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**Econometric Problems in Analyzing the  
Mule in Southern Agriculture**

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# Econometric Problems in Analyzing the Mule in Southern Agriculture

by Larry Sawers

This paper is a supplement to *The Mule, the South, and Economic Progress*, @ *Social Science History*, Fall 2004, which presents an analysis of the predominance of the mule in the South in the late nineteenth and early twentieth centuries. This paper presents a detailed critique of the econometric analysis of this problem by Garrett and Kauffman.

## Why Ignoring Crop Mix Is Wrong

Even though Garrett (1990) found that the share of crop land in cotton was closely associated with cotton cultivation and my regressions show that what the farm produced (cotton, tobacco, sugar, or beef cattle) was an important determinant of draft animal choice, Kauffman has consistently downplayed the importance of crop mix. Two of Kauffman's statistical studies did not include any measure of crop mix and thus cannot provide statistical support for discounting its importance (1992; 1993*b*, 343-345).<sup>1</sup> A third study (Kauffman 1993*b*, 347-349) used county-level data for Georgia from the 1920 census. He included in his regressions the proportion of improved acreage devoted to cotton, but argued that its statistical significance was low and erratic. In what follows, I show that his choice of data biased his results and that, in any case, a properly specified model produces highly significant regression coefficients on the crop-mix variable.

Kauffman offers no explanation for choosing Georgia to study the choice of draft animal in the South as a whole. It may appear that Georgia would be an especially appropriate case study since it had the highest proportion of mules among equines of any state in 1920. It is for this very reason, however, that Georgia is an especially inappropriate case study. As Kauffman himself points out, path dependence and scale economies may explain the choice of draft animals in any particular locale (1993*b*, 348). Species-specific human capital accumulates, and markets for the dominant form of livestock develop. If almost everyone nearby is using mules, then it may make sense for one to choose a mule, too, even though in other circumstances the horse would be more appropriate.<sup>2</sup> In that case, crop mix would have

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<sup>1</sup> The first of these studies (1992) analyzed Census data for sixteen Southern states in 1910. Kauffman used only one independent variable (the ratio of sharecroppers to other farmers). When I replicated his analysis for 1910 and 1920 and included a measure of crop mix (cotton share), I found that multicollinearity, especially in the 1920 data, was a serious problem because of the small sample size. There are a number of other statistical and methodological weaknesses in this study analyzed later in this working paper.

A second study by Kauffman (1993*b*, 343-345) used a sample of 35 Georgia plantations in 1911. Virtually all of the draft animals given to the sharecroppers and wage workers on these plantations were mules. Since Kauffman did not offer any information about what was grown on the plantations, this study can shed no light on the importance of the crop mix in the choice of draft animal.

<sup>2</sup> The regression model presented above provides statistical support for the path dependence/scale economies argument. In that regression, Georgia had more large residuals (larger than two standard deviations from the predicted value) than any other state, and all were positive. In contrast, Virginia (with the lowest proportion of mules in the South) had the largest number of large, negative residuals of any state. In other words, mules were more prevalent in Georgia and less so in Virginia than would be expected on the basis of my model, which is consistent with the path dependence/scale economies hypothesis. This may also explain Garrett's (1990, 930) finding that regression coefficients on all of the state dummies except one were significant at the 97 percent level or better. The states with the largest positive regression coefficients either had a large proportion of mules or an important breeding industry. The states with large negative coefficients either had few mules or substantial beef cattle ranching. Garrett mentions no reason for including the state dummies in his regression and offers no rationale for their statistical significance, but the pattern he found is easily explained.

little influence over the choice of draft animal. Our aim is to explain the choice of draft animal in the South. The appropriate data are for the South as a whole, not for one state or for each Southern state taken separately, and not in a state completely dominated by the mule.

Even if a case study of Georgia could shed light on the question Kauffman has posed, he fails to provide convincing statistical support for omitting crop mix from the analysis of draft animal choice. In regressing the mule-horse ratio on the cropper ratio and the cotton share, he used the Box-Cox model, which computes equations in all combinations of linear and logarithmic forms and then selects the >best=one based on goodness of fit (Pindyck and Rubinfeld 1991, 242). He presents only the two >best=equations as determined by the Box-Cox criterion. In only one of the two is the crop mix variable significant at the 95 percent level; on that basis, he concludes that it should be omitted from the analysis and that only the cropper share variable should be considered statistically validated. In a replication of Kauffman=s regression analysis, five of the eight possible equations in the Box-Cox specification had a regression coefficient on the cotton share variable that was significant at the 99.9 percent level. In two other equations it was significant at the 95 percent level. In only one of the eight equations (one of the two presented by Kauffman) does the regression coefficient on cotton share fail to reach the 95 percent level of significance. The Box-Cox model thus offers faint support for discarding crop mix as an important explanation of draft animal choice.

