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THE STEAM ENGINE AND U.S. URBAN GROWTH DURING THE LATE NINETEENTH CENTURY

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The Steam Engine and U.S. Urban Growth  
During the Late Nineteenth Century

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## **Abstract**

There is an on-going debate concerning the role that the steam engine played in fueling urban growth in the U.S. during the second half of the nineteenth century. While a consensus has been building that steam power played little or no role in affecting urban growth, we find evidence to the contrary by using previously untapped county-level data on steam power in manufacturing.

Keywords: urbanization, technology, convergence

JEL codes: N32, O14, O18

### **1. Introduction.**

Several recent papers focus attention on the economic impact of the steam engine in the United States during the latter half of the nineteenth century [Atack, Bateman, and Margo (2008, hereafter ABM), Kim (2005 and 2007), Rosenberg and Trajtenberg (2004, hereafter RT), and Abrams, Li, and Mulligan (2008, hereafter ALM)]. ABM (p. 197) note “considering all of the specific technologies that diffused in manufacturing between 1850 and 1880, none may have had a bigger impact in the sense of affecting more manufacturing workers, than the shift to steam power.” RT (p. 61) add that “the steam engine has long been regarded as the icon of the Industrial Revolution.”

While there is general agreement that the steam engine’s rise in importance in manufacturing occurred at the same time as large increases in firm size and growing urbanization, there is a debate concerning the degree to which the steam engine served as

an independent force fueling urban growth. ABM emphasize that manufacturing's small fraction of aggregate output in the nineteenth century implied that steam power might have had little impact on productivity growth, while Kim (2005) using firm-level data suggests that the steam engine by itself had at best a small impact on urban growth. In a more recent paper Kim (2007) provides empirical support for the hypothesis that inflows of unskilled immigrants in the middle of the century may have provided an exogenous force for the expansion of factory manufacturing and urban growth at least up to 1880.

In contrast, RT offer empirical evidence that a particular version of the steam engine made by the Corliss company of Providence, Rhode Island, "served as a catalyst for the industry's massive relocation into large urban centers, thus fueling agglomeration economies and further [urban] population growth" in the latter half of the nineteenth century (RT, p. 61). RT, while acknowledging that the Corliss engine was just one particular manifestation of the long march of steam, state "we would like to emphasize that the results presented here should be interpreted with great caution, primarily because the Corliss variable in the growth regressions probably proxies for wider phenomena than just the number of Corliss users" (p. 88). Recently ALM raised questions about RT's findings concerning the Corliss steam engine, but neither ALM nor RT addressed the more important question concerning the impact of steam power in general on urban growth as their studies lacked data on steam engine usage.

In this paper we use previously untapped Census data on steam power to test directly the hypothesis that steam power encouraged urban development in the latter half of the nineteenth century. Using a two-stage neoclassical growth model that controls for the endogeneity of steam power per capita, we find strong evidence supporting the

hypothesis that the steam engine did play an important role in driving urbanization in the United States during the latter half of the nineteenth century. Our results are consistent with standard neoclassical theory that predicts that labor flows to capital intensive areas. For example, we find that a county with steam horsepower per capita one standard deviation above the mean and with values at the mean for all other variables is predicted to grow thirty percent faster. While such a county would double population size in fifty years, a county at one standard deviation below the mean would take nearly one hundred years to do so. In the next section we describe the empirical approach and data. In Section 3 we provide the results of the two-stage model. For illustrative purposes we also provide estimates of a single equation OLS model and the results of robustness checks on the specification of the model. Section 4 provides a conclusion.

## **2. Empirical Approach and Data.**

We base our approach on the large literature on growth and convergence of income per capita over time. For example, in an often cited article Barro and Sala-i-Martin (1992) find that since the year 1840 U.S. states are converging in income per capita. This convergence, in large part, is likely due to changes in capital or labor across states. States with high capital-labor ratios and with relatively high wages are likely to attract labor, while states with low capital-labor ratios and low wages are likely to attract capital and lose labor, other things equal. Inflows and outflows of capital and labor contribute to convergence in per capita income across states. The literature on convergence in income per capita across countries is large. Evidence strongly suggests “conditional” convergence, convergence in incomes per capita after controlling for numerous country-specific institutional and cultural arrangements. See, for example,

Abrad, et al. (2009), Desli (2009) and Barro (1997). U.S. states, in contrast, are much more homogeneous and require far fewer control variables to support convergence.

