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Full Length Research Paper

Wage augmented stochastic frontier model with truncated normal distribution

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This study considered wage augmented production frontiers with inefficiency effects model proposed by Battese and Coelli (1992) where the efficiency wage hypotheses was tested. An unbalanced panel data on 31 manufacturing firm for the period 1989 to 2000 was used in this study. The wage augmented Cobb-Douglas production function was originated to be an unsatisfactory representation of the data compared to wage augmented Translog frontier model. The results showed that the wage level was one of the significant factors contributing to the output and technical efficiency in truncated normal distribution which was found to be of inferior quality in manufacturing industry in Bangladesh.

Key words: Inefficiency effects, production model, truncated normal distribution.

INTRODUCTION

The manufacturing process may play a vital role in the development process by creating new jobs, increasing exports, and displacing imports. But efficiency is the first condition that has to be achieved to be competitive internationally. In order to accelerate the development process, industries have to be come technically efficient. Without improving its technical efficiency, the manufacturing sector cannot play the desired role in the process of economic development of the country. The way, efficiency analysis is an issue of interest given that the overall productivity of an economic system is directly related to the efficiency of production of the components within the system.

We are concerned with the study of wage level efficiency in manufacturing firm of Bangladesh using stochastic frontier production model since the wage level is a significant factor in determining efficiency at the firm level in the manufacturing firm. However, efficiency wage hypothesis states that work effort depends positively on the wage level.

A number of studies have been done in the context of wage level efficiency (for example Solow, 1979; Shapiro and Stiglitz, 1984, for shirking version; Salop, 1979 for rnover version; Weiss, 1980 for adverse selection version; Akerlof, 1982 for sociological version). In this same context, a few works have been done for the efficiency measurements of firms (Riveros and Bouton, 1994; Saygili, 1998; Rogers, 2002; Mahadevan, 2002a; Ogloblin and Brock, 2005; Jajri and Ismail, 2006; Brock and Ogloblin, 2006; Blackaby et al., 2007; Brown and Taylor, 2008; Okoye et al., 2008; Rana et al., 2010) using stochastic frontier analysis. This study is motivated by the informal structure of the industrial wage market in Bangladesh. In order to test the efficiency wage hypothesis, this study was employed both wage augmented Cobb-Douglas and standard Translog production frontiers to measure technical efficiency of industries of firms in Bangladesh. Here the effect of the wage level on a firm's performance is directly tested using Battese and Collie (1992) model.

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MATERIALS AND METHODS

The data obtained from the Census of Manufacturing Industries (CMI) is conducted by the Bangladesh Bureau of Statistics (BBS) every year. The study area covered selected 3-digit census factories, under the registered manufacturing sector of Bangladesh over the reference period 1988-1989 to 1999-2000. As data for three years, viz. 1994 to 1995, 1996 to 1997 and 1998 to 1999 were not published; data for the remaining 9 years are considered for this study. The estimates at constant prices (1988 to 1989 = 100) are derived. We have considered 31 industries for each year

Table 1. Summary statistics of output, input and explanatory variables.

Variable	Description	Mean	Std. deviation	Minimum	Maximum
Y	Gross output	14.619	2.544	5.332	19.482
X_1	Capital	13.633	2.562	4.779	18.864
X_2	Manual labor	4.753	.611	1.000	7.086
X_3	Non-manual labor	4.807	.614	2.647	7.381
X_4	Wage rate for manual labor	3.913	.583	.500	5.381
X_5	Wage rate for non-manual labor	3.239	.565	1.465	19.216
X_6	Cost of raw materials	14.106	.564	.020	19.216
X_7	Time trend				

N = 279.

and we have total 279 observations over the nine year time period. The motivation for the choice of this data set is that, to the best of our knowledge, it is the only existing comprehensive firm level data set available in Bangladesh followed by standard input–output classification, Bangladesh Bureau of Statistics. Variables considered in this study including dependent, independent variables are listed in Table 1.

Application of an average production function as well as the stochastic production frontier framework is appropriate to analyze wage efficiency on productivity and efficiency. Cobb-Douglas production frontier and Translog frontier production model were used for the analysis of panel data, using frontier analysis. The model is discussed in this study assuming that the data are available for a sample of N firms over T time periods.

