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Using nonlinear testing procedures to specify the right hand side of an aggregate production function containing financial variables in the period 1967–2011 ☆

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ABSTRACT

Starting with Sinai and Stokes (1972), a number of papers that followed included various measures of the financial sector (real balances) in an aggregate production function. Sinai and Stokes (1972) and many, but not all, of the studies used the Christensen and Jorgenson (1969, 1970) data on output, labor and capital for the period 1929–1967. While generalized least squares, GLS, was used to remove serial correlation, Fisher (1974) and others, including Sinai and Stokes (1972), were concerned about increasing returns to scale that were observed, even in the cases where the financial variable was omitted from the model. Stokes (2013) chose the four original datasets (annual data 1929–1967, non-financial quarterly data 1953:1 to 1977:3, annual data 1930–1978 and annual data 1959–1985) and used various nonlinear estimation techniques to test whether the estimated increasing returns might be due to an inappropriate functional forms rather than variable mismeasurement. In that paper, the finding of significant nonlinearities suggested that the choice of functional form might indeed be the cause of increasing returns. For a proper test of the source of the problem, however, other data and periods need to be investigated to rule out the possibility that data mismeasurement might have given a false indication of nonlinearity. If the estimated increasing returns could be removed and nonlinearity was not detected in models with alternative data, that finding would be consistent with the hypothesis that the original research was marred by data mismeasurement rather than function misspecification. The current paper uses a new annual dataset 1967–2011 and experiments with Divisia real monetary aggregates, in contrast to work which used the original real financial variables which were based on the usual simple sum M2 data. In addition an improved labor variable using hours was found to be superior, with the result that increasing returns is removed and no measured nonlinearity remains.

1. Introduction

Starting with Sinai and Stokes (1972), a number papers followed, such as Short (1979), Boyes-Kavanaugh (1979), Simos (1981), Nguyen (1986) and Benzing (1989) and others, that put various measures of the financial sector (real balances) in an

☆ This research builds on work I have done with Allen Sinai and Hugh Neuburger in prior research. Editorial help from Diana Stokes is appreciated. Important comments from William Barnett concerning Stokes (2013) that was presented to the Society of Economic Measurement at the University of Chicago on August 20.

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aggregate production function. At issue in this early research was whether Cobb–Douglas was the correct functional form of the production function and whether a financial variable belonged in the function at all. Stokes (2013) and Sinai and Stokes (1989) surveyed much of this research, which will not be discussed in any detail here. Earlier contributions to this literature are contained in Sinai and Stokes (1975, 1977, 1981a, 1981b). The basic theory for adding a measure of real balances to the production function is contained in Bailey (1962) and Nadiri (1969, 1970). Butterfield (1975) looked at business demand for real balances. Sinai and Stokes (1972) and many, but not all, of the studies used the Christensen and Jorgenson (1969,1970) data on output, labor and capital for the period 1929–1967 and added financial variables. One focus of the original Sinai and Stokes (1972) research was to correct for serial correlation with GLS. In later responses to comments, the focus shifted to investigation of alternative functional forms. Fisher (1974) questioned the plausibility of the initial findings of increasing returns to scale that had been noted by Sinai and Stokes (1972), even in the cases where the financial variable was not in the model. In Sinai and Stokes (1972, 293) it was suggested that "the high degree of increasing returns to scale exhibited in equation (3-6) may have been due to omission of an appropriate variable for neutral technological progress." They further noted, "The finding of increasing returns to scale in the aggregate production function is similar to results obtained by Bodkin and Klein (1967)." Later in their paper's conclusion they again stressed "The Cobb–Douglas functions we estimate exhibit increasing returns to scale, a result that is consistent with Bodkin and Klein's (1967) estimates of the Cobb–Douglas for the period 1909–1949. The returns to scale change little when real balances are added to the production function. The coefficient of capital services is hardly affected by the presence of money, however the labor service coefficient falls anywhere from 12 to 30 percent, depending on the measure of real balances employed." No further work on explaining the cause of the estimated increasing returns to scale appeared until Stokes (2013).