As is common in this literature, Barro and Sala-i-Martin assume that technology is the same across states. A similar process can be expected for U.S. counties as they also represent small, open economies subject to both capital and labor inflows and outflows. The hypothesis that steam power served to fuel urbanization presumes that steam power was an important capital asset that provided job opportunities that pulled labor into steam-power abundant geographical markets. We test this hypothesis using county-level Census data. Since data on steam engine usage do not exist at the city level, we follow RT and ALM by assuming that county population growth is a reasonable proxy for urban growth.

We use Census data from eleven Eastern states to test the effect of steam power on county population growth in the 1870 to 1900 period.<sup>1</sup> These eleven states were used by RT and ALM to study the effect of the Corliss steam engine on county population growth; however these authors did not focus on the role of capital intensity in driving population growth. By using these same states, we have a same-sample comparison of findings for the effect of our broader measure of steam power.

We work with two sample sizes. The largest sample includes all 242 counties of record in 1900. Population growth for 34 of these counties had to be estimated due to creation of thirteen new counties drawn from old counties over the time period under investigation. Ten new counties were formed by 1860, one in the 1860s, and two in the 1870s. Twenty-one counties contributed to the formation of these new counties. We

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<sup>1</sup> The eleven states are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island and Vermont.

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 was the same as the growth of the contributing counties. As one robustness test of our findings, we delete these 34 counties for an alternative sample of 208 counties. As the empirical results do not depend on the sample selection, we only report findings using all 242 counties. The dependent variable in our models is growth in county population between 1870 and 1900 and the 1880 to 1900 sub-period.

Our primary variable of interest is steam power. Did steam power facilitate county population growth and fuel urbanization? We use county-level Census data on steam horsepower per capita as the variable to measure the relative abundance of steam power. We include the following control variables in the model. Several of these variables appear in both RT and ALM in some form. However, in keeping with neoclassical growth models, we enter most of these variables in per capita terms:

**Number of watermills per capita in 1870.** This provides another measure of capital per capita at the county level, but an old capital technology that is location dependent and in decline during this time period.

**County taxes per capita in 1870.** This variable measures the extent of government involvement and provision of services in the county.

**State dummy variables.** These variables control for state-specific effects not captured by the other variables in the model.

**Capital per establishment in 1870.** This variable controls for average manufacturing firm size in the county at the start of the period. As noted earlier, ABM

attribute importance to firm size in the decision to adopt capital. As a result, we expect this variable to be an important control for the decision to adopt steam power.

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

**State tax revenues per capita.** This variable controls for state-specific effects of taxation and is used as an alternative to the state dummies.

**Capital per capita in manufacturing.** Since we include steam and windmill variables in the model, ideally we would also like to have a separate measure of non-windmill and non-steam capital per capita. Unfortunately, total capital per capita in manufacturing has steam and watermill-related capital nested within it and these various types of capital cannot be separated. The variables, capital per capita and capital per establishment, have a very high simple correlation (0.78).

### **3. Results**

In this section we first present results for a simple, single-equation OLS model as an illustrative example of the potential problems of collinearity among certain variables mentioned in the previous section. Next, we provide results of a two-stage model that addresses these issues and results of several robustness tests concerning the specification of the model.

#### **3.1. Single Equation OLS**

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). These results generally support the hypothesis that steam horsepower per capita induced labor flows into counties. However, the same can be said

for capital per capita and manufacturing firm size. Unfortunately, collinearity among these variables makes it difficult to separate their independent effects. But we can say that 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 rich in physical capital including steam power. This preliminary finding is consistent with the convergence literature: capital rich geographical areas attract labor which tends to equalize capital-labor ratios and incomes across areas.

More 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 ( $t = 2.54$ ). The simple correlation between capital per establishment and steam horsepower per capita is 0.486, so their simultaneous inclusion weakens the significance of both. In models 5 and 7, where both enter the model, they 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  $t = 1.93$ ). 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.

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 windmills 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*.

### **3.2 Two-Stage Model**

RT note in their study of the Corliss steam engine's effect on population growth that a single-equation model is likely to be subject to simultaneity bias. A similar potential problem exists for our model as steam horsepower is likely to affect population growth, but population growth may also affect the adoption of steam horsepower. To correct for simultaneity bias, we first estimate a predicted value for steam horsepower per capita and then use this predicted value to explain population growth. The equation used to predict steam horsepower per capita includes the following variables: county population in 1850, growth in county population between 1850 and 1870, capital invested in manufacturing per establishment in 1870, library books per capita in the county in 1870, state dummy variables, and an intercept term.