Wage augmented Cobb-Douglas stochastic frontier production model

Assuming a standard log-linear (Cobb-Douglas) production function and taking logs produces the production frontier model in the form proposed by (Lovell et al., 1992):

$$\ln y_{it} = \beta_0 + \sum_{i=1}^{7} \beta_i \ln x_{it} + v_{it} - u_{it} \quad (1)$$

where y_{it} represent the gross output level of the i-th sample industry in t-th time, x_{it} of input variables (capital, manual labor, non-manual labor, wage rate for manual labor, wage rate for non-manual, cost of raw materials and time) the i-th industry in t-th time and a vector, β, $\beta_i\ (i = 1, 2, \ldots, 7)$ stands for the output elasticity with respect to the i-th input. V_{it} s are assumed to be independent and identically distributed random errors which have normal distribution with mean zero and variance σ^2 and independent from U_{it}; U_{it} s are non-negative random variables associated with the technical inefficiency of production.

Wage augmented translog stochastic frontier production model

We used a stochastic frontier production model for panel data proposed (Battese and Coelli, 1992), in which inefficiency effects are assumed to be distributed as truncated normal variables with time varying inefficiency effects. In investigating the influence labor wage awareness efficiency a wage augmented standard Translog production function with composed errors can be defined as:

$$\ln y_i = \beta_0 + \sum_{i=1}^{7} \beta_i \ln x_{it} + \frac{1}{2}\sum_{i=1}^{7}\sum_{j=1}^{7} \beta_{ij} \ln x_{it} \ln x_{it} + \sum_{i=1}^{7}\sum_{i>j}^{7} \beta_{ij} \ln x_{it} \ln x_{it} + v_{it} - u_{it} \quad (2)$$

Given the specifications of the stochastic frontier production function, defined by equation (1) and (2), the technical efficiency of the i-th industry in the t-th year is defined by (Battese and Coelli, 1988; Taymaz and Saatci, 1997; Kumbhakar and Lovell, 2000).

$$TE_{it} = \exp\left(-U_{it}\right) \quad (3)$$

The technical efficiency can be predicted using the Computer program FRONTIER Version 4.1 (Coelli, 1996a) which calculates the maximum-likelihood estimators of the predictor for equation (5) that is based on its conditional expectation (Battese and Coelli, 1993).

In stochastic frontier production model defined by equation (1) and (2), using the composed error terms we utilize the parameterization of (Battese and Corra, 1977) who replace σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \frac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2}$. In the truncated and half-normal distribution, the ratio of firm specific variability to total variability γ is positive and significant, implying that industry specific technical efficiency is important in explaining the total variability of output produced.

Hypothesis test

In this study the hypothesis tests are conducted to determine the distribution of the random variables associated with the existence of technical inefficiency and the residual error term. Test of hypothesis for the parameters of the frontier model is conducted using the generalized likelihood-ratio statistics, λ defined by

$$\lambda = -2\ln\left[L(H_0)/L(H_1)\right], \quad (4)$$

Where $L(H_0)$ is the value of the likelihood function for the frontier model, in which parameter restrictions specified by the null hypothesis, H_0, is imposed; and $L(H_1)$ is the value of the likelihood function for the general frontier model. If the null hypothesis is true, then λ has approximately a chi-square (or mixed square) distribution with degrees of freedom equal to the difference between the parameters estimated under H_0 and H_1, respectively. If the null hypothesis involves $\gamma = 0$, expressing that the technical inefficiency effects are not present in the model. Setting the null hypothesis that $H_0: \eta = 0$ provides the technical inefficiency is time-invariant. If parameter η is positive, the technical efficiency of the sample country increases over time and vice versa. However, if parameter η is zero, then the country effect will be constant over time. Again, a half-normal distribution as the most appropriate assumption for the inefficiency distribution is undertaken to the model. The half-normal distribution is a special case of the truncated normal distribution, and implicitly involves the restriction $H_0: \mu = 0$. If parameter μ is zero, then country effect would have a half normal distribution instead of a truncated normal distribution.