Stokes (2013), using the four original datasets (annual data from 1929–1967, nonfinancial quarterly data from 1953:1 to 1977:3, annual data from 1930–1978 and annual data from 1959–1985), used various nonlinear estimation techniques to test whether the estimated increasing returns might be due to misspecification rather than variable mismeasurement. In Stokes (2013), the finding of significant nonlinearities suggested that this indeed might be the case. A major problem with this research is that the increasing returns to scale continued to be found even when nonlinearity was found. As noted in Stokes (2013, 110) "clearly more work has to be done on improving the monetary variable to be used in the production function."

For a proper test of the source of the problem, other data and periods need to be studied to determine whether data mismeasurement had caused a false indication of nonlinearity. If the estimated increasing returns can be removed and nonlinearity is not detected in models containing alternative data sources, that finding will be consistent with the hypothesis that the original research was marred by data mismeasurement rather than misspecification. The present paper uses a new annual dataset from 1967–2011 and experiments with both Divisia real monetary aggregates (to be discussed later) rather than the original real financial variables which involved simple sum M2 aggregation. An improved labor variable using hours worked and a utilization-adjusted real capital variable were placed in the production function with the result that the measured increasing returns to scale were removed and no non-linearity was found for two out of the three Divisia money series investigated. Divisia money series were investigated in view of the fact that a large number of recent papers have established the superiority of this approach to aggregation. For example Serletis and Gogas (2014) found using cointegration analysis that previous rejections of the balanced growth hypothesis and the classical money demand function could be attributed to mis-measurement of the money aggregate implicit in the usual M2 series. A related paper, Serletis and Rahman (2013) studied Divisia money targeting and concluded that monetary policies that focus on the Divisia monetary aggregates and target their growth rates will contribute to higher overall economic growth.

After a brief discussion of the model to be estimated, a more in depth discussion of measurement and miss-specification is presented. The development of the data is followed by the empirical results from estimation of log-linear Cobb–Douglas models with alternative variables. Significant nonlinear evidence is found with the Hastie and Tibshirani 1990 GAM (general additive model) approach with the original variables that for log-linear models showed increasing returns to scale. Models using the alternative right-hand side variables did not have increasing returns to scale when estimated in log-linear form. As a further test, there was no significant nonlinearity remaining when the revised models were estimated with the GAM approach using two out of the three Divisia financial variables. These results are consistent with the hypothesis that the original research had mismeasured inputs.

2. Estimation of a Cobb–Douglas production function

A major goal of this paper is to test the hypothesis that the increasing returns to scale found in log-linear forms of an aggregate production function are due to mismeasurement of the of right-hand side variables. Initial tests reported in Stokes (2013) found evidence of nonlinearity as measured by the (GAM) approach and multivariate adaptive regression splines model (MARS) developed by Friedman (1991). This finding would be consistent both with the hypothesis that an incorrect functional form of the aggregate production function was used and with the alternative hypothesis of mismeasurement of the right-hand side variables. The next section of this paper discusses in some detail how to distinguish between these two explanations.

The functional form of the estimated model could be inappropriate because the form has shifted over time or is inherently faulty for any period. While t (time) has been used in all models to proxy for possible changes in total factor productivity, at issue is whether the inputs themselves need adjustment. The Cobb–Douglas production function is

$$Y = Ae^{\lambda t}L^{\alpha}K^{\beta}M^{\gamma}e \quad (1)$$

which can be estimated in log-linear form as

$$\ln(y) = \ln(A) + \lambda t + \alpha \ln(L) + \beta \ln(K) + \gamma \ln(M) + \ln(e) \quad (2)$$

where Y, L, K and M are output, labor, capital and a real monetary variable such as M1 or M2 in the original research. To remove notational clutter t subscripts are not shown. In Sinai and Stokes (1972, footnote 5) the reported Kmenta (1967, p. 180–181) test suggested that the Cobb–Douglas function was more appropriate than the CES function for the Christensen and Jorgenson (1969, 1970) data, although others argued for the CES or translog models. Stokes-Sinai (1989) discussed some of this research for the United States which will not be discussed further here. To control for the effect of possible alternative functional forms, in preliminary results reported in this paper, only the Cobb–Douglas models (Eq. (1)) using alternative labor, capital and real balances variables are reported. Due to data availability, only two periods 1959–2011 and 1967-2011 are used.

