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Efficiency and productivity of the Mongolian livestock sector in an open economy

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Abstract

In the early 1990s, Mongolia initiated a transition from a command to a market economy; accordingly, significant changes took place in the livestock sector, including decollectivization, privatization, and greater exposure to international trade. Taking into account these changes, this study measures technical efficiency and its sources—including trade openness—of the Mongolian livestock sector by using a stochastic production frontier model on province-level panel data for the period 2001–2011. Furthermore, we measure and decompose changes in total factor productivity (TFP) by using the results from the stochastic frontier analysis and the Malmquist TFP index. Our results suggest that trade openness is one of the most important determinants increasing efficiency of the sector, in addition to herd size and access to electricity. TFP increased during 2001–2011, but at a decreasing rate. The technical change was progressive until 2009, but turned regressive afterwards, suggesting a pressing need for technical improvements in the sector.

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1. Introduction

The Mongolian livestock sector has undergone considerable changes since Mongolia's transition from a command to an open market economy in 1990. With the privatization of livestock, state collectives were broken down into small household farms, which were mostly subsistence-based. Moreover, in the early transition period many newly unemployed from the collapse of state owned enterprises moved to rural areas to earn a livelihood from herding. The urban-rural migration was reversed in the early 2000s, as many herders with a small herd size were unable to survive the consecutive harsh winters of 1999–2002 and the drought in 2003. At the same time, households with large herd sizes were increasing, indicating their successful transition towards a more commercialized livestock production.

One of the major changes in the livestock sector was the withdrawal of direct support from the government. As the physical infrastructure and socio-economic support by the rural collectives collapsed, livestock production became more "traditional," that is, extensively managed livestock production depended almost entirely on natural forage (World Bank 2010). Furthermore, due to lack of maintenance the depreciation of irrigation systems and wells, built during the socialist period, has made livestock herding more vulnerable to weather shocks and associated loss of animals.

Although resumption of the more traditional livestock herding management may be viewed as a step backward from the relatively intensive livestock production management of the socialist period, the current form of livestock production is a rational response of herders to structural changes (World Bank 2010). Currently, herders have no choice other than expanding the herd size to manage risks and increase output. Moreover, the fact that pastoral land and water resources are kept under state ownership creates no incentive for herders to invest in improving land productivity.

While operating private herding on public land and being subject to environmental risks, Mongolian herders gradually converted into profit-oriented commercial producers in the open market economy. Rapidly increasing the number of livestock, overcrowding pastureland close to markets, and changing herd composition are indications of transition to the commercialization of the sector. Since privatization, most species of livestock have increased with the most significant increase in goat numbers. Understanding the commercial aspects of the livestock production, as Mongolia opened up for international trade, herders increase goat numbers in response to greater demand for cashmere from China and some European Union countries. Currently, Mongolia is the second largest raw cashmere exporter after China.

However, exports of other livestock products are still negligible, as Mongolia has become more open in trade as a share of GDP. There are a number of reasons for this, one of which is the low productivity of the sector trying to compete in world markets. Many of the livestock products are subject to sanitary and product standards in the export market, while Mongolian herders lack technology and knowledge to comply with these standards.

In order to transform to a more commercialized production system and successfully participate in the world markets, the challenge facing the Mongolian livestock sector is to improve productivity and efficiency, and invest in technology. For this reason, it is important to study the current level of productivity and efficiency of the sector in relation to market changes and openness to trade. The relationship between trade and technical efficiency is an empirical question because trade theories do not provide a clear explanation of this link (Rodrik 1992). Researchers have studied the relationship between trade openness and technical efficiency at the industry or national level, whereas the case of the agricultural sector has rarely been studied with the exception of Shaik and Miljkovic (2011) and Miljkovic *et al*. (2013). Both studies find no empirical relationship between trade openness and technical efficiency of the agricultural sector. Therefore, this study intends to contribute to the empirical literature of technical efficiency of the agricultural sector and trade openness. In addition, productivity and efficiency analysis in Mongolia is limited to partial indicators of productivity. Thus, we aim to fill this gap in the literature regarding Mongolia.

The objective of the study is to measure technical efficiency and its sources, including trade openness measured by the share of trade in GDP, of the Mongolian livestock sector. We use a stochastic production frontier analysis and its associated inefficiency model on province-level panel data for the period 2001–2011. In addition, we further aim to measure and decompose changes in TFP using the results from the stochastic frontier analysis (SFA) and the Malmquist TFP index.

The rest of the paper is organized as follows. Section 2 describes the data and methodology. Section 3 conducts the hypothesis tests and chooses the empirical model. Section 4 discusses the results and section 5 concludes.

2. Methodology and Data

2.1. Stochastic Frontier Analysis

Following Battese and Coelli (1995), the stochastic production frontier and its associated inefficiency model is expressed as equations (1) and (2).

$$y_{it} = x_{it}\beta + v_{it} - u_{it} \qquad (1)$$

where y_{it} is the value of gross livestock production in province i at time t, x_{it} are factors of production in province i at time t, β are parameters to be estimated, v_{it} are random error components which are assumed to be independently and identically distributed as $N(0, \sigma_v^2)$, and independent of u_{it}, which are non-negative random variables that account for technical inefficiency in production. u_{it} is assumed to be independently distributed as truncations at zero of $N(\mu_{it}, \sigma_u^2)$, with

$$\mu_{it} = z_{it}\delta \qquad (2)$$

where z_{it} are variables that may explain inefficiency, and δ are unknown parameters to be estimated.

The technical efficiency (TE) of herding in each province can be predicted from the estimated production frontier as

$$TE_{it} = \frac{E(y_{it}|u_{it}, x_{it})}{E(y_{it}|u_{it}=0, x_{it})} \qquad (3)$$

where E is the expectations operator and $TE_{it} \in [0,1]$. It measures the output of livestock production in province i relative to that of the fully efficient province given the same input vector.

2.2. Calculation and Decomposition of TFP Change

Using the SFA results, we can construct the Malmquist TFP index to measure TFP change between two periods. The traditional Malmquist TFP index does not capture scale changes. If an industry of interest is subject to variable returns to scale, the traditional Malmquist index may produce biased results. The problem can be solved by imposing constant returns to scale upon the production technology. However, for sectors such as agriculture where constant returns to scale do not usually hold, it is preferable to include a scale change component. In this case, the Malmquist TFP index can be composed as

$$TFP_{it} = TEC_{it} \times TC_{it} \times SC_{it} \qquad (4)$$

where TEC_{it}, TC_{it}, and SC_{it} are the technical efficiency change, technical change, and scale change for i-th province at t-th time respectively, which are computed using the SFA results in equations (5), (6), and (7).

$$TEC_{it} = \frac{TE_{it}}{TE_{i,t-1}} \qquad (5)$$

To compute the technical change index, we can take the partial derivatives of the production function with respect to time and evaluate at periods *t* and *t-1* for each province. Then, the technical change index between two periods is calculated as the geometric mean of these two partial derivatives. For the production function in the log form, the technical change index is the exponential of the arithmetic mean of the log derivatives:

$$TC_{it} = exp\left\{\frac{1}{2}\left[\frac{\partial \ln y_{i,t-1}}{\partial(t-1)} + \frac{\partial \ln y_{it}}{dt}\right]\right\} \quad (6)$$

Following, the scale change index can be expressed as

$$SC_{it} = exp\left\{\frac{1}{2}\sum_{n=1}^{N}\left[\varepsilon_{ni,t-1}SF_{i,t-1} + \varepsilon_{nit}SF_{it}\right] ln\left(x_{nit}/x_{ni,t-1}\right)\right\} \quad (7)$$

where $SF_{i,t-1} = \left(\varepsilon_{i,t-1} - 1\right)/\varepsilon_{i,t-1}$, $\varepsilon_{i,t-1} = \sum_{n=1}^{N}\varepsilon_{ni,t-1}$ and $\varepsilon_{ni,t-1} = \frac{\partial \ln y_{i,t-1}}{\partial \ln x_{ni,t-1}}$. The subscript *n* indexes the factors of production.

2.3. Data

The data used in this study are obtained from the annual livestock census data collected by the National Statistical Office of Mongolia (NSO). The data is a panel at the province level consisting of 21 provinces and the capital city for the period 2001–2011. The descriptive statistics of the variables used are explained in Table 1.

Table 1. Descriptive statistics of variables

Variable	Measurement	Mean	Std. Dev.	Min	Max
Frontier Production Function					
Livestock production	million 2010 MNT	38,360.3	25,200.7	916.0	114,297.6
Number of herders	thousand persons	16.5	10.1	0.8	40.2
Pasture land	thousand hectare	5,254.9	3,411.0	39.1	14,597.7
Number of total livestock	thousand *bod* [1] heads	401.4	229.1	17.1	1,085.4
Fodder	fodder unit[2], ton	23,299.6	20,150.1	276.4	103,535.9
Technical inefficiency model					
Farm size per household	*bod*	56.2	18.0	22.9	102.2
Share of households with electricity	%	53.7	29.8	2.8	100.0
Share of households with auto vehicles	%	19.9	10.3	3.1	58.5
Share of households with livestock fences	%	69.3	17.1	24.7	100.0
Fodder per livestock	Kg/*bod*	76.8	90.4	1.7	482.7
Exposure to trade	%	4.4	11.5	0.2	84.5
Number of observations		242			

Source: Author's computations based on NSO (2013)

Notes: [1] The total number of five species of livestock is added up on the basis of the *bod* unit, a traditional stock unit used in Mongolia. The transformation coefficients for *bod* units are 1 cattle-1 *bod*, 1 horse-1 *bod*, 1 camel-1.5 *bods*, 6 sheep-1 *bod*, and 8 goats-1 *bod*.

[2] The NSO measures total amount of fodder by adding up different types of fodder by conversion coefficients.

The value of livestock production is converted to constant 2010 Mongolian togrogs (MNT) using the annual inflation rate data from the World Economic Outlook database (International Monetary Fund 2013). Assuming that each province is exposed to trade proportional to its share in national GDP, we construct the variable "exposure to trade" as $\text{Trade}/\text{GDP} \times \text{province GDP}/\text{GDP} \div 100$.

3. Hypothesis tests

The SFA has several advantages over other methods of inefficiency, including the data envelopment analysis and the deterministic frontier model. The SFA takes account of measurement and other random errors upon the frontier, and allows the estimation of standard errors and hypothesis tests using maximum-likelihood methods, which were not possible with different approaches (Coelli *et al*. 2005). However, the SFA is also subject to criticisms that there is generally no *a priori* justification for selection of any particular functional form for the production function and distributional form for the inefficiency term. Various functional forms have been used in the literature from Cobb-Douglas to the less restrictive translog production function. Likewise, various distributional forms have been used in the literature from normal distribution to the more general truncated-normal distribution.

Therefore, we conduct several formal hypothesis tests to determine the preferred functional form for the production frontier and the distributional form for the inefficiency term. The results of the hypothesis tests using likelihood ratio tests are presented in Table 2.

Table 2. Hypothesis tests

Null hypothesis	Log-likelihood	χ^2 statistic	Critical $\chi^2_{v,\,0.95}$	Decision
Unrestricted model	189.82			
Cobb-Douglas	55.94	267.76	$\chi^2_{14,\,0.95} = 23.68$	Reject H_0
No technical inefficiency	111.73	156.19	Mixed $\chi^2_{29,\,0.95} = 41.98$	Reject H_0
No time trend	141.01	97.63	$\chi^2_{6,\,0.95} = 12.59$	Reject H_0
Half normal distribution	138.28	103.09	$\chi^2_{1,\,0.95} = 3.84$	Reject H_0

Source: Author's estimations
Notes: The critical value for the mixed chi-square distribution is taken from Kodde and Palm (1986).

The first null hypothesis that the Cobb-Douglas production function of the following form:

$$y_{it} = \beta_0 + \sum_{j=1}^{4} \beta_j x_{jit} + \beta_t t + \beta_d D_d + v_{it} - u_{it} \qquad (8)$$

is the appropriate specification for the Mongolian livestock sector is tested against the alternative hypothesis of the translog production function

$$y_{it} = \beta_0 + \sum_{j=1}^{4} \beta_j x_{jit} + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4} \beta_{jk} x_{jit} x_{kit} + \sum_{j=1}^{4} \beta_{tj} t x_{jit}$$
$$+\beta_t t + \frac{1}{2}\beta_{tt} t^2 + \beta_d D_d + v_{it} - u_{it} \qquad (9)$$

where *y* is the log of aggregate livestock production, and *x* are production inputs that are the log of the number of herders, land, number of livestock, and fodder. *t* is the time trend, and D_d is the dummy variable used to adjust for the harsh winters or *dzud* (in local language terms) of 2001–2003 and 2009–2010. The maximum-likelihood estimates of parameters of equations (8) and (9) are estimated using Frontier 4.1 (Coelli 1996), given the associated inefficiency model of the type

$$\mu_{it} = \delta_0 + \sum_{j=1}^{6} z_{jt}\delta_j + \sum_{k=1}^{21} P_k \delta_{pk} \qquad (10)$$

where *z* are variables to explain inefficiency. P_k are dummy variables for province *k*. The result of the null hypothesis strongly rejects the Cobb-Douglas production function specification in favor of the translog production function.

The second hypothesis that there is no technical efficiency ($H_0\colon \gamma = \delta_j = \delta_{pk} = 0, j = 0, \cdots 6, k = 1, \cdots ,21$) is rejected, indicating that the frontier model is a significant improvement over an OLS function. The third test hypothesis that there is no technical change ($H_0\colon \beta_{tj} = \beta_t = \beta_{tt} = 0, j = 1, \cdots ,4$) is also rejected. Therefore, the data indicates that over time there is technical change in the Mongolian livestock sector. Finally, the null hypothesis that the technical inefficiency effect has a half-normal distribution ($H_0: \mu = 0$) is rejected in favor of the less restrictive truncated-normal distribution.

Therefore, our empirical model is the translog production frontier of equation (9) and its associated inefficiency model given by equation (10) with the inefficiency term following the $N(\mu_{it}, \sigma_u^2)$ distribution.

4. Results

The maximum-likelihood estimates of equations (9) and (10) are reported in Table 3. The parameterization of the log-likelihood function of the stochastic production frontier follows Battese and Corra (1977) by replacing σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/\sigma^2$. The parameter γ lies between 0 and 1, with $\gamma = 0$ implies that the deviation from the frontier is due to random effects, whereas $\gamma = 1$ implies variations are due to technical inefficiency across provinces. Our result, $\gamma = 0.4$, indicates that although efficiency differences may be present, most of the differences are from random variables.

The translog production function variables are mean-corrected, so that the estimated parameters can be interpreted as production elasticities (evaluated at the sample mean). The sum of the production elasticities demonstrates that the livestock sector in Mongolia has decreasing returns to scale. The production elasticities are dominated by the elasticity of the livestock number. This finding is consistent with the fact that Mongolian livestock produces constant low yield per animal over time due to high dependence on weather conditions and the livestock production is primarily characterized by large size. The privatization of livestock created incentives for herders to increase their herd size. As there are few investment alternatives, herders invest their surplus income in livestock. Furthermore, the disappearance of the support infrastructure following the collapse of the collectives and consecutive natural disasters led herders to increase the number of livestock to manage risks.

The elasticities of labor and fodder show that each additional unit of these inputs increases livestock production. Conversely, the elasticity of land is insignificant. This result may suggest operation in stage 3 of the production function, where adding more land to the livestock production activities does not increase output. In addition, it indicates that a large amount of land is already been used by the sector. Currently, more than 70% of the total land is used for pasture. Recently, it has been argued that the number of livestock has already exceeded the land capacity and over-stocking degrades land productivity, leading to desertification, which in turn decreases productivity of the sector. Still, herders have no incentive to improve land productivity; they merely grow the herd size as the pastoral land belongs to the state, whereas livestock is privatized.

The time trend and its square are both statistically significant. Inclusion of time trend as a measure of technical change suggests technology has been increasing but at a decreasing rate. Technical progress occurred in the livestock sector at the rate of 6% annually. However, the growth rate has been declining by 2% annually. The livestock production declines during the years of the harsh winters or *dzud*.

The results of the stochastic production frontier suggest that the livestock sector may have reached its maximum attainable output, given the current technology and land. Therefore, the mean efficiency is quite high at 86%, reflecting the ability of herders to obtain maximum output from the given set of inputs. The technical efficiency is driven by the increased farm size, access to electricity and exposure to trade.

Particularly, production inefficiency is reduced for each additional stock of animal. According to the World Bank (2010), subsistence-based herders are unable to survive harsh winters; consequently, they are forced to migrate. Conversely, herders with a sufficient number of livestock (more than 300 sheep units or approximately 50 *bod* units) can manage to overcome extreme weather conditions and produce marketable surplus. These herders are profit oriented, commercial producers, who rationally respond to changes in markets. In addition, herders with more than 500 sheep units are wealthy, commercial herders, who are the most profitable.

Table 3. The Stochastic production frontier and technical inefficiency model estimation for the Mongolian livestock sector

	Translog Model				Inefficiency Model		
	Coefficient	t-ratio			Coefficient	t-ratio	
Constant	0.12	3.42	***	Constant	0.24	0.27	
Number of herders	0.16	2.77	***	Farm size per household	-0.45	-2.72	***
Pasture land	0.01	0.17		Share of households with			
Number of total livestock	0.52	7.37	***	electricity	-0.07	-1.84	*
Fodder	0.25	12.24	***	auto vehicles	0.18	2.69	***
Time trend	0.06	10.70	***	livestock fences	0.23	1.48	
Herders^2	0.59	2.13	**	Fodder per livestock	0.23	3.79	***
Herders x Land	-0.14	-2.01	**	Exposure to trade	-0.34	-6.65	***
Herders x Livestock	-0.35	-1.40					
Herders x Fodder	-0.15	-4.00	***	Sigma-squared	0.01	5.91	***
Herders x Time	0.01	0.77		Gamma	0.39	2.64	***
Land^2	0.12	2.83	***	Log likelihood function	189.82		
Land x Fodder	0.02	0.75					
Land x Time	0.00	0.30		Mean technical efficiency	0.86		
Livestock^2	0.38	1.46					
Livestock x Fodder	0.01	0.30					
Livestock x Time	-0.03	-1.49					
Fodder^2	0.15	6.72	***				
Fodder x Time	0.01	1.74	*				
Time^2	-0.02	-7.94	***				
Dzud dummy	-0.07	-3.32	***				

Source: Author's estimations

Notes: Maximum likelihood estimates. *, **, and *** denote statistical significance at 10, 5, and 1% levels respectively. The variable Land x Livestock is removed owing to collinearity. The provincial dummy variables are not reported.

The exposure to international trade reduces farm inefficiency. We can as well interpret this indicator as a proxy for access to markets. It can be implied that herders have more access or can afford market information, if they are more exposed to markets or international trade. Therefore, these herders have an incentive to create greater marketable surplus, which can easily be exchanged for cash in markets. An example could be cashmere production, which has increased substantially since Mongolia’s accession to the World Trade Organization in 1997. Currently, raw cashmere is the most exported livestock product of Mongolia.

