Productivity Growth of Sailing: An Evidence from Slave Transportation from Baltimore to New Orleans, 1818-1856[1]

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Abstract

This paper uses a new dataset for domestic packets collected by Clayton. This dataset consists of tonnage and traveling time information of vessels that transports slaves from Baltimore to New Orleans. In order to analyze these records, a production function of sailing is considered using a neoclassical production technology. Using this production function, the growth of total factor productivity (TFP) is estimated. According to this estimate, the TFP growth is about 50% $\sim$ 60% in the studied forty years (1818 and 1856). Since it is found that the TFP is measured by an increase in the sailing speed, this implies that traveling time from Baltimore to New Orleans declined from four weeks in 1818 to less than three weeks in 1856 on average. In addition, using other data sources, the evolution of price markup rate is estimated that shows a slow-but-steady decline during the studied period. Thus, it is also suggested that the maritime transportation market approaches competitive environment slowly but steadily.

1 Introduction

There are several works in the Western Rivers (for example, Haites and Mak [9], [10], Kane [13], Mak *et. al.* [11], and Paskoff [21]) and international maritime transportations (for example, recent studies are Jacks and Pendakur [12], Mohammed and Williamson [20], and Rahman [22]). Among these works, especially the development of steamboat networks in the Western Rivers has impacted in the development of the antebellum South. In addition, Craig *et al.* [4] shows the impact of railroad development in land pricing, Slaughter [24] the commodity price convergence caused by improvements of transportation systems, and Fishlow [7] the impact of evolutions of various transportation systems. However, there is almost no work that focuses on domestic maritime transportation in the antebellum United States.

It is actually a challenge to measure productivity of antebellum domestic maritime transportation due to difficulties in finding good data. Yet, it is doubtless that improvements of transportation systems did affect economic performances of relevant regions. This paper tries to estimate the productivity of domestic maritime transportations in the antebellum era using the data set of Clayton [3]. The dataset contains more than 300 effective observations of voyages from Baltimore to New Orleans between 1818 and 1856. The productivity is computed as a total factor productivity (TFP) in a neoclassical production model. In the model, tonnage is regarded as a proxy for capital input. In addition, labor input is considered a function of tonnage. The product of each voyage is measured by *tonnage-mile per hour*. We then find that the TFP growth between 1818 and 1856 was nearly 60%. The estimate also suggests that the theoretical price-markup declines slowly but steadily during the studied period.

The discussion is developed as follows. Section 2 introduces the main data set with preliminary assessments to estimate the TFP growth in Section 3. The estimations in Section 3 is further verified in Section 5 and applied to derive the price-markup rate. For more robustness, Section 4 investigates inclusions of dummies for the two wars during the studied period and deletions of some suspicious entries. We then conclude in Section 6.

2 Preliminary Assessments

2.1 Data

The dataset collected by Clayton [3] is based on in-bound slave manifests in New Orleans and newspaper articles in *the American and Baltimore Daily Advertiser* (see Clayton [3, pp. 625-39]). The dataset has 378 samples with seven variables. Among these seven variables, date of departure, days of voyage, ship type, and tonnage are used.

Distributions of departure dates, length of voyage, and tonnage are shown in Figure 1. In this sample, ship types are Barque ($N = 75$), Brig (183), Schooner (29), Sloop (3), and Steamer (1). The unknown is classified as Ship (85) in Clayton [3]. In this study, sloops are merged into unknown and a 5,499-ton steamer in 1839, *Osceola*,[1] is dropped; whence, by dropping samples due to lack of tonnage information or traveling time information, the effective sample size becomes $N = 305$. The summary statistics for tonnage and length of voyage in the effective sample is provided in Table 1.

Table 1: Summary of Effective Observations ($N = 305$)

	Mean	**S.D.**	**Min.**	**Max.**
Tonnage	253.72	113.78	51	729
Length of Voyage	26.16	9.33	11	75

The relationship between traveling time and year for all observations are depicted in Figures 3. In this figure, we can see a downward trend of traveling time.

2.2 Tonnage Expansion

Figure 4 depicts the evolution of tonnage for each vessel type. These figures show apparent upward trends in Barque, Schooner, and unknown ship type (Ship). Brig does not show the same trend as its tonnage is limited by definition: a brig must have two square-rigged masts and then larger vessels tend to be classified as barque or schooner.[2]

In order to convert calendar date $(month_i, date_i, year_i)$ into continuum series t_i, we define

$$t_i = \frac{(month_i - 1) + (date_i - 1)/30}{12} + (year_i - 1818). \tag{1}$$

With this conversion, t_i indicates $t_i = 0$ for January 1, 1818 and it increments as the date increments. In the actual sample data, the first and the last voyages in this sample are December 12, 1818 and December 6, 1856, respectively, so that the actual range is $0.947 \leq t_i \leq 38.94$. The mean of converted departure dates is $\bar{t} \simeq 19.58$. The next equation then estimates the tonnage of each vessel X_i in logarithm $x_i \equiv \ln X_i$:

[1] This "ship" left Baltimore on October 16, 1839 to reach New Orleans on October 28, 1839. Thus, the traveling time was twelve days.

[2] Although schooners in the sample are smaller than brigs on average, the tonnage of schooners continued increasing until the end of the sail-ship age: for example, at the beginning of the twentieth century, a seven-mast ca. 5,000t schooner was built.