3. Measurement vs misspecification

Griliches (1986, p. 1469) contrasted the two sides of the measurement problem. The first problem involved measurement problems in the data themselves, such as might occur with aggregation. The second was "that there are no data problems only model problems in econometrics. For any set of data there is the'right model' ". Due to the cautions raised by Bound, Brown, Mathiowetz, Heckman and Leamer (2001, 3708), which are cited below,

> "Standard methods for correcting for measurement error bias, such as instrumental variables estimation, are valid when errors are classical and the underlying model is linear, but not, in general, otherwise. While statisticians and econometricians have been quite clear about the assumptions built into procedures they have developed to correct for measurement error, empirical economists have often relied on such procedures without giving much attention to the plausibility of the assumptions they are explicitly or implicitly making about the nature of the measurement error. Not only can standard fixes not solve the underlying problem, they can make things worse!"

alternative approaches to patching a possibly poorly measured variable with instrumental variable methods have not been attempted.

Table 1 summarizes data from 1967–2011 when Divisia monetary data are available for alternative monetary aggregates and when capital stock data are available from the St. Louis Federal Reserve Databank. Table 2 summarizes data for the longer period (1959–2011), which will be used as a partial control. Data on labor and capital and output were obtained from the Federal Reserve Databank in St. Louis. Q is real gross domestic product in chained 2009 dollars. K is the real capital stock that was originally obtained from the Penn World Table 8.0 based on Feenstra, Inklaar and Timmer (2013). Unemployment (*unemp*) obtained from the U.S. Department of Labor was used to adjust the capital stock (*adj_k*) for utilization by the formula *adj_k*=*k**(1.-*unemp*). Fig. 2 shows logs of the two series. Both *lnk* and *ln_adj_k* were used in alternative models. The *lnk* series, in contrast to the *ln_adj_k* series appears to increase in almost a straight line, which makes the series very

Table 1
Annual Data for Period 1967–2011.

Variablel	Description	Mean	Std. Dev.
Hourwork	Hours Worked	188,884	33,262.65
lnl_hw	ln(hourwork)	12.1332	.1807461
Capital	Unadjusted Capital Stock	2.56e+07	8,884,285
realm2	SA Real M2 in 1982–1983 dollars	2455.038	691.7248
Labor	Total Nonfarm Payroll	104,979.9	3240.56
cpi	Consumer Price Index	123.4083	60.13691
real_gnp	Real GNP	9180.813	3526.293
unemp	Unemployment	6.168889	1.643558
dm4	ln(Divisia M4 / CPI)	1.334935	.2138698
dm4_t_cp	ln((Divisia M4 – T Bills)/CPI)	1.303846	.2045941
dm4_t_	ln((Divisia M4	1.263872	1.656467
lnk	ln(Capital)	16.99745	.3596384
lnrm2	ln(realm2)	7.769246	.2708849
lnl	ln(labor)	11.53608	.2317384
lnq	ln(real gnp)	9.049893	3,963,179
adj_k	capital*(1. – (unemp/100.))	2.40e+07	8,324,259
ln_adj_k	ln(adj_k)	16.93362	.3582489

Notes: For variable descriptions see text. Series dm4_T and dm4_t-cp=Divisia M4-T bills and t bills and– Commercial paper respectively where both are divided by the CPI.

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Table 2
Annual data for period 1959–2011.

Variable	Description	Mean	Std. Dev.
Hourwork	Hours Worked	178,583.5	39,389.12
lnl_hw	ln(hourwork)	12.06767	.2296242
Capital	Unadjusted Capital Stock	2.33e+07	9,863,815
realm2	SA Real M2 in 1982–1983 dollars	2267.313	781.5209
labor	Total Nonfarm Payroll	97,765.62	27,518.59
cpi l	Consumer Price Index	109.3934	64.70186
real_gnp	Real GNP	8326.432	3838.209
unemp	Unemployment	6.037736	1.575684
lnk	ln(capital)	16.86961	.4520903
lnrm2	ln(realm2)	7.666862	.3532927
lnl	ln(labor)	11.44796	.3008488
lnq	ln(real_gnp)	8.91556	.4881815
adj_k	capital*(1. − (unemp/100.))	2.19e+07	9,226,004
ln_adj_k	ln(adj_k)	16.80719	.4490829

Data sources listed in the text.

