of labor force quality and is included as an instrumental variable. We expect that a higher quality labor force attracts capital, other things equal.

State dummy variables: State dummy variables might capture potential state-specific effects that may encourage or discourage capital formation. Since RT included state dummy variables in some of their estimations, we also experimented by including them in just the first equation and, also, in both equations. The results presented in this paper include only dummy variables for the states of Rhode Island and Pennsylvania in the first equation. Both dummies were the only ones with coefficients that were consistently statistically significant in the estimations. Rhode Island was the home of the Corliss Company, while Pennsylvania was highly steam-power intensive in both the eastern (several counties near Philadelphia) and western (near Pittsburgh) counties. More importantly, as explained later, our results did not vary significantly regardless of how the dummy variables were used.

County population in 1850 and growth in county population between 1850 and 1870: We include these variables as potential factors affecting capital investment decisions. Populous counties offer producers a nearby market for output and a potentially richer pool of labor inputs. Rapidly growing counties may signal county characteristics that also might induce inflows of capital. However, given that previous population levels and growth may influence future population growth, ceteris paribus, we also included these variables in the second equation.

In the first-stage estimation, capital invested in manufacturing per establishment is consistently positive and significant in explaining steam horsepower per capita. This indicates that large manufacturing firms more readily adopted the new power source than smaller manufacturing firms and is consistent with ABM's (2008) findings obtained using firm-level data. We also tested the robustness of our results to various sub-sets of the explanatory variables and with substituting total capital per capita for capital per establishment. Results were not sensitive to these changes.

As mention above, dummy variables for two states, Rhode Island and Pennsylvania consistently had positive and significant coefficients in the first equation. This provides some support for Kim's (2007) hypothesis that immigration through the major ports was a factor in the decision to adopt steam power. Both these states had important ports, proximity to the most important port of entry (New York City), and counties with relatively high steam power per capita. All other variables, including the intercept term and various port dummies, proved to be consistently insignificant in explaining steam horsepower per capita.

The first-stage equation used in the reported analysis had an adjusted R-square of 0.36. We tested the strength of the correlation of the instruments (capital per establishment, library books per capita, and the dummy variables for Pennsylvania and Rhode Island) to the endogenous regressor (steam horse power per capita). We obtained an F value of 28.2. Thus, we do not have a weak instruments problem[7]. As reported in the last row of Table 2, we find that conditional on an exact identification the additional instruments are valid.

We report six second-stage regression models in Table 2 explaining population growth for 1870 to 1900 (models 1-4) and 1880-1900 (models 5-6). We include all the explanatory variables that were included in the single-equation OLS models except the instrumental variables. We include steam horsepower per capita (predicted), the number of watermills per capita, population in 1850, population growth from 1850 to 1870, county taxes per capita, state taxes per capita and capital in manufacturing per capita. As

[7] Since RT estimated some of their models using state dummies, we estimated the model with ten state dummies in each equation. In this case there were only two instruments (capital per establishment and library books per capita) and the F value was 17.02.

an added robustness check, we included state dummies in both equations but these proved insignificant.

The findings from the two-stage procedure are broadly consistent with those from the single-equation OLS model. Steam power, the new power technology, always has a statistically significant coefficient except, not surprisingly, when capital in manufacturing enters the equation for population growth from 1880 to 1900 (model 6). Capital in manufacturing and predicted steam horsepower are collinear (simple correlation is 0.58) so including both variables in the regression equation lowers the t-statistic for each variable and suggests inaccurate estimates. The coefficient on the number of watermills per capita is always negative and statistically significant. This is also the case if we use watermill horsepower per capita, instead. Regardless of model, county and state taxes are never significant; while prior population growth is always positive and highly significant.

The coefficient on the primary variable of interest, steam horsepower per capita, is significant in models 1-5 and ranges from 7.31 to 9.98. If we accept a mid-point estimate of 8.46, a one standard deviation increase in horsepower per capita would raise predicted annual population growth by 0.319 percentage points. Given that the mean annual growth rate in the 1870 to 1900 period is 1.08 percentage points, a one-standard deviation increase in horsepower per person produces a substantive but not an implausibly large increase in the county's population growth rate.