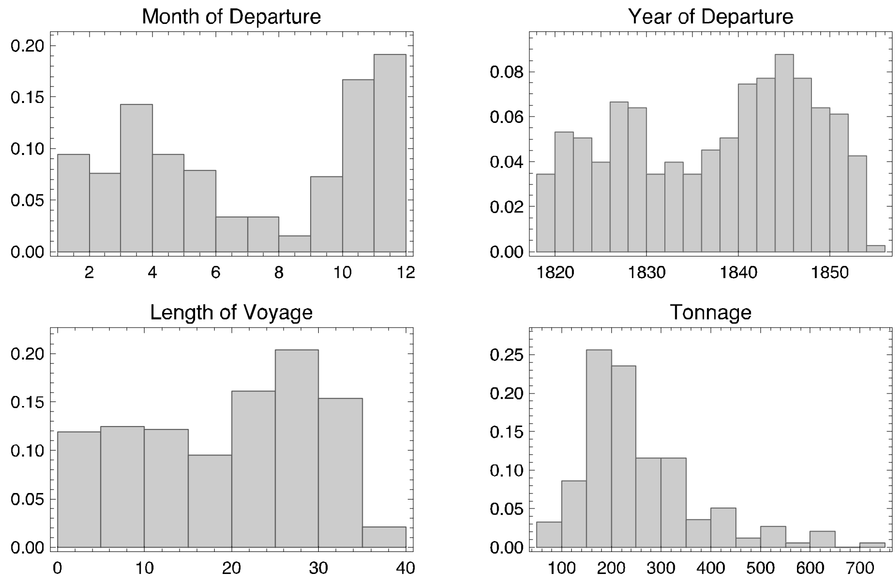

Figure 1: Histograms of the sample data

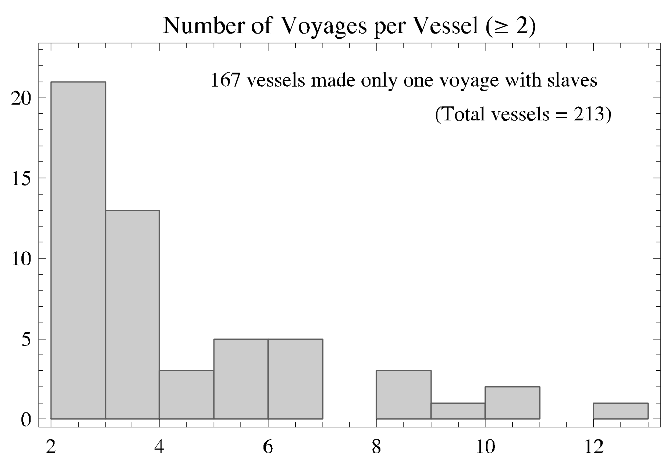

Figure 2: Histogram of number of voyages per vessel

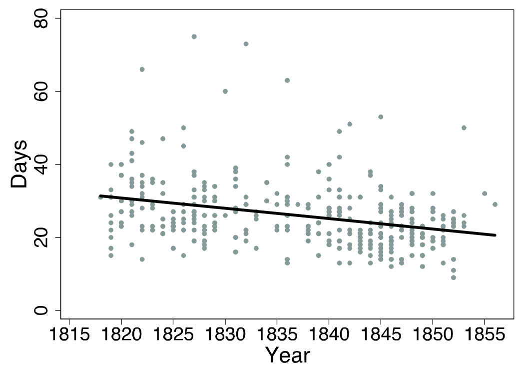

Figure 3: Evolution of Traveling Time

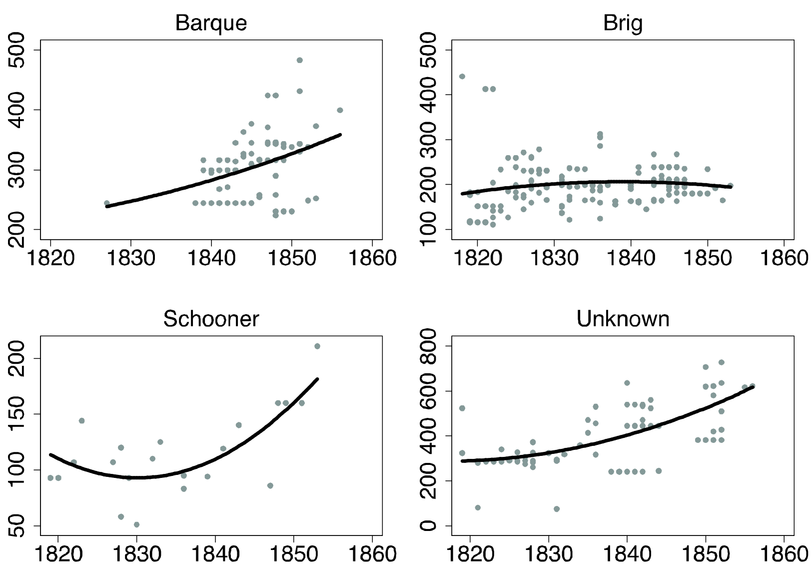

Figure 4: Observed tonnage expansions

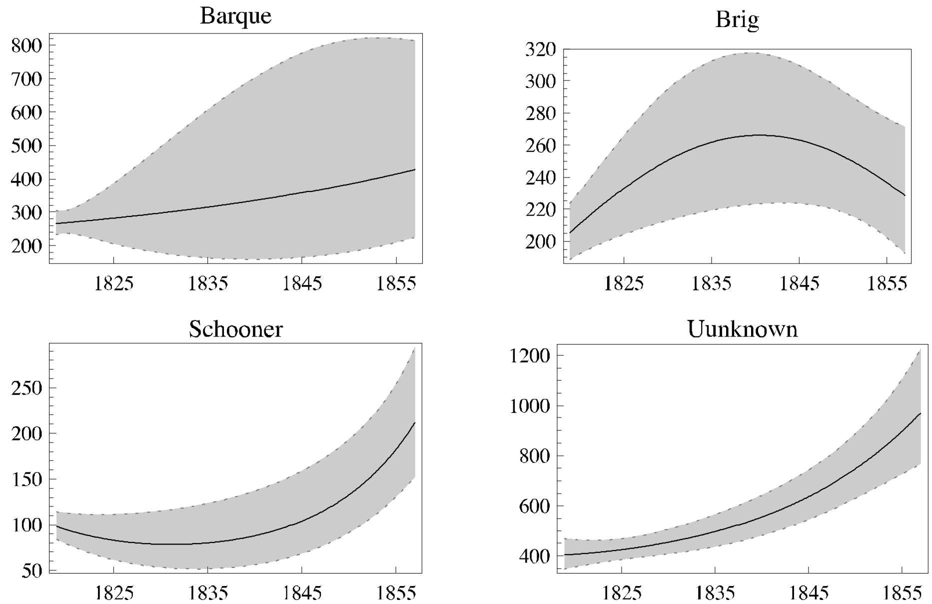

Figure 5: Estimated tonnage expansions

$$x_i = \bar{x} + I_M + \sum_{j \in S} \sum_{k=1}^{n_j} \left\{ I_S + b_{j,k} \left(t_i - \bar{t} \right)^k \right\}, \tag{2}$$

$$S = \{Barque, Brig, Schooner, Unknown\}, \tag{3}$$

where x_0 represents the constant (average of logarithm tonnage), I_S the ship dummy, I_M the month dummy, $t_i - \bar{t}$ the centered time indicator, and $\beta_{j,k}$ the coefficient on $(t_i - \bar{t})^k$ for each ship-type $j \in S$. This estimation is also taken as the first stage regression for the 2SLS estimation in the next section. As the first stage regression, the F statistic of this estimation is sufficiently above the thumb-up rule by Bound [1] (e.g., larger than 10).

The result is shown in Table 2 and depicted in Figure 5 with 95% confidence interval (shaded area). From this estimation, we can see a steady growth of tonnage in each ship type except for Brig. The month effect shown in Table 3 shows no significant month effect in tonnage except for October.

Table 2: Pooled regression ($N = 305$)

Basis	**Unknown**		
b_1 (*s.e.*)	0.0228^{**} (0.0041)		
b_2 (*s.e.*)	0.0005 (0.0006)		
$\bar{x}$ (*s.e.*)	0.3753^{**} (0.0846)		
I_M	Provided in Table 3		
S	**Barque**	**Brig**	**Schooner**
$b_{S,1}$ (*s.e.*)	$-0.0103^{\dagger}$ (0.0056)	-0.0206^{**} (0.0044)	-0.0067 (0.0065)
$b_{S,2}$ (*s.e.*)	-0.0004 (0.0007)	$-0.0011^{\dagger}$ (0.0006)	0.0016^{*} (0.0007)
I_S (*s.e.*)	-0.2467^{**} (0.0807)	-0.5105^{**} (0.0800)	-1.3174^{**} (0.1133)
$F\,(22, 282)$	25.62		
R^2	0.67		

Table 3: Month dummies

Month (M)	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**
I_M (*s.e.*)	—	-0.0305 (0.0582)	-0.0013 (0.0496)	-0.0168 (0.0574)	-0.0222 (0.0807)	-0.0202 (0.1256)
Month (M)	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
I_M (*s.e.*)	-0.0904 (0.0766)	-0.0404 (0.1433)	-0.0059 (0.0658)	$0.0955^{\dagger}$ (0.0491)	-0.0111 (0.0604)	0.0497 (0.0578)

3 TFP Growth

3.1 A Theoretical Consideration

A product of voyage i is measured by *tonnage miles per hour* (tons m.p.h.), as often used in related literatures:

$$Z_i \equiv X_i \text{ tons} \times \frac{D \text{ miles}}{H_i \text{ hours}}, \tag{4}$$

where X_i is the tonnage, H_i the hours of voyage, and D the distance between Baltimore and New Orleans (circa 1,880 miles). The input factors to produce Z_i are labor and capital. We assume that tonnage X_i is the proxy of capital input. Such an assumption could not be given if we look at steamboating on the Western Rivers, as capital inputs should include investments on various facilities on the river for provisions and safety (for example, see Paskoff [21]). However, such investments are not made around the coastal line during the studied period.

Let us suppose the production technology is represented by a Cobb-Douglas form such that

$$Z_i = A_i X_i^{1-\eta} L_i^{\eta}, \tag{5}$$

where L_i is the labor input, $\eta \in (0, 1)$ the share of labor input, and A_i the parameter related to the total factor productivity (TFP). The production function is arranged as

$$Y_i \equiv \frac{Z_i}{X_i} = A_i \left(\frac{X_i}{L_i} \right)^{-\eta}, \tag{6}$$

where $Y_i \equiv Z_i/X_i$ represents per-tonnage production equivalent to *sailing speed*. In the per-tonnage production function, the input factor, X_i/L_i, is crews per tonnage.

Klein [14, p. 85] reports that the average number of crews per tonnage of transatlantic slave ships before the Nineteenth Century is about 0.17-0.19 and that of cargo ships is about 0.1. For interstate slave transportation, Clayton's dataset does not provide the number of crews, so that X_i/L_i is unknown and hard to make predictions. In order to overcome the lack of information, let L_i have a structural relationship with tonnage as

$$L_i = B_i^{-1} X_i^{\rho} \quad \Rightarrow \quad \frac{X_i}{L_i} = B_i X_i^{1-\rho}, \tag{7}$$

where $B_i > 0$ and $\rho \geq 0$ are parameters associated with number of crews operating a vessel of $X_i > 1$ tons. It can be said that tonnage and labor are compliments of each other when $\rho \in [0, 1]$ while they are substitutes of each other when $\rho > 1$; hence, a larger ρ implies a larger substitutability between tonnage and labor. B_i is the productivity of labor to put the vessel into work, *à la* TFP. Substituting (7) into (6) provides

$$Y_i = A_i B_i^{-\eta} X_i^{\eta(\rho-1)}. \tag{8}$$

With this formulation, the TFP is subsequently computed as the product of two TFP related parameters as $A_i B_i^{-\eta}$.