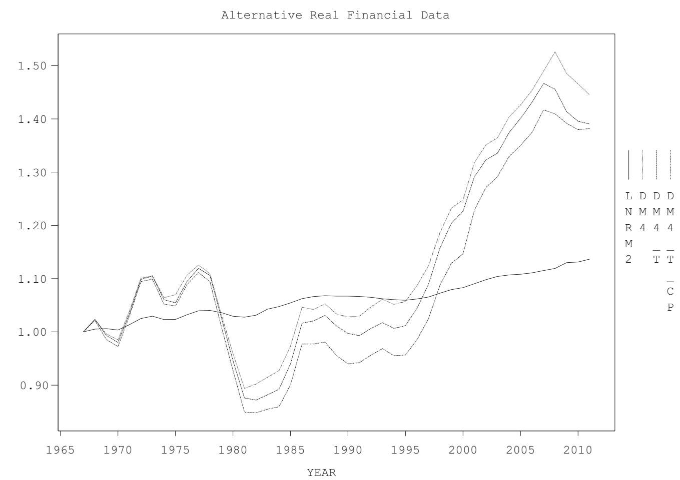

Fig.1. Alternative financial series.

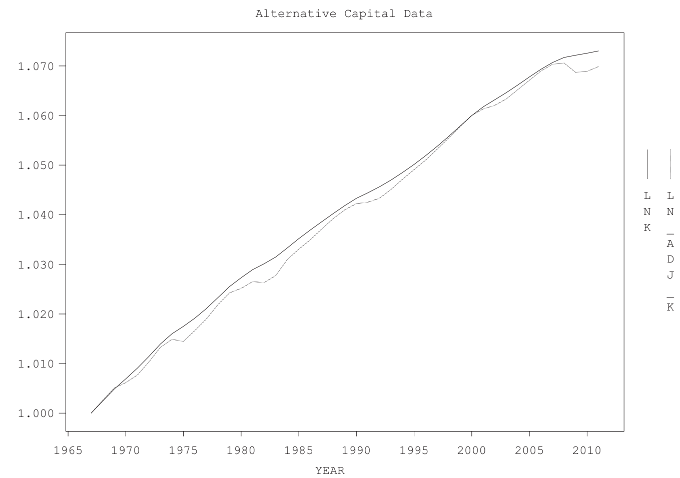

Fig. 2. Alternative capital series.

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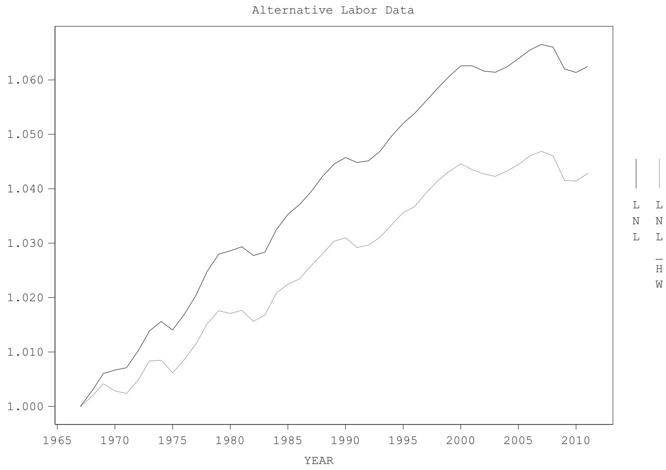

Fig. 3. Alternative labor series.

collinear with *time*. The labor series, *lnl*, was total nonfarm payroll because in an efficient market payroll should measure labor productivity. An alternative labor measure was hours worked by full-time and part-time workers, *hourwork*, which was obtained from the US Bureau of Economic Analysis. In later reported empirical work this measure proved to be more satisfactory. This variable is similar to the one used by Neuburger and Stokes (1974) in their German banking study using a Cobb–Douglas production function that did not show increasing returns to scale. Fig. 3 shows a plot of the natural log of the two alternative labor series. For Figs. 1–3 the data have been scaled for display purposes so that in 1967 the log values were 1.00. In empirical work the scaled data were not used.