RESULTS AND DISCUSSION

Ordinary least square estimation

At the first step we carried out the ordinary least square estimation to assess the significance of the seven input variables in Table 2. The parameter estimates of this OLS method showed the average performance of the industries or firms. The coefficient of the capital input was found to be highly significant. Manual labor and non-manual labor are also significant. The wage rate for non-manual labor was found to be significant. The cost of raw material used in this analysis was established highly significant effect on the production function. The wage rate for manual labor and year were found to be insignificant. It was apparently implied that all input variables used in this method except wage rate for manual labor were essential contributing factors for enhancing the productivity of the manufacturing industries.

Maximum-likelihood estimation from wage Augmented Cobb-Douglas production frontier

The maximum likelihood estimates of wage augmented Cobb-Douglas frontier production function were presented in Table 3. We Model (1) corresponding to wage augmented Cobb-Douglas frontier function presented the basic specifications. In model (1) the parameter estimate of capital was found positive, and highly significant at 1% level. Manual labor coefficient was observed significant at 10% level for the model (3) and model (4) while the parameter estimate for non-manual labor was not significant for each of the models. Therefore we concluded that capital was found to be more crucial than labor in determining output in Bangladeshi manufacturing industries.

The results also indicated that the technical inefficiency effects tended to upwards over time since the estimated value of η was negative and significant. However, the γ-estimate associated with the variance of the technical inefficiency effect was found large and significant.

Furthermore, with regard to the specification of the error term, the estimation results it was shown that the traditional that is Cobb-Douglas production function was observed strongly rejected, implying that the technical inefficiency effects associated with this industry was significant.

Maximum-likelihood Estimation from Wage Augmented Translog Production Frontier

The functional specification of the stochastic production frontier was determined by testing the adequacy of the Translog specification to the data relative to the more restrictive Cobb-Douglas. Table 5 reports this test, where the null hypothesis was rejected showing that the Translog specification fitted the data better than the Cobb-Douglas. Table 4 presented the maximum likelihood estimates of conventional wage augmented Translog frontier production functions. Model (1) presented the basic specifications, that is, all the input variables were included in this model (1) and we did not use wage variable on the model (4).

In model (1) the augmented the production frontier was formulated by the wage rate relative to the industry average *WRML* and *WRNML*; its coefficient signs were negative and insignificant. The parameter estimate of capital was positive, but insignificant. Square term of the capital was found highly significant at 1% level in each of the models. Manual labors were significant at 1% level for both the model (3) and model (4) and were insignificant for the remaining models. The parameter estimates for non-manual labor was found not significant for each of the models. The similar results were observed once again that capital was more crucial than labor in determining output in Bangladesh manufacturing industries. Wage rate for manual labor and wage rate for non-manual labor were found to be negative and statistically insignificant. From the findings of “Sollow codition” (Sollow, 1979) implied that the estimated coefficients of the wage level and physical labor input in the production function should be same. The estimated results indicated that the Sollow condition does not hold since the coefficient of the relative wage level were significantly varied than the coefficients of the labor variable. Based on the asymptotic t-values, the cost of raw materials coefficient came out to be statistically significant at 1% level in each of the models. All other coefficients except square term of capital and cost of raw materials turned out to be statistically insignificant. This is rather a surprising result. This altogether indicated that the square term of capital and cost of raw materials variable are extraordinarily important for the manufacturing industries of Bangladesh. The new variable time trend included in this

Table 2. OLS Estimates of Cobb-Douglas production function.

Variable	Parameter	Coefficient	S.E.	T-ratio
Constant	β_0	1.131*	0.288	3.916
X_1	β_1	0.257*	0.023	10.979
X_2	β_2	0.0891***	0.054	1.624
X_3	β_3	- 0.099**	0.055	-1.801
X_4	β_4	0.075@	0.074	1.021
X_5	β_5	-0.107***	0.075	-1.419
X_6	β_6	0.710*	0.021	33.732
X_7	β_7	0.014	0.012	1.159
Sigma square	σ^2	0.200		
Ln-Likelihood		-167.457		

*, **, *** are significant at 1, 5 and 10% levels respectively. @ means insignificant, S.E. = Standard error.

Table 3. Maximum-likelihood estimates of the Cobb-Douglas Stochastic Production Frontier.