3.2 Estimating the TFP (Sailing Speed)

Estimations of TFP apply ordinary least square (OLS), instrumental variable method (IV), and nonlinear least square (NLS), where the first stage regression for the IV is the estimation for tonnage given by (2) in the previous section. Nonlinear least squares (NLS) estimates the following nonlinear equation directly:

$$Y_i = e^{a_i} X_i^{\phi} + \varepsilon_i, \tag{9}$$

where ε_i denotes the error term.[3] In this equation, the TFP is represented by e^{a_i}. For OLS and IV, (9) is transformed by taking logarithm:

$$y_i = a_i + \phi x_i + \varepsilon_i, \tag{10}$$

where $y_i \equiv \ln Y_i$, $\ell_i \equiv \ln L_i$, $a_i \equiv \ln A_i - \eta \ln B_i$, $x_i \equiv \ln X_i$, and

$$\phi = \eta \left(\rho - 1\right). \tag{11}$$

For NLS and OLS estimations, letting J_M and J_S be dummy variables for month and ship, respectively, $a_i = a\left(t_i\right)$ is provided as:

$$a\left(t_i\right) = \alpha + J_M + J_S + \sum_{k=1}^{n} \beta_k \left(t_i - \bar{t}\right)^k, \tag{12}$$

and similarly for the IV estimation as:

$$a\left(t_i\right) = \alpha + J_M + \sum_{k=1}^{n} \beta_k \left(t_i - \bar{t}\right)^k. \tag{13}$$

The difference between (12) and (13) is the inclusion of J_S (ship dummy). The IV model uses 2SLS method with (2) as the first stage regression, where the ship dummy I_S is included.

[3]For simplicity of notation, let us abuse ε_i to denote errors in other estimations henceforth, so long as there is no confusion.

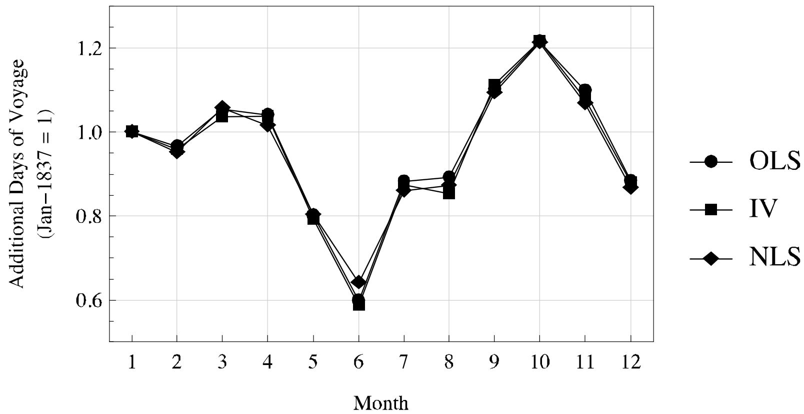

Figure 6: Estimated month effects

The degree of polynomial n is determined by comparing AIC and BIC obtaining $n = 2$ (Appendix 6). The results are shown in Table 4 with HC3 standard errors, as heteroskedasticity may exists as suggested by Appendix 6. The month dummies for each estimation are depicted in Figure 6 (January 1830 basis), as nominal values, $\exp(J_M)$.

Since $\phi = \eta(\rho - 1)$ and $Z_i = Y_i X_i$, the *tons m.p.h.* production function is rewritten as

$$Z_i = A_i B_i^{-\eta} X_i^{1+\phi}, \tag{14}$$

where tonnage input X_i is considered as a composite input factor to produce Z_i. By definition, the production function exhibits diminishing returns to scale to tonnage for $\phi > 0$, constant returns to scale for $\phi = 0$, and increasing returns to scale for $\phi \in (-1, 0)$.

In Table 4, the estimate of ϕ of OLS suggests $\phi > 0$ while that of IV and NLS imply ϕ is insignificant. The Cragg-Donald Wald F statistic for the IV estimate is 43.543. Using the Stock-Yogo weak ID test critical values ([25]), the obtained F statistic rejects the weak identification hypothesis by 5% significance level; hence, we can say that the bias of IV is less than that of OLS. This observation is claimed as follows.

Claim 1 *The production technology of sailing exhibits constant returns to tonnage, as* $\phi \simeq 0$.

Comparing with other studies in water transportation systems of the same era that suggest existence of scale economy—especially in the Western Rivers such as Haites and Mak [9], [10], Kane [13], Mak *et. al.* [11], and Paskoff [21]—this result is rather weak. The source of non-decreasing returns to scale is tonnage and the result anticipates the race of tonnage expansion in the much later period.