Series *dm4*, *dm4_t* and *dm_t_cp* were obtained from the Center for Financial Stability in monthly form. The raw data were normalized to 1.00 in January 1967 before being divided by the *cpi* to form the real Divisia series.. The data used in the production function are for December of each year. Series *dm4*=Divisia M4. It is a broad aggregate, including negotiable money-market securities, such as commercial paper negotiable CDs, and T-bills. *Dm4*'s components are similar to those of the monetary aggregate once called *L*, but modernized to be consistent with current market realities using the Divisia methods as discussed in Barnett (2012) and Barnett (1980). Series *dm_t* excludes T-bills while series *dm_t_cp* in addition excludes those money-market securities not issued by financial intermediaries, such as commercial paper and T-bills, but does include negotiable CDs and repurchase agreements. The construction of Divisia data is complex and beyond the scope of this paper. Barnett (2012) is an excellent resource concerning the details of the calculation. Aggregation theory requires that to correctly form a money measure such as M2, each of the component series must be a perfect substitute. Clearly, this requirement is not satisfied by the usual *M2* series that just adds the component series. Divisia data attempt to correct for this problem by weighting the components of an aggregate series. Barnett makes a convincing case that the reported money series understates the true money supply with the result that the Federal Reserve has been getting a biased measurement of changes in liquidity. The conclusion from Fig. 1 is that in the latter period of the series the ln Divisia data appear to rise more steeply than the *lnrm2* series. A possible problem is that we are comparing ln real *M2* with the broader Divisia series. This is the best that can be done, since the Federal Reserve stopped reporting *M3* and *M4* (called *L*) in 2006 for reasons that have not been explained. Perhaps the Federal Reserve became aware of problems in these more aggregate monetary measures that were built by just adding up the components. A quote from Barnett (2012, 132) regarding *M1* that highlights another problem is shown next:

> "Banks have complete data on their demand deposits, since they need to service them and to do so as checking accounts, not as savings accounts. But to camouflage the evasion of reserve requirements on checking accounts, banks report sweeps to the Federal Reserve as being in the money-market deposit savings accounts (MMDAs), rather than in demand-deposit checking accounts. …. As a result *M1* is severely biased downward."

Footnote (9) to the above quote states:

> "It might appear that the damage to monetary aggregation from misclassification of sweeps is offset by using the broader monetary aggregate, M2, since the simple sum M2 includes MMDA's as well as regular checking accounts. The sweeps improperly removed from checking accounts are added back into MMDAs in the sum. But checking accounts and MMDA's are not perfect substitutes and are not treated as such in properly weighted monetary aggregates, such as Divisia *M2*. The misclassification of sweeps damages all properly constructed monetary aggregates."

Barnett (2012, 44–45) recounts that he met with Milton Friedman after Barnett (1980) appeared. Friedman noted his statement in Friedman-Schwartz (1970, 151–152) that indicates his awareness of the problems of simple aggregation of the components of *M2*. At that time Friedman did not have a satisfactory solution, nor did anyone else.

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Table 3
Alternative models of lnq in period 1967–2011.

Variable ı	MOD_1	Mod_2	MOD_3	MOD_4	MOD_5	MOD_6	MOD_7	MOD_8
Lnl	1.0356		.9707		.9406		. 99,865	
	9.22		11.08		11.36		11.27	
Lnk	−.41788		−.3712		−.3571		−.3801	
	−1.73		−2.34		−2.36		−2.38	
Lnrm2	.2102	.1547						
	4.54	4.33						
time	.01884	.0086	.02114	.0118	.02178	.01251	.02166	
	3.42	2.64	6.26	5.20	6.72	5.58	6.33	
Lnl_hw		.6436		.6795		.67313		.6988
		4.47		6.35		6.46		6.48
Ln_adj_k		.3496		.2899		.27315		.2844
		1.94		2.23		2.14		2.19
Dm4			.1562	.0969				
			6.86	6.11				
Dm4_t					.1496	.09314		
					7.39	6.35		
Dm4_t_cp							.14301	.08813
							6.88	6.18
Constant	2.141	−6.078	3.4619	−4.50	3.573	−4.152	3.311	−4.63
	.67	−3.94	1.75	−4.09	1.90	−3.82	1.67	−4.22
R**2	.9995	.9997	.9996	.9997	.9996	.9997	.9996	.9997
rho	.88332	.7933	.5330	.4455	.5212	.44331	.5459	.4556
RSS	.00384	.0024	.0036	.0022	.0034	.00212	.0035	.0022
DW-Orig.	.34770	.44836	.9376	1.116	.9613	1.1211	.9102	1.096
DW-GLS	2.0003	1.9636	1.905	1.800	1.922	1.8103	1.932	1.812
RTS	NA	1.1479	NA	1.066	NA	1.0394	NA	1.071

R**2 R squared of OLS Model. Rho=GLS Coef, RSS=GLS residual sum of squares. DW_ORIG=Durbin Watson for OLS Eq. DW-GLS=Durbin Wartson for GLS model. RTS= returns to scale set NA for models with negative coefficients. The t score is listed under the coef. Prais Winsten method used in GLS estimation. MOD_i=model i. For further discussion see text.