Variable	Parameter	Cobb-Douglas							
		Model (1)		Model (2)		Model (3)		Model (4)	
		Coe	t-ratio	Coe	t-ratio	Coe	t-ratio	Coe	t-ratio
Constant	β_0	4.459*	10.384	4.396*	9.578	4.259*	10.149	4.434*	9.201
X_1	β_1	0.197*	6.798	0.210	0 .751	0.215*	7.721	0.212*	7.558
X_2	β_2	0.055	1.014	0.050	1.005	0.064***	1.332	0.076***	1.569
X_3	β_3	0.059	1.048	0.041	0.750	0.024	0.478	0.024	0.499
X_4	β_4	0.026	0.431			0.044	0.769		
X_5	β_5	0.075	1.171	0.076	1.290				
X_6	β_6	0.540*	20.112	0.544*	19.251	0.552*	20.595	0.551*	19.976
X_7	β_7	0.064*	4.684	0.069*	5.322	0.067*	4.811	0.070*	5.249
Variance parameter									
Sigma	σ	0.729*	8.410	0.735*	8.601	0.706*	8.112	0.724*	7.107
Sigma-Squared (u)	σ_u^2	0.456		0.465		0.421		0.446	
Sigma-Squared (v)	σ_v^2	0.076		0.075		0.078		0.078	
Lamda (σ_u/σ_v)	λ	2.449		2.489		2.323		2.391	
ε		0.532		0.541		0.499		0.524	
$\mathrm{var}(u)/\mathrm{var}(\varepsilon)$		0.857		0.859		0.843		0.851	
Gamma	γ	0.858*	35.363	0.860*	4.406	0.843*	29.947	0.852*	26.002
Mu	μ	1.353*	6.276	1.364*	5.669	1.298*	5.956	1.337*	5.767
Eta	η	-0.022*	-2.252	-0.025*	2.730	-0.024**	-2.262	-0.022**	-2.114
Ln-likelihood		-98.221		-98.447		-98.997		-99.097	
Mean Efficiency		.309		.309		.326		.322	

*, **, *** are significant at 1, 5 and 10% respectively. *Model (1) means with WRML and WRNML; *Model (2) means without WRML; *Model (3) means without WRNML; *Model (4) means without WRML and WRNML.

Table 4. Maximum-likelihood estimates for parameters of the Translog Stochastic Frontier production function.

Variable	Parameter	Translog production function							
		Model(1)		Model(2)		Model(3)		Model(4)	
		Coe	t-ratio	Coe	t-ratio	Coe	t-ratio	Coe	t-ratio
Constant	β_0	7.221*	7.461	6.533*	4.896	5.105*	5.203	4.817*	4.823
X_1	β_1	0.025	0.109	0.017	0.099	0.079	0.370	0.026	0 .162
X_2	β_2	-0.562	-1.077	-0.340	-0.782	-0.928*	-2.251	-0.909*	-2.507
X_3	β_3	-0.302	-0.553	-0.251	-0.484	0.391	0.998	0.459	1.311
X_4	β_4	-0.566	-.848			-0.381	-0.743		
X_5	β_5	-0.801	-1.193	-0.912	-1.660				
X_6	β_6	0.931*	4.886	0.869*	5.994	0.947*	5.370	0.888*	6.355
X_7	β_7	-0.025	-.196	-0.030	-0.248	-0.136	-0.111	-0.113	-1.087
X_1^2	β_{11}	0.034*	3.411	0.035*	3.546	0.043*	4.433	0.044*	4.915
X_2^2	β_{22}	-0.057	-.871	-0.024	-0.707	-0.026*	-4.722	-0.003	-0.118
X_3^2	β_{33}	-0.004	-.089	0.034	0.860	-0.019	-0.556	-0.011	-0.351
X_4^2	β_{44}	-0.002	-.021			0.041	0.560		
X_5^2	β_{55}	0.044*	3.178	0.375*	3.815				
X_6^2	β_{66}	0.038*	4.701	0.036*	4.699	0.037*	4.853	0.035*	4.605
X_7^2	β_{77}	0.019*	5.023	0.019*	4.921	0.015*	3.891	0.016*	4.789
$X_1 * X_2$	β_{12}	0.096**	1.768	.089**	1.803	0.098**	2.042	0.117*	2.511
$X_1 * X_3$	β_{13}	-0.038	-.695	-0.048	-0.899	-0.061	-1.195	-0.067	-1.316
$X_1 * X_4$	β_{14}	-0.009	-.124			-0.014	-.286		
$X_1 * X_5$	β_{15}	0.006	.103	-0.0005	-0136				
$X_1 * X_6$	β_{16}	-0.074*	-4.686	-0.071*	-4.401	-0.087*	-5.80	-0.092*	-6.120
$X_1 * X_7$	β_{17}	-0.006	-.810	-0.010	-1.571	-0.004	-0.644	-0.007	-1.064
$X_2 * X_3$	β_{23}	0.061	.783	0.008	0.195	0.041	0.661	0.016	0.379
$X_2 * X_4$	β_{24}	0.073	.889			0.109***	1.473		
$X_2 * X_5$	β_{25}	-0.192**	-1.784	-0.182**	-1.883				
$X_2 * X_6$	β_{26} 0	-0.003	-0.068	-0.002	-0.044	-0.053***	-1.328	-0.052***	-1.321
$X_2 * X_7$	β_{27}	-0.008	-0.268	0.005	0.239	0.005	0.197	0.008	0.385
$X_3 * X_4$	β_{34}	0.849	0.783			0.049	0.626		
$X_3 * X_5$	β_{35}	0.179***	1.388	0.211***	1.959				
$X_3 * X_6$	β_{36}	-0.023	-0.469	-0.005	-0.115	0.024	0.562	0.041	0.982