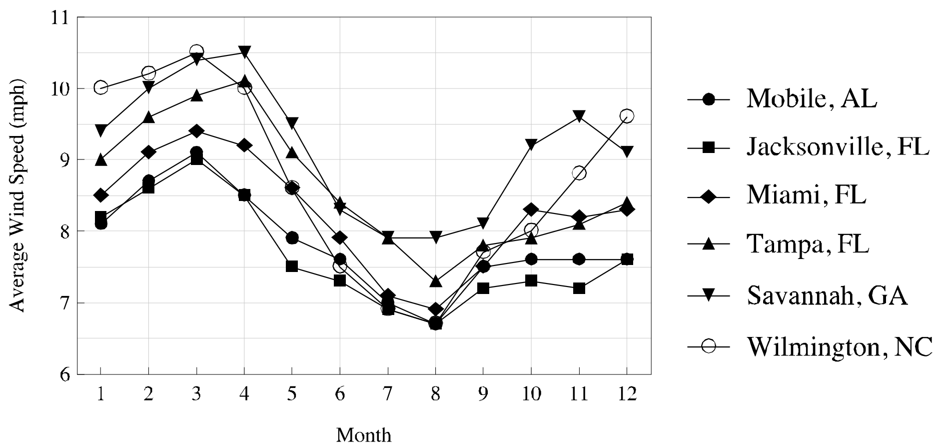

Figure 7: Average wind speed *en route*

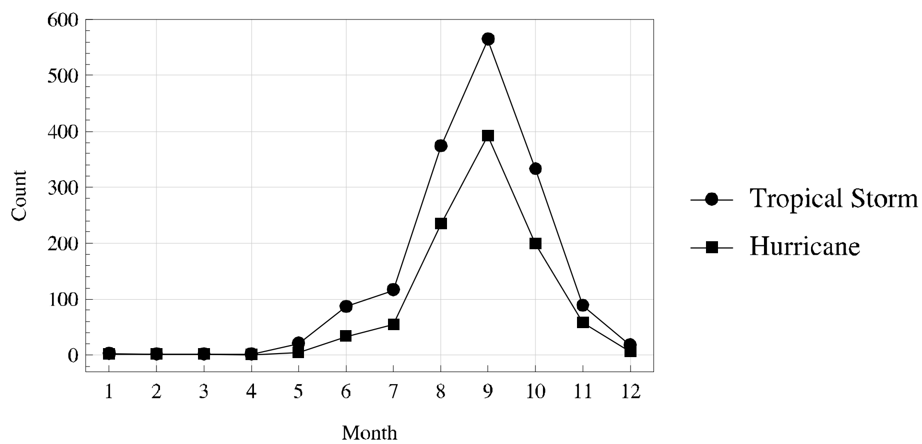

Figure 8: Exclusive storms to hit the U.S., 1851-2011

3.3 Cruising and Weather Conditions

Average wind speed of each month and exclusive storms hitting the U.S. are shown in Figures 7 and 8, respectively.[4] Rough weather reduces sailing speed, so that too strong wind and storms have negative effects. Referring to Figure 6, traveling time decreases as wind speed decreases until June, but it start rising as number of exclusive storms increases. This observation confirms that seasonal factors in the TFP estimation are fairly controlled.

[4]Sources are NOAA's public records.

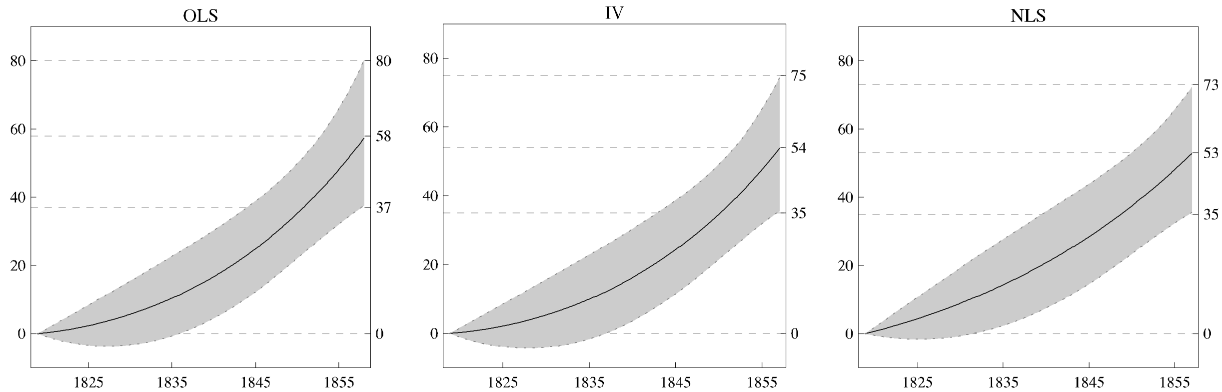

Figure 9: Estimated % of TFP growth (shaded area: 95% CI)

3.4 TFP Growth Rate

For observations i and j such that $t_i = t$ and $t_j = s \leq t$, respectively, the TFP growth rate between t and s is computed as

$$1 + r(t, s) = e^{a(t)-a(s)}, \tag{15}$$

where

$$a(t) - a(s) = \ln \frac{A_i}{A_j} - \eta \ln \frac{B_i}{B_j}. \tag{16}$$

Predictions of TFP growth rates based on estimations in Table 4, $r(t, s) \times 100\%$ for $s = 0$ (December 12, 1818), are shown in Figures 9 with each 95% confidence interval (shaded area). In accordance with these estimates, we claim the result as follows.

Claim 2 *The growth rate of TFP (sailing speed) seems to reach at least 50-60%.*

4 Additional Assessments

4.1 Impacts of Two Wars

There were two wars between 1818 and 1856 that might have affected the maritime transportation as suggested by Rahman [22]. One is the War of Texas Independence from October 2, 1835, to April 21, 1836, and the other is the Mexican-American War from April 25, 1846, to February 2, 1848. Within the two periods of the two wars, according to Clayton's record, there were 7 voyages and 23 voyages, respectively. If the Mexican navy was capable of intercepting the freighters between Baltimore and New Orleans, the traveling time would be increased by their naval activities. To test the impacts of the two wars, we test two dummy variables of the corresponding two periods: *MEX-TX* for the War of Texas and *MEX-US* for the Mexican-American War. In addition, the war dummy (*WARS*) that combines the effects of two wars for 30 voyages is also tested. These dummies are inserted into each model.

The results are shown in Table 5. According to these results, we cannot identify any significant impacts of wars. The p-values of F-tests for the joint significance of *MEX-TX* and *MEX-US* are 0.6378 in OLS; 0.8337 in IV; and 0.7098 in NLS. Therefore, we can conclude that there is no significant impact of the two wars in traveling time and tonnage.

4.2 Deletions of Suspicious Entries

In the sample, we can find 213 vessels. Most of them made only one voyage with slaves (167 vessels). Of the remaining 54 vessels, as shown in Figure 2, 34 vessels made less than 4 voyages. Only 20 vessels made more than 5 voyages. In the data, there are six too-close departures of the same vessel name. Yet, these observations were not excluded in the estimations because there is no evidence to show the two vessels are the same one, *i.e.*, sisters or merely by chance.