Fig. 1 shows the differences in the pattern of *lnrm2* and the ln of the three Divisia series. The Divisia series, while broader than *lnrm2*, show substantially more variance than the traditional *lnrm2* series, especially in the latter part of the period when there was a substantial increase, as shown in Fig. 1, which normalizes the beginning of the data to be 1.0.

Table 2 summarizes the data from 1959–2011, which show only small changes compared to the listed series that was shown in Table 1 for the shorter period. Models estimated with this longer dataset are a control to test if another ten years of earlier data alter the results. As noted earlier, the Divisia data are not available for this earlier period.

Table 4
Models 1959–2011 Where Divisia Data Are Not Available for the Complete Period.

Variable	MOD_9	MOD_10	MOD_11	MOD_12
Lnl	.8943	1.001		
	7.09	9.84		
Lnk	-.00265	-.2829		
	-.01	−1.47		
Lnrm2		.2328		.1617
		5.49		5.03
time	.0145	.01536	.0092	.00982
	2.72	3.59	3.20	4.03
Lnl_hw			.5144	.7054
			3.63	5.71
Ln_adj_k			.5143	.2639
			3.25	1.86
Constant	−31.05	−30.05	−24.2	−24.77
	−3.94	−4.91	−5.43	−6.55
R**2	.9988	.9993	.9995	.9997
rho	.9084	.9007	.7944	.8152
RSS	.0072	.0044	.00405	.00265
DW-Orig.	.3359	.3081	.4925	.4233
DW-GLS	1.616	1.983	1.733	2.016
RTS	NA	NA	1.029	1.131

For notes see Table 3.

4. Results

Table 3 reports alternative GLS models for the period 1967–2011 that were estimated by the Stata version 14 **prais** command which calculates an AR(1) model, using the Prais-Watson method. The results were verified with the **ar1** command of Rats version 9. The Prais-Watson method of estimation was selected since the GLS smoothing parameter is estimated jointly with the coefficients, and the first observation is not lost as would be the case with Cochrane–Orcutt and Hildreth–Lu and other similar methods. Doan (2014, 50) notes that in small samples there can be differences in the two approaches that arise in part due to the fact that the Prais-Watson maximum likelihood method "steers the estimates of ρ away from the boundaries at plus and minus one, with the difference becoming noticeable as ρ approaches these boundary values." In Tables 3 and 4 ρ = rho. The label RTS on the bottom of the table reports the estimated returns to scale that is defined if the input coefficients are greater than 0.0; otherwise NA is listed.

Model 1 in Table 3 reports results using the original definitions of the natural logs of labor and capital and real M2. The problem with this model is the coefficient on *lnk* is −.41788, which is not consistent with any theory. Model 2 reformulates the model by changing *lnl* to *lnl_hw* which, in place of the total nonfarm payroll measure, uses hours worked. In this model

Table 5
Generalized additive model tests for nonlinearity.