Table 4. Contd.

$X_3 * X_7$	β_{37}	-0.003	-0.125	-0.008	-0.337	-0.007	-0.304	-0.009	-0.420
$X_4 * X_5$	β_{45}	-0.048	-0.243						
$X_4 * X_6$	β_{46}	0.019	0.273			-0.028	-0.573		
$X_4 * X_7$	β_{47}	-0.022	-0.860			-0.003	-0.149		
$X_5 * X_6$	β_{56}	-0.121**	-2.002	-0.100**	-2.307				
$X_5 * X_7$	β_{57}	-0.042***	-1.452	-0.046***	-1.923				
$X_6 * X_7$	β_{67}	0.017**	2.257	0.016**	2.107	0.010***	1.407	0.008***	1.334
Variance parameter									
Sigma	σ	0.557*	5.371	0.852***	1.513	0.658*	7.317	0.630*	6.560
Sigma-Squared (u)	σ_u^2	0.261		0.677		0.383		0.343	
Sigma-Squared (v)	σ_v^2	0.050		0.049		0.051		0.054	
Lamda (σ_u / σ_v)	λ	2.284		3.489		2.740		2.520	
ε		0.311		0.726		0.434		0.397	
$\mathrm{var}(u/\varepsilon)$		0.839		0.932		0.882		0.864	
Gamma	γ	0.839*	19.523	0.932*	19.615	0.882*	36.912	0.864*	29.456
Mu	μ	1.022*	5.373	1.134*	3.138	1.238*	6.099	1.173*	5.556
Eta	η	-0.025**	-2.058	-0.326***	-1.715	-0.021***	-1.910	0.023***	-1.818
Ln-Likelihood		-39.726		-39.256		-36.266		-37.325	
Mean Efficiency		0.398		0.3882		0.3226		0.3585	

*, **, *** are significant at 1, 5 and 10% respectively.

model was found totally insignificant. But the square product of year was significant at 1% level and the sign of this square of time trend is positively indicated that the technical efficiency turned down over time. The second order parameters β_{11} *and* β_{66} were expected to show negative signs but they appeared positive and statistically significant. So the wrong signs did not considerably distort the results.

The coefficient of the interaction variables between capital, manual labor and cost of raw materials driven out to be statistically significant at 1% level of significance based on the asymptotic t-values whereas the interaction between capital and non-manual labor, and interaction between capital and wage rate for manual labor were found to be negative and insignificant. The interaction between capital and wage rate for non-manual labor was found positive but insignificant for the model (1) and it was found to be negative for the model (2). The parameter estimates of the interaction between manual labor and non-manual labor with the time trend turned out to be insignificant. The interaction between manual labor and wage rate for manual labor was found significant only for the model (3).

The interaction between manual labor and wage rate for non-manual labor came out to be significant at 5% level of significance for both the model (1) and model (2). The interaction between non-manual labor and wage rate for non-manual labor was identified significant at 10% level for both the model (1) and model (2). The second order coefficient of wage rate for non-manual labor and cost of raw materials was negative and significant. And also interaction between these two variables (wage rate of non-manual labor and cost of raw materials) with the time trend found to be significant.