Suspicious entries are listed in Table 6. To test the influence of these observations, we apply the Hausman test. The Hausman test looks at the statistical significance of the difference of estimated coefficients in regressions with and without suspicious entries. The results for the OLS and IV are shown in Table 7. For NL, the test is to examine if all the coefficients are statistically equal between the two estimations with and without suspicious entries. According to these tests, there is no difference between the estimated coefficients. That indicates that inclusion (or exclusion) of suspicious entries does not affect the estimations.

5 Predicting Market Competitions

5.1 Price Markup and TFP Growth

Let the factor price be W. For a given output level Z_i, the cost minimization problem is provided by

$$\min_{X_i} \; WX_i \quad \text{s.t.} \quad Z_i = A_i B_i^{-\eta} X_i^{1+\phi} \tag{17}$$

to obtain the corresponding cost function:

$$C(Z_i) = W\left(\frac{Z_i}{A_i B_i^{-\eta}}\right)^{1/(1+\phi)}. \tag{18}$$

Table 4: Estimated TFP growth path

	OLS	**IV**	**NLS**
ϕ	0.1277^{*}	-0.0259	0.0844
(s.e.)	(0.0591)	(0.0524)	(0.0614)
β_1	0.0112^{**}	0.0111^{**}	0.0110^{**}
(s.e.)	(0.0020)	(0.0018)	(0.0019)
β_2	0.0002	0.0002	0.0001
(s.e.)	(0.0002)	(0.0002)	(0.0002)
α	0.3567	1.1267^{**}	0.6886^{*}
(s.e.)	(0.3531)	(0.3100)	(0.3700)
J_{Barque}	-0.0257	—	-0.0588
(s.e.)	(0.0553)		(0.0524)
J_{Brig}	0.1234^{*}	—	0.0671
(s.e.)	(0.0549)		(0.0568)
$J_{Schooner}$	0.1171	—	0.0628
(s.e.)	(0.0997)		(0.1044)
J_M	Depicted in Figure 6		
R^2	0.3190	0.2889	0.9382

Table 5: Impacts of wars in OLS and 2SLS models

	MEX-TX		*MEX-US*		*WARS*	
Model	**Coef.**	**S.E.**	**Coef.**	**S.E.**	**Coef.**	**S.E.**
OLS	-0.0939	0.1407	0.0446	0.0665	0.0197	0.0603
IV	-0.0397	0.1440	0.0361	0.0674	0.0225	0.0610
NLS	-0.1007	0.1527	0.0299	0.0595	0.0101	0.0552

Table 6: Suspicious entries

Vessel (tonnage)	**Departure**	**Voyage Length**
Arctic (231t)	*January 24, 1828*	26 days
	January 29, 1828	21 days
Arctic (231t)	*October 8, 1828*	22 days
	October 9, 1828	17 days
Arctic (231t)	*January 28, 1829*	34 days
	January 31, 1829	31 days
Henry Clay (371t)	*December 4, 1828*	35 days
	December 8, 1828	31 days
Intelligence (152t)	*April 5, 1823*	36 days
	April 12, 1823	29 days
Tweed (306t)	*October 15, 1836*	26 days
	October 20, 1836	26 days

Table 7: Hausman tests for deletions of suspicious entries

Model	Test Stat.	p-value
OLS	$\chi^2(17) = 1.36$	1.0000
IV	$\chi^2(14) = 0.86$	1.0000
NL	$F(18, 287)$	1.0000

Thus the marginal cost function is provided by

$$C'(Z_i) = \frac{W}{(1+\phi) A_i B_i^{-\eta}} \left(\frac{Z_i}{A_i B_i^{-\eta}} \right)^{-\phi/(1+\phi)}. \tag{19}$$

Now we consider a Cournot competition among $N \geq 2$ transportation service suppliers. Let the *inverse demand function* for transportation service be

$$T = \frac{T_0}{\sum_{j=1}^{N} Z_j}, \tag{20}$$

where T is the transportation fee (dollars per tons m.p.h.) and $T_0 > 0$ the constant parameter associated with the fee. With this formulation, the elasticity of demand for transportation service is computed always as unity.

Using obtained cost function (18) and provided inverse demand function (20), the profit maximization problem for each supplier is provided by

$$\max_{Z_i} \Pi_i = \frac{T_0 Z_i}{\sum_{j=1}^{N} Z_j} - W \left(\frac{Z_i}{A_i B_i^{-\eta}} \right)^{1/(1+\phi)}, \tag{21}$$

The first order condition with respect to Z_i for this problem requires

$$\frac{T_0 \left(\sum_{j=1}^{N} Z_j - Z_i \right)}{\left(\sum_{j=1}^{N} Z_j \right)^2} = \frac{W}{(1+\phi) A_i B_i^{-\eta}} \left(\frac{Z_i}{A_i B_i^{-\eta}} \right)^{-\phi/(1+\phi)}. \tag{22}$$

We assume that any transportation services are homogeneous, so that $Z_j \equiv Z^*$ for all j at the Cournot-Nash equilibrium, Z^*. In this case, the first order condition is written as

$$\left(\frac{N-1}{N} \right) T_0 = MC^*, \tag{23}$$

where $MC^* \equiv C'(Z^*)$. The provision of services at the equilibrium is then provided by

$$Z^* = \left(\frac{(1+\phi)(N-1)T_0}{WN^2}\right)^{1+\phi} A_i B_i^{-\eta}, \tag{24}$$

and the marginal cost by

$$MC^* = \frac{(N-1)T_0}{N^2 A_i B_i^{-\eta}} \left(\frac{WN^2}{(1+\phi)(N-1)T_0}\right)^{1+\phi}. \tag{25}$$

Thus, from (20) and (24), the transportation fee T^* at the Cournot-Nash equilibrium satisfies

$$T^* = \frac{T_0}{NZ^*} \quad \Rightarrow \quad T^* = \gamma MC^*, \tag{26}$$

where $\gamma = N/(N-1)$ turns out to be the markup rate for transportation fee, as it is well-known.