Model 13: Basic Model						
RSS	3.474611823925028E-03					
R**2	0.9994972335893030					
TSS	6.910986394472003					
Variable	df	coef	st err	z score	nl pval	lin_res
Constant	1.	−7.47800	0.9933	−7.528	NA	NA
LNL_HW	3.	0.345427	0.8169E-01	4.229	0.9210	0.4112E-02
LN_Adj_K	3.	0.720645	0.1066	6.763	1.000	0.6038E-02
TIME:	1	0.580989E-02	0.1997E-02	2.910	NA	0.3475E-02
Model 14: Basic Model Plus LNRM2						
RSS	2.090572269376180E-03					
R**2	0.9996975001613304					
TSS	6.910986394472003					
Variable	df	coef	st err	z score	nl pval	lin res
Constant	1.	−6.62619	0.8042	−8.240	NA	NA
LNL_HW	3.	0.56845	0.8343E-01	6.814	0.9999	0.3425E-02
LN_ADJ_K	3.	0.454540	0.9768E-01	4.653	1.000	0.3637E-02
LNRM2	3.	0.116494	0.2335E-01	4.988	0.8969	0.2471E-02
TIME	1.	0.768973E-02	0.1618E-02	4.751	NA	0.2091E-02
Model 15: Basic Model Plus DM4						
RSS	1.938153037091370E-03					
R**2	0.9997195547890759					
TSS	6.910986394472003					
Variable	df	coef	st err	z score	nl pval	lin_res
Constant	1.	−5.28129	0.7796	−6.775	NA	NA
LNL_HW	3.	0.544464	0.7328E-01	7.430	0.8447	0.2237E-02
LN_ADJ_K	3.	0.435986	0.8924E-01	4.885	0.8342	0.2228E-02
DM4	3.	0.880279E-01	0.1022E-01	8.617	0.9525	0.2390E-02
TIME:	1.	0.977224E-02	0.1579E-02	6.190	NA	0.1938E-02
Model 16: Basic Model Plus DM_t						
RSS	2.020335567009962E-03					
R**2	0.9997076632116327					
TSS	6.910986394472003					
Variable	df	coef	st err	z score	nl pval	lin_res
Constant	1.	−4.89966	0.8027	−6.104	NA	NA
LNL_HW	3.	0.571910	0.7431E-01	7.696	0.8859	0.2374E-02
LN_ADJ_K	3.	0.392276	0.9187E-01	4.270	0.6928	0.2235E-02
DM4_T	3.	0.945388E-01	0.9794E-02	9.652	0.5057	0.2163E-02
TIME	1.	0.106326E-01	0.1630E-02	6.524	NA	0.2020E-02
Model 17: Basic Model Plus DT_t_CP						
RSS	1.997287462384051E-03					
R**2	0.9997109982065684					
TSS	6.910986394472003					
Model	df	coef	st err	z score	nl pval	lin_res
Constant	1.	−5.26856	0.7910	−6.661	NA	NA
LN_HW	3.	0.594736	0.7581E-01	7.846	0.8839	0.2344E-02
LN_ADJ_K	3.	0.398918	0.9125E-01	4.372	0.7528	0.2240E-02
DM4_t_CP	3.	0.860433E-01	0.9345E-02	9.207	0.6824	0.2204E-02
TIME	1.	0.103706E-01	0.1612E-02	6.435	NA	0.1997E-02
	11.0					

Notes: nl pval is the significance that the variable is nonlinear. Lin-res measures the RSS if that variable is constrained to be linear.

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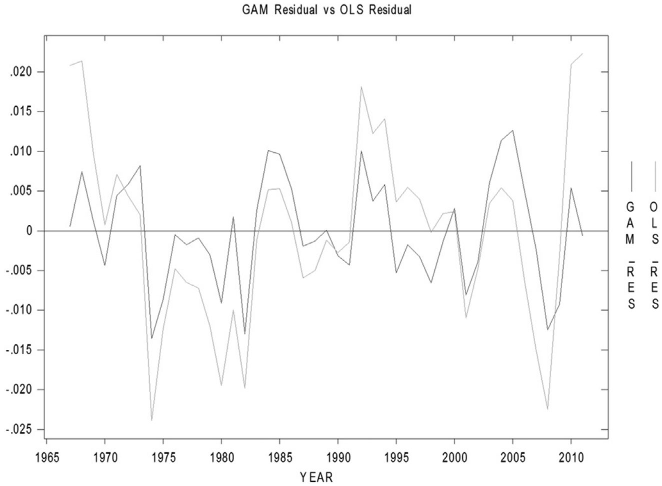

Fig. 4. GAM and OLS residuals by year.

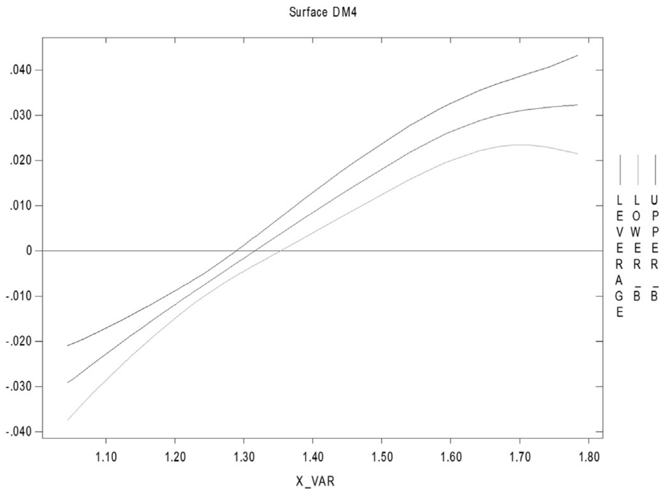

Fig. 5. Nonlinear surface for DM4 as a function of its value.