We include the population size and population growth variables as potential factors affecting capital investment decisions. ABM (p. 185) report that “[l]arge establishments ... were much more likely to use steam power than smaller establishments.” So we use capital invested in manufacturing per establishment, a measure of firm size, as an explanatory variable.

Library books per capita give a measure of labor force quality. We expect that a higher quality labor force attracts capital, other things equal. State dummy variables enter the equation to capture state-specific effects that may encourage or discourage capital formation. We also experimented with additional county-level dummy variables to capture the effects that major ports (i.e., counties containing New York City, Philadelphia and Boston) might have on capital formation. These port cities were primary disembarkation points for the waves of immigrants entering the United States in the nineteenth century. The port-dummy variables never proved significant or affected the findings. We elected to delete the port-dummies from the first-stage regression. 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.

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 results using firm-level data.

Dummy variables for two states, Rhode Island and Pennsylvania, consistently had positive and significant coefficients. This provides some support for Kim’s hypothesis

that immigration into 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 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 capital per establishment which now enters in the first stage. We include steam horsepower per capita (predicted), the number of windmills per capita, population growth from 1850 to 1870, county taxes per capita, state taxes per capita and capital in manufacturing per capita. As an added robustness check, we included state dummies in lieu of state taxes per capita and major-port dummies, but these proved insignificant.

The findings from the two-stage procedure are broadly consistent with those from the single-equation OLS model. Steam power is always significant except 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. Regardless of model, county and state taxes are never significant; watermills enter with a negative and significant effect and prior population growth with a positive and highly significant effect.

The coefficient on the primary variable of interest, steam horsepower per capita, is significant in models 1-5 and ranges from 8.22 to 10.84. If we accept a mid-point estimate of 9.5, a one standard deviation increase in horsepower per capita would raise predicted annual population growth by 0.349 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.

#### **4. Concluding Remarks.**

Using a previously untapped source of county-level data for steam horsepower, we find evidence supporting the hypothesis that the steam engine played an important role in driving U.S. urbanization in the nineteenth century. Our finding is consistent with neoclassical theory supporting convergence: capital intensive areas with relatively high wages and accessible manufacturing jobs attracted inflows of labor that helped to spur urbanization. Theory suggests that these labor inflows in turn would serve to lower capital-labor ratios, reduce wages and encourage convergence of incomes across geographical areas.

Our estimates for the effect of steam horsepower are statistically significant and economically substantive. A county with steam horsepower per capita one standard deviation above the mean and with values at the mean for all other variables is predicted to grow thirty percent faster. This county would double in population size every fifty years. A similar county but whose steam horsepower per capita is one standard deviation below the mean would take nearly one-hundred years to double in population size. In sum, our empirical analysis provides strong 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 urbanization in the last half of the nineteenth century.

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**Table 1****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 <sup>2</sup>	0.46	0.45	0.46	0.47	0.48	0.42	0.45

OLS with White corrected t-statistics in parentheses. 242 observations.

Intercepts not reported.

\*\*Statistically significant at the 5% level

\*Statistically significant at the 10% level.

**Table 2**

**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)	10.62** (3.80)	8.49** (2.67)	10.84** (3.82)	8.22** (2.38)	9.55** (3.02)	6.23 (1.61)
Number of watermills per capita 1870	-52.18** (-2.28)	-52.08** (-2.28)	-51.45** (-2.24)	-52.43** (-2.28)	-49.18* (-1.89)	-47.93* (-1.85)
Population Growth 1850-1870	0.39** (8.89)	0.38** (8.66)	0.39** (8.86)	0.38** (8.43)	0.43** (8.70)	0.43** (8.35)
County Taxes per Capita 1870	0.01 (0.27)	0.02 (0.36)	0.01 (0.46)	0.01 (0.32)	0.009 (0.19)	0.02 (0.43)
State taxes per capita 1870	----	----	0.03 (0.46)	-0.01 (-0.20)	----	0.04 (0.55)
Capital in manufacturing per capita	----	0.003 (1.40)	----	0.004 (1.33)	----	0.006* (1.86)
Adjusted R <sup>2</sup>	0.46	0.46	0.46	0.46	0.42	0.43

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, the number of library books per capita, and state dummy variables. 242 observations.