6. Concluding Remarks.

We find evidence supporting the hypothesis that capital abundance played an important role in population movements in the latter half of the nineteenth century. Our estimates for the effect of capital in the form of steam horsepower are statistically significant and economically substantive. Our empirical analysis provides support for the view that the location of physical capital, especially steam power sources, played a significant role in influencing the location decisions of workers and contributed significantly to population movements and urbanization in the last half of the nineteenth century.

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Table 1-OLS Model

Annual Population Growth, by County

Variables	Growth between 1870 And 1900					Growth between 1880 And 1900	
	1	2	3	4	5	6	7
Total steam horsepower per capita, 1870	3.76* (1.64)	5.67** (2.54)	4.36* (1.91)	4.32* (1.79)	3.25 (1.34)	5.71** (2.42)	3.38 (1.33)
Number of Watermills per capita, 1870	-48.01* (-1.68)	-53.22* (-1.90)	-53.13* (-1.79)	-50.25* (-1.75)	-43.51 (-1.46)	-47.70 (-1.58)	-52.17 (-1.54)
Capital per capita	-----	-----	0.005* (1.93)	----	----	----	----
Population Growth 1850-1870	0.39** (5.83)	0.44** (7.56)	0.40** (6.25)	0.44** (7.38)	0.40** (5.75)	0.48** (7.73)	0.44** (6.10)
Capital Invested in Manufacturing Per Establishment 1870	2.5E-05** (2.36)	----	----	----	1.79E-05 (1.36)	----	1.45E-05 (1.052)
County Taxes per Capita 1870	0.002 (0.04)	-0.02 (-0.36)	-0.007 (-0.15)	-0.02 (-0.30)	-0.1 (-0.19)	-0.008 (-0.16)	0.02 (0.28)
State dummies	----	----	----	Yes	Yes	---	Yes
State tax per capita 1870	-0.07 (-0.95)	0.005 (0.07)	-0.05 (-0.69)	----	----	0.09 (1.24)	---
Adjusted R^2	0.46	0.45	0.46	0.47	0.48	0.42	0.45

OLS with White corrected t-statistics in parentheses. N=242 observations.
Intercepts not reported.
**Statistically significant at the 5% level
*Statistically significant at the 10% level.

Table 2 –Two-Stage Estimations
Annual Population Growth, by County,
Using Predicted Steam Horsepower per Capita as Instrumental Variable

Variables	Growth Between 1870 and 1900				Growth Between 1880 and 1900	
	1	2	3	4	5	6
Total steam horsepower per capita 1870 (predicted)	9.88** (3.41)	8.22** (2.52)	9.78** (3.30)	7.31** (2.07)	8.56** (2.66)	5.22 (1.33)
Number of watermills per capita 1870	-46.63** (-1.98)	-47.57** (-2.04)	-46.67** (-1.98)	-48.02** (-2.06)	-40.13 (-1.53)	-42.03 (-1.62)
Population Growth 1850-1870	0.39** (8.74)	0.39** (8.63)	0.39** (8.64)	0.38** (8.38)	0.44** (8.73)	0.43** (8.38)
Population 1850	1.90E-6 (1.57)	1.57E-6 (1.27)	1.97E-6 (1.52)	1.81E-6 (1.41)	3.02E-6** (2.24)	2.35E-6 (1.65)
County Taxes per Capita 1870	0.01 (0.23)	0.01 (0.30)	0.01 (0.19)	0.01 (0.16)	0.005 (0.11)	0.01 (0.23)
State taxes per capita 1870	----	----	-0.01 (-0.16)	-0.05 (-0.66)	----	0.001 (0.01)
Capital in manufacturing per capita	----	0.003 (1.06)	----	0.003 (1.24)	----	0.005* (1.75)
Adjusted R^2	0.45	0.46	0.45	0.46	0.43	0.43
Over-identification test F value (Probability > F)	0.41 (0.74)	0.53 (0.66)	0.41 (0.74)	0.70 (0.55)	1.24 (0.29)	1.65 (0.18)

Note: T-statistics in parentheses. Intercepts not reported.
**Statistically significant at the 5% level *Statistically significant at the 10% level
First-stage equation (predicting horsepower per capita in 1870) has the following RHS variables: intercept, county population in 1850, county population growth between 1850 and 1870, capital invested in manufacturing per establishment in 1870, the number of library books per capita in 1850, and state dummy variables. N=242.