lnk is also changed to *ln_adj_k*. For model 2, all input coefficients are greater than 0.0 and significant and the measured returns to scale is 1.14792. Model 3 uses the original labor and capital data but replaces *lnrm2* by the Divisia *dm4* measure. Again, we see a negative sign for lnk of −.37124, as was the case in model 1. Models 1 and 3 indicate that the negative capital coefficient is not due to the monetary variable *lnrm2*.

Model 4, like model 2, replaces the *lnl* and lnk variables with *lnl_hw* and *ln_adj_k* respectively, while retaining the *dm4* variable. Here the measured returns to scale fall to 1.0663, with all input coefficients positive and significant. Models 5 and 6 and models 7 and 8 repeat the process again to test whether there are effects on the results using the slightly less broad Divisia monetary aggregates *dm4_t* and *dm4_t_cp* respectively. The results follow the same pattern with *lnk* again being negative in equations 5 and 7 that contain *dm4_t* and *dm4_t_cp* respectively. In equations 6 and 8, where *lnl_hw* and *ln_adj_k* replace *lnk* and *lnl*, all the input coefficients are positive and the returns to scale fall to 1.03942 and 1.03132 respectively. In summary, the findings in Table 3 support the hypothesis that the Divisia monetary variables are superior to lnrm2.

Table 4 lists results for the extended period dataset (1959–2011). Models 9 and 10 use the original data and show the exact same problems, the coefficient of *lnk* is negative and not significant without and with *lnrm2*, respectively. Models 11 and 12 contain the revised labor and capital and have returns to scale of 1.0289 and 1.131, respectively.

5. Diagnostic tests

GAM models were estimated to validate the effects of the alternative date specifications on reducing measured nonlinearity using the B34S software developed by Stokes (1997) using Fortran code originally developed by Hastie and Tibshirani (1990). Model 13 on Table 5 shows that a model that contains only adjusted labor, adjusted capital, and time shows nonlinearity for the adjusted capital variable since if the linear restriction is imposed, $e'e$ increases from.0034746 to.006038. Model 14 shows that if the log of real M2 is added to the model, the result is that both the adjusted labor and adjusted capital variables are nonlinear. In model 15 we find that if *dm4* is added, it is found to be nonlinear at 95.25%, although now the nonlinearity in the adjusted capital and labor series is removed. This finding is consistent with the hypothesis that *dm4* may not be the appropriate aggregate monetary variable since it contains *t-bills*. model 16 tests this by using *dm4_t* in the model in place of *dm4*. For this specification no nonlinearity is found. Model 17 replaces *dm4_t* with *dm4_t_cp*, further narrowing the monetary variable. Again no nonlinearity is found.

Fig. 4 shows the residuals of model 15. Note the periods when the OLS fit is substantially worse than the GAM fit. Fig. 5 shows the surface of *dm4*, which is found to be nonlinear. This finding is especially pronounced for high values of *dm4* which occur in the latter period. The tentative conclusion is that as the composition of *dm4* was changed to include relatively more t-*bills*, the marginal product of real balances declines.

6. Conclusion

Stokes (2013) found nonlinearity in most of the familiar production function papers that indicated increasing returns to scale. At issue is whether this finding is due to misspecification of the functional form or to data mismeasurement which manifests itself as nonlinearity. Two new datasets were developed. One dataset is for 1959–2011 when Divisia money data are not available and one for 1967–2011 where Divisia monetary data are available. Alternative labor and capital series as well as *dm4*, *dm4_t* and *dm4_t_cp* have been tested in alternative specifications. Models that use the natural log of hours worked for the labor variable and the natural log of the capital stock adjusted by one minus the unemployment rate for utilization with the addition of *dm4_t* or *dm4_t_cp* have removed the measured increasing returns and have indicated no nonlinearity in the residual. These models have been found to be substantially more suitable than those using the natural log of the usual M2 data as was done in prior research discussed in Stokes (2013).

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