As the variance parameter, γ which lies between 0 and 1, indicated that technical inefficiency was stochastic and it was relevant to obtain an adequate representation to the data. The values of the variance parameter are observed 0.84, 0.93, 0.88 and 0.86 for the respective models. These interpreted that the variance of the

Table 5. Generalized likelihood-ratio tests of hypothesis for parameters of the Stochastic Frontier Production Function for manufacturing industries in Bangladesh.

Null hypothesis	Log likelihood	Test statistics λ	Critical value	Decision
Wage Augmented Translog Model (1)	-39.726			
$H_0: \beta_{ij} = 0, i \leq j = 1,2.3,4,5,6,7$	-98.221	116.99	18.3	Reject H_0
$H_0: \beta_7 = \beta_{i7} = 0, i = 1,2,3,4,5,6,7$	-45.821	12.19	11.07	Reject H_0
$H_0: \gamma = 0$	-109.22	138.997	7.05	Reject H_0
$H_0: \mu = 0$	-39.805	0.158	3.84	Reject H_0
$H_0: \eta = 0$	-42.568	5.684	3.84	Reject H_0

All critical values are at 5% level of significance.
*The critical values are obtained from table of Kodde and Palm (1986). The null hypothesis which includes the restriction that γ is zero does not have a chi-square distribution, because the restriction defines a point on the boundary of parameter space.

inefficiency effects was a significant component of the total error term variance and then, firms deviations from the optimal behavior were not only due to random factors. Since the estimated σ^2 and γ were statistically significant at 1% level so these indicated the justification of using a stochastic frontier production model in this case because of the presence of technical inefficiencies in manufacturing industries in question.

Mean technical efficiencies were observed 39.8, 38.82, 32.26 and 35.85 respectively for each of the models. These were interpreted as follows: In the short run, there was a scope for increasing manufacturing production by 40, 39, 32 and 36% by adopting technologies and techniques used by the best practice manufacturing firms. These also suggested that, on the average; about 60, 61, 68 and 64% of production yield are lost due to inefficiency.

Tests of hypothesis

To test the hypothesis, a nested hypothesis was performed to determine whether the Cobb-Douglas specification was an adequate representation of the frontier production function or not. This test used the log likelihood ratio test. Table 5 outlined the results of the null hypothesis. The null hypothesis, $H_0: \beta_{ij} = 0$ was rejected in favor of the Translog production function.

The second null hypothesis $(H_0: \beta_7 = \beta_{i7} = 0,\ i = 1,2,3,4,5,6,7)$ explored the test that there was no technical progress for the frontier as it was rejected the hypothesis, implying the production frontier shifted over time. The null hypothesis $H_0: \gamma = 0$, that specified no technical inefficiency effects which was strongly rejected for all industries. This showed that Translog production function was not equivalent to the traditional average response function. Then, the frontier model could not be reduced to a mean response production function (OLS estimation) to represent the data precisely.

Given the specification of the stochastic frontier with time varying inefficiency effects, the null hypothesis $H_0: \eta = 0$ and $H_0: \mu = 0$, which also explored that the technical inefficiency effects are time invariant and half normal distribution, were rejected indicated that technical inefficiency effect varied significantly over time and that truncated normal distribution was preferable to the half normal distribution for inefficiency effect.

CONCLUSION

In this study we experienced the implication of wage efficiency hypothesis for the manufacturing industry of Bangladesh. We anticipated both Cobb-Douglas production function and Translog production function. Translog Production function was found better characterized data than Cobb-Douglas production function. Wage rate for manual labor and wage rate for non-manual labor were found to be negative and statistically insignificant. The interaction between manual labor and wage rate for manual labor was found significant only for the model (3). In those analyses we can say that in developing country like Bangladesh administrator body is not showing much interest about giving much wage to labor and also labor are not much conscious about what they are receiving. Usually we can see that higher wage enhances workers effort and as well as production output. But in this study we see that the wage level is not in a satisfactory position which can produce increase production and we get low production output. On the basis of region wage level differs significantly so further research can be done by researchers in the context of wage augmented model with regional wage level data.

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