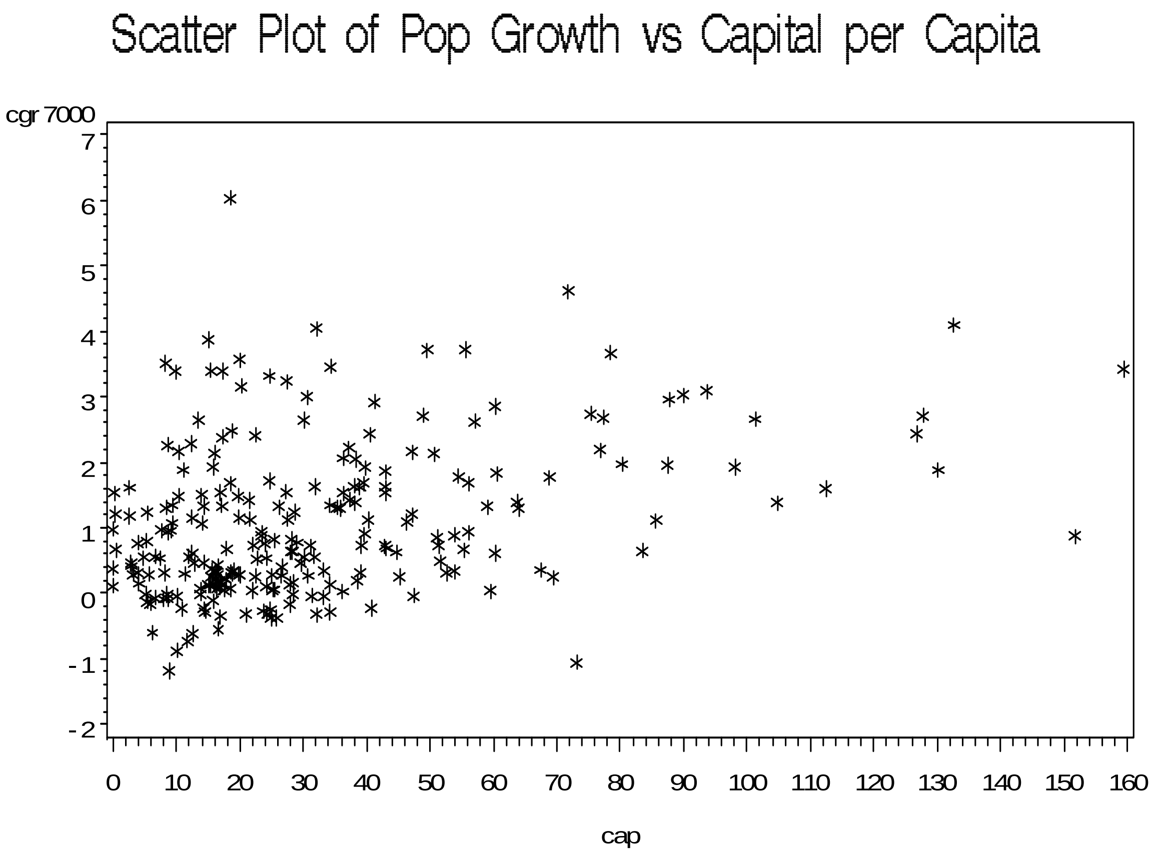

Figure 1. Scatter plot for County Population Growth from 1870 to 1900 versus Capital Per Capita in 1870.