In order to use the Box-Cox model, Kauffman had to exclude from his analysis five counties where the cotton share was zero (since the logarithm of zero is undefined). I recomputed the regression in linear form and could therefore use the data for all 155 Georgia counties. Additionally, I replaced the cotton share variable with the cotton and tobacco share, producing the following equation:<sup>3</sup>

$$\begin{array}{lcl} \text{Mule-Equine Ratio in Georgia in 1920} & = & .652 + 0.287(\text{Cropper share}) + 0.177(\text{Cotton-tobacco share}) \\ (5.94) & & (4.15) \end{array}$$

The  $R^2$  is 0.434, considerably higher than in either equation that Kauffman reports. More important, the  $t$  statistic on the crop-mix variable (4.15) is significant at the 99.9 percent level. The crop mix variable is somewhat less significant than the cropper share. This is to be expected since the data are for only one state, telling us nothing about the relative importance of the two variables in the South as a whole. In sum, the county-level data from Georgia in 1920 using properly specified regressions strongly support the notion that crop mix is an important determinant of mule use.

I then estimated this same equation for all Southern states. In addition to Georgia, there were only three other states where the sharecropper variable had a higher statistical significance than the cotton share variable. In contrast, in six Southern states, the cotton share variable was the more significant, and in four of those, the sharecropper variable was insignificant at the 95 percent level. In one state, neither variable was significant, and in another, the two variables were of approximately equal significance. Thus, the state-by-state analysis does not support Kauffman=s contention that the crop mix was unimportant in explaining the prevalence of mules, and that only the sharecropper variable survives a statistical analysis.

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<sup>3</sup> Furthermore, all variables used the  $\alpha/\beta$  form instead of the  $\alpha/(\alpha+\beta)$  form. See footnote 4 for an explanation. I also used the mule-equine share for animals two years and older as the dependent variable to account for mule breeding.

## How to measure mule prevalence

The way that Garrett and Kaufman constructed their measures of mule use and the prevalence of share tenancy or sharecropping poses difficult problems of interpretation and potentially biased regression results. Take, for example, the mule-horse ratio that both used as their dependent variable. Let  $\alpha$  be the number of mules and  $\beta$  be the number of horses. The mule-horse ratio takes the form of  $\alpha / \beta$ . As the proportion of mules among all draft animals [ $\alpha / (\alpha + \beta)$ ] rises from zero to 100 percent, the mule-horse ratio rises from zero to infinity. At the upper tail of the distribution, even a small increase in the use of mules produces a disproportionately large (and ultimately infinite) increase in the mule-horse ratio.<sup>4</sup> In the 1910 state-level data that Kaufman uses, for example, the cropper ratio varies from .003 to .096 and has an almost perfectly linear size distribution. The mule-horse ratio, however, varies from .07 to 2.46 and is strongly curvilinear. Regressing one variable on the other, then, does not produce a very good match and thus an artificially low correlation. Both authors find that a logarithmic transformation of these variables outperforms the untransformed variables. The foregoing discussion suggests an explanation of these results. The logarithmic transformation changes the shape of the size distribution by reducing the curvilinearity of the variable. Note also that both Garrett and Kaufman mix and match different variable forms. Their measures of mule use and tenancy take the  $\alpha / \beta$  form, but their measure of crop mix takes the  $\alpha / (\alpha + \beta)$  form, further compounding the problem of interpreting regression results and contributing a possible bias to estimates of standard errors.

Using variables that take the form  $\alpha / (\alpha + \beta)$  avoids the mathematical quirk built into Garrett=s and Kaufman=s variables and in most instances produces correlations with a higher statistical significance. For example, a bivariate regression (using 1910 state-level data) of the mule-equine ratio (mules among all draft animals) on the sharecropper share (sharecroppers among all farmers) produces an  $R^2$  of .623, noticeably higher than the .476 when using Kaufman=s mule-horse and cropper-noncropper ratios. Since there is no economic rationale for using the  $\alpha / \beta$  form instead of the  $\alpha / (\alpha + \beta)$  form (and no economic rationale for then taking the logarithm of the variable to reduce the problem you have just created), the variable definition

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<sup>4</sup> The incidence of  $\alpha$  within the entire population  $\alpha + \beta$  is as follows:

The following table gives numerical examples to show how  $\alpha / (\alpha + \beta)$  and  $\alpha / \beta$  are related:

$\alpha / (\alpha + \beta)$	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1
$\alpha / \beta$	0	.11	.25	.42	.67	1.0	1.5	2.3	4.0	9.0	4

that produces the better fit is preferable. For the models presented below, therefore, I use the  $\alpha/(\alpha+\beta)$  form of all variables.<sup>5</sup>

Using the same state-level data for 1910 that Kaufman used, the following regression is estimated:

$$\begin{array}{l} \text{(1) Mule-Equine Share in 1910} \\ = .131 + 2.875(\text{Cropper share}) + 0.713(\text{Cotton share}) \qquad R^2 = .799 \\ \qquad \qquad \qquad (2.20) \qquad \qquad \qquad (3.38) \qquad \qquad \qquad N = 16 \end{array}$$

The cropper share variable is just barely significant at the 95 percent level, but the crop-mix variable is significant at the 99.5 percent level. The  $R^2$  is substantially higher than when the crop mix variable is omitted.<sup>6</sup>

This equation uses a crop-mix variable that measures the importance of cotton cultivation because this is the variable used by Garrett (1992) and Kaufman (1993b). As I have argued earlier, however, the appropriate variable is the share of land in *all* of the crops for which the mule was especially appropriate, not just cotton. Substituting the cotton + tobacco share for the cotton share in equation (1) raises the  $R^2$  to .805 (from .799) and reduces the  $t$  statistic on the sharecropper variable from 2.20 to 1.92 (so that it is not significant at the 10 percent level). The new crop-mix variable (cotton + tobacco share) has a slightly higher  $t$  statistic than does the old crop-mix variable (cotton share).

There is an additional problem with equation (1). Most of the mules used throughout the South were bred in Missouri, Kentucky, and Tennessee. These states, therefore, had a disproportionately large number of young (less than two years old) mules whose presence had nothing to do with the crops grown in those states or how many sharecroppers worked the land. Missouri is not in Kaufman's sample of Southern states, but both Kentucky and Tennessee have unusually large residuals in equation (1). Thus, equations that do not take into account the presence of large-scale mule breeding are misspecified.<sup>7</sup> The following equation uses a dummy variable (Kentucky and Tennessee = 1, other states = 0) to account for mule breeding. In addition, the ratio of mule prices to horse prices (as defined earlier) is included.

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<sup>5</sup> No substantive conclusions reached in this article, however, were changed by using the  $\alpha/(\alpha+\beta)$  variable definition instead of the  $\alpha/\beta$  form.

<sup>6</sup> Note that my definition of the variables is, as expected, more favorable to Kaufman's hypothesis than his own definition. The following regression was estimated using the  $\alpha/\beta$  form for all variables:

$$\begin{array}{l} \text{Mule-Horse Ratio using state level data for 1910} = \\ .112 + 5.111(\text{Cropper Ratio}) + 1.788(\text{Cotton-Non Cotton Ratio}) \qquad R^2 = .734 \\ \text{(1.08)} \qquad \qquad \qquad (3.56) \qquad \qquad \qquad \qquad \qquad \qquad \qquad N = 16 \end{array}$$

The coefficient on Kaufman's Cropper Ratio is not close to being significant.

<sup>7</sup> Garrett (1990, 929) includes dummy variables for all (except one) states in his sample. He does not justify why this was appropriate and does not discuss his findings of significant coefficients on all but one of the dummies.

(2) Mule-Equine Share in 1910 =

$$.147 + 1.953(\text{Cropper share}) + 0.962(\text{Cotton-tobacco share}) + 0.151(\text{Breeding dummy}) - .035(\text{Mule-horse prices})$$

(1.58)                      (4.41)                      (2.08)                      (-.255)

R<sup>2</sup> = .866  
N = 16

Properly specifying the equation by making allowance for mule breeding makes the coefficient on sharecropping drop far below a statistically significant level. The new formulation boosts substantially the *t* statistic on the crop-mix variable (from 3.38 to 4.41) so that it is significant at better than the 99.9 percent level. The coefficient on the dummy for mule breeding is significant at the 93 percent level, but the price variable is nowhere close to acceptable levels of significance. The R<sup>2</sup> for the regression is .866.