When $\phi \simeq 0$ as estimated (Claim 1), the marginal cost at the Cournot-Nash equilibrium is computed as

$$MC^* = \frac{W}{A_i B_i^{-\eta}}. \tag{27}$$

In this case, from (26) and (27), the logarithm of transportation fee becomes

$$\ln T = \ln \gamma + \ln w - \ln A_i B_i^{-\eta}. \tag{28}$$

Totally differentiating (28), the rate of change in transportation fee, $\tau(t,s)$, is further computed as

$$\tau(t,s) = \delta(t,s) + \omega(t,s) - r(t,s), \tag{29}$$

where $\delta(t,s)$ represents the rate of change in mark-up rate, $\omega(t,s)$ the rate of change in wage rate, and $r(t,s)$ the rate of change in TFP between periods t and s, respectively.

5.2 Calibrations without Changes in Competition Environment

Using (29), we try to evaluate if the estimate of TFP growth shown in Figure 9 is consistent with another estimate using different data sources. Let us assume the following property.

Assumption 1 *The rate of change in mark-up rate is time-invariant or the rate change is ignorable, so that $\delta(t,s) \simeq 0$.*

Table 8: Transportation cost of slaves (Evans [6, p. 335], arranged)

Year	**# of Slaves**	**Cost per Slave**	**Departing Port**
1832-35	201	$17.00-20.00	Norfolk, VA
1833	21	19.52	Norfolk, VA
1834	10	17.10	Norfolk, VA
1834	20	16.50	Norfolk, VA
1849	10	15.10	Baltimore, MD
1850	3	15.25	Baltimore, MD

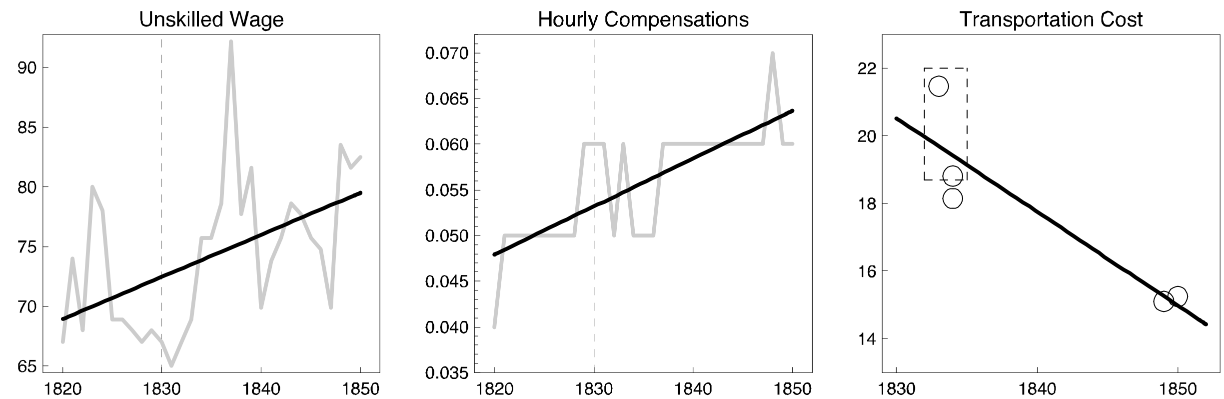

Figure 10: Evolutions of key variables

Under Assumption 1, (29) becomes

$$r(t,s) = \omega(t,s) - \tau(t,s). \tag{30}$$

In our model, such a case is applied when N is sufficiently large, *e.g.*, the market is almost competitive.

In order to obtain the estimate for $r(t,s)$ with a constant markup rate γ, the data from MeasuringWorth.com for wage rate and from Evans [6, p. 335] for transportation cost are employed. For the wage rate, there are two estimates: one is unskilled wage and the other is hourly compensation of production workers in manufacturing (both nominal), where the rates of changes of the two wage rates are written as ω_0 and ω_1, respectively. The two wage rates are depicted in the left and the middle charts of Figure 10 and the linear-estimate for the growth rates of the two wage rates are given in Table 9 as ω_0 and ω_1.

The transportation cost of slaves from Norfolk to New Orleans around the first half of the 1830s and that of Baltimore to New Orleans in 1849 and 1850 are provided by Table 8. In order to obtain the transition of the transportation cost, as depicted in the right chart of Figure 10, Evans's data are modified as follows. The mileage between Baltimore

Table 9: Rates of changes in key parameters

	ω_0	ω_1	τ
Annual Average Rate	0.99%	0.49%	-1.35%

Table 10: Rates of changes in key parameters

	r from ω_0	r from ω_1	IV [95% C.I.]
Annual Average Rate	2.33%	1.84%	—
20 Years	46%	37%	32% $[0.27, 0.37]$

and Norfolk is about 200 miles, which would take 2 days at 3 m.p.h. or 3 days at 4 m.p.h. Traveling between Baltimore and New Orleans would take 26 days at 3 m.p.h. or 20 days at 4 m.p.h. If the transportation cost is linear in the traveling time, the transportation cost from Baltimore must add 10% to the cost from Norfolk. The linear-estimate for the growth rate of the transportation cost is then given in Table 9 as τ.

The annual rates of changes in the wage rates and the transportation cost depicted in Figure 10 are provided in Table 9. According to the estimate (Table 4 and Figure 9), the growth rate from January 1830 to December 1850 (20 years) is about 32% with 95% confidence interval of between 27% and 37%. The estimate for r using ω_0 is out of this range, but the estimate using ω_1 is within. Maritime workers were not unskilled workers in the Nineteenth Century. In this sense, our estimate will imply that the two estimates using Clayton's data (Table 4 and Figure 9) and other data sources (Table 10) are not too far from each other.