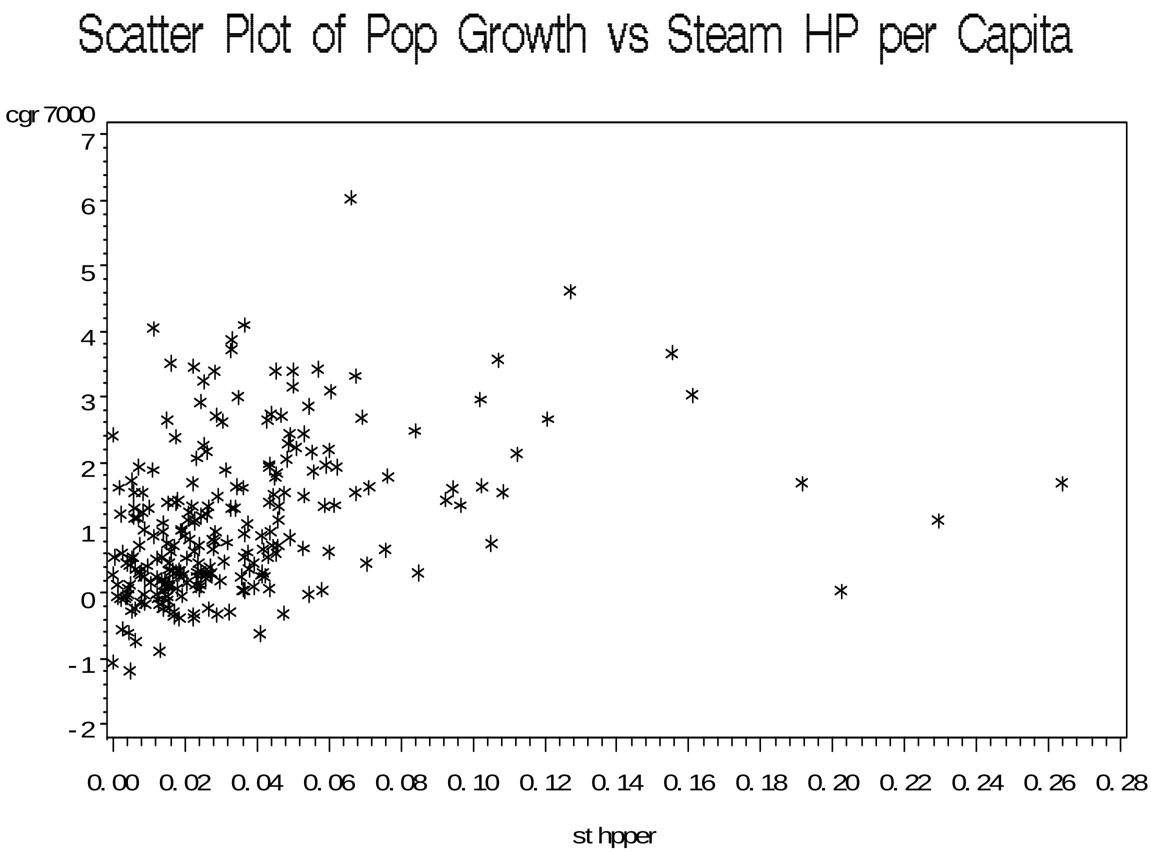

Figure 2. Scatter plot for County population growth 1870-1900 and steam horsepower per capita in 1870.

Appendix: Statistics for Variables.

Variable	Minimum	Maximum	Mean	Standard Deviation
County Population 1850	633	515,547	38,293	47,825
Steam horsepower per capita 1870	0.000	0.264	0.035	0.037
Watermills per capita 1870	0.000	0.353	0.076	0.065
Population Growth 1850-1870	-3.525	9.67	1.42	1.56
Population Growth 1870-1900	-1.18	6.05	1.08	1.17
Population Growth 1880-1900	-1.46	4.83	0.99	1.29
County Taxes per Capita 1870	0.00	9.75	1.55	1.41
State taxes per capita 1870	0.04	6.39	1.07	0.91
Capital in manufacturing per capita 1870	0.00	159.47	32.43	28.06
Capital in Manufacturing Per Establishment 1870	599	41,815	8,694	7,406
Library books per capita in 1850a	0.00	0.010	0.001	0.002