Caution should be exercised before dismissing the hypothesis that mule use is associated with tenancy. The unstable *t* statistic on the sharecropping variable suggests that multicollinearity is a problem. The independent variables measuring crop mix and tenancy are highly correlated. The R<sup>2</sup> between the cropper ratio and the cotton/non-cotton ratio used in equation (1) is 0.472. The R<sup>2</sup> between the cropper share and the cotton + tobacco share used in equation (2) is .525. Given this correlation between the independent variables, we cannot be sure that it is crop mix rather than tenancy that explains the use of mules. What these equations do show, however, is that the crop-mix variable is strongly correlated with mule use and, contrary to Kaufman's assertions, cannot be ignored in the attempt to understand the choice of draft animal in Southern agriculture.

As noted earlier, the U.S. Census Bureau did not enumerate sharecroppers before 1920. The data on sharecropping that Kaufman uses in his 1910 study came from an unpublished paper by Alston (1991). In these data, the proportion of farmers that were sharecroppers in the sixteen Southern states averaged only 4.5 percent; at 9 percent, North Carolina had the highest proportion. The 1920 Census, however, indicates that 14.5 percent of farmers were sharecroppers in the average Southern state, with Georgia's 32 percent the highest. There is nothing in the literature, however, to indicate that the incidence of sharecropping tripled in this decade. Furthermore, Alston's 1910 measure of sharecropping is correlated with the Census's 1920 data for the sixteen Southern states with an R<sup>2</sup> of only .636. Again, there is nothing in the literature to indicate that interstate patterns of tenancy changed markedly in the intercensal period. The most likely explanation for these differences is simply that Alston and the Census Bureau employed different definitions of sharecropping. As pointed out earlier, there are many different factors in the farm leases of the period, producing a confusing pattern that blurs the distinction between sharecropping and other forms of share tenancy.

These difficulties with measuring sharecropping and the potential multicollinearity in the 1910 data encourage us to seek other data. Accordingly, we should explore the possibility that more robust results could be obtained using data from the 1920 Census. Presented below is a regression on the mule-equine share in 1920. Equation (3) uses state-level Census data and takes the same form as equation (2) except that it uses 1920 data instead of 1910 data:

(3) Mule-Equine Share in 1920 =

$$.219 + 1.023(\text{Cropper share}) + 0.65(\text{Cotton-tobacco share}) + 0.107(\text{Breeding dummy}) - .015(\text{Mule-horse prices})$$

(1.71)

(1.53)

(1.03)

(-.07)

$R^2 = .769$

N = 16

In 1920 using state-level data, none of the coefficients are close to being significant at the 95 percent level yet the  $R^2$  is very high (0.769). This equation demonstrates the classic symptoms of multicollinearity. The two independent variables, cropper share and cotton + tobacco share, are highly correlated with each other ( $R^2 = .695$ ). This multicollinearity is noticeably higher than it was in 1910 (though remember that sharecropping was defined differently). Multicollinearity and the small size of the data set are in one sense the same problem. Accordingly, a larger data set may allow us to sidestep the difficulties posed by the state-level data.

A similar regression was computed using data for all 1370 Southern counties in 1920. In equations (2) and (3) reported earlier, a dummy variable was used to control for the presence of breeding activity that would bias our attempt to analyze the use of mules as work stock. The 1920 data allows us to deal with this issue without using a dummy variable. Instead, the mule-equine share is computed for animals two years and older:

(4) Mule-Equine Share for animals two years and older in 1920 =

$$.416 + 0.843(\text{Cropper share}) + 0.358(\text{Cotton-tobacco share}) + .082(\text{Mule to horse prices}) \quad R^2 = .451$$

(16.82)                      (9.72)                      (-2.49)                      N = 1370

This equation shows that both the sharecropper variable and the crop-mix variable are highly significant (the  $t$  statistics are 16.82 and 9.72).<sup>8</sup> The coefficient on the price variable has the expected sign and is significant at the 98 percent level.<sup>9</sup> Because the equation is properly specified, the coefficient on the sharecropper share is credibly low. With the large sample size, multicollinearity is no longer a problem and all regression coefficients are highly significant.

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<sup>8</sup> I experimented with a wide variety of variable definitions (for example, using all draft animals, not just those 2 years and older, cotton share, not the cotton + tobacco share, and the mule-horse ratio instead of the mule-equine ratio).  $R^2$ 's and  $t$  statistics were slightly smaller, but the conclusion that the crop-mix variable is highly correlated with mule use is robust.

<sup>9</sup> Transport costs of mule and horse should be broadly similar within each state and variations in mule and horse prices among countries are likely to be affected by a variety of extraneous factors. Thus, the variable used in this equation is the ratio of mule to horse prices by state, not by county.



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