Next, we consider using another data source. Margo [18] estimates the growth rate of real wage rate between 0.7% and 1.6%. The consumer price index between 1820 and 1850 is depicted in Figure 11. From this data, we can compute the annual inflation rate as $\pi = -0.64\%$. From these numbers, the annual rate of change in the real transportation cost becomes about -0.7% and then the annual rate of change in the TFP growth ranges between 1.4% and 2.3% to reach between 28% and 46% for twenty years. Interestingly, this prediction is also not far from my prediction.

5.3 Markup Rate Convergence and Competition

The estimate in Table 10 presumes the market is already almost competitive, as the rate of change in γ is assumed ignorable or zero. Next, let us suppose γ is time-variant and the estimate of TFP growth using Clayton's data $r(t, s)$ is fairly computed. In order to see the

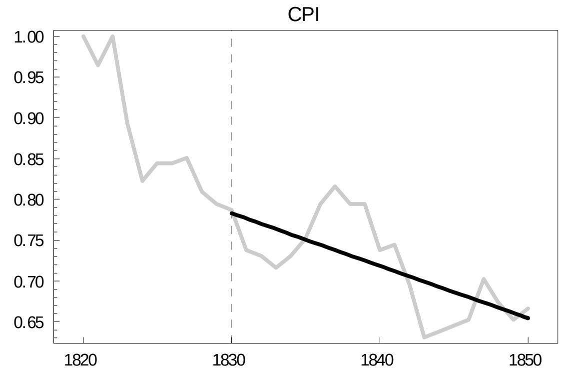

Figure 11: Consumer Price Index between 1820 and 1850

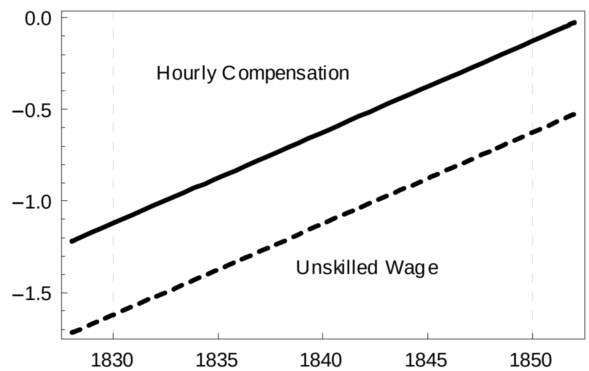

Figure 12: Rate of Change in Markup Rate (%)

rate of change in mark-up rate, (29) is rearranged as

$$\delta(t,s) = \omega(t,s) - \tau(t,s) + r(t,s). \tag{31}$$

Using the same hourly compensation and unskilled wage data as in the previous subsection and Evans's transportation cost data, the evolution of markup rate is computed as shown in Figure 12. According to this estimate, we can find that the markup rate has continued declining slowly but steadily during the studied period. Although we cannot identify if the market reached competitive environment from our estimation, we can still say that the maritime transportation market approached competitive market from the movement of markup rate. For 20 years, between 1830 and 1850, the markup rate declined about 20%.

A similar evidence in other input factor markets is also suggested by Slaughter [24], as an evidence of the factor-price equalization theorem (Samuelson [23] and Lerner [16]) that suggests commodity prices are equalized in a competitive environment and subsequently factor prices as well. In our case, the commodity is the maritime transportation and the factor price is the operation fee of a vessel represented by the transportation fee. In the model, the TFP growth implies shorter traveling time and that indicates an increase in the potential supply of transportation services to raise N to reduce γ.

6 Conclusion

Using Clayton's dataset of interstate slave transportation, this study investigated the TFP measured by the speed of sailing vessels during the antebellum era. During the antebellum period, it is believed there was a marginal improvement in the maritime transportation productivity compared with steamboating mainly flourished in the Western Rivers. However, this study showed the improvement of the TFP between 1818 and 1856 (40 years) was slow but steady, as estimated to be nearly 60% (about 1.5% on the annual basis). This also implies that the sailing speed became faster 1.6 times in the studied 40 years. This improvement means that the traveling time from Baltimore to New Orleans was about 4 weeks on average in 1818, but it became 2.5 weeks on average by 1857, which is not a small change.

At the same time, we could see that the maritime transportation market slowly but steadily approached more competitive environment, as the price-markup rate continued declining. For 20 years since 1830, the mark up rate declined about 20%. The decline of the markup rate is consistent with the TFP growth, as the TFP growth shortens traveling time to increase the potential transportation service supply.

Furthermore, the estimate suggests the tonnage miles per hour production is non decreasing returns to scale to anticipate the future rate of tonnage expansion.

Appendix

Model Selection

In order to determine the degree of polynomial k for each estimation, Akaike's Information Criterion (AIC) and Baysian Information Criterion (BIC) are provided in Table 11. As a result, $k = 2$ is chosen for all estimations since both AIC and BIC are maximized then. For reference, p-values for Breusch-Pagan test (BP) and Ramsey's RESET test (RESET) for the OLS are provided that cannot reject existences of heteroskedasticity and of misspecification for $k = 2$.

Table 11: Results for model selection

	OLS				IV		NLS	
k	*AIC*	*BIC*	*BP*	*RESET*	*AIC*	*BIC*	*AIC*	*BIC*
1	87.5	150.7	0.0817	0.1766	94.0	146.1	810.7	874.0
2	*87.9*	*154.8*	*0.1198*	*0.1836*	*95.0*	*150.8*	*812.2*	*879.2*
3	82.1	152.8	0.0263	0.0327	90.7	150.2	802.7	873.3
4	72.2	146.6	0.0283	0.0320	81.0	144.3	793.4	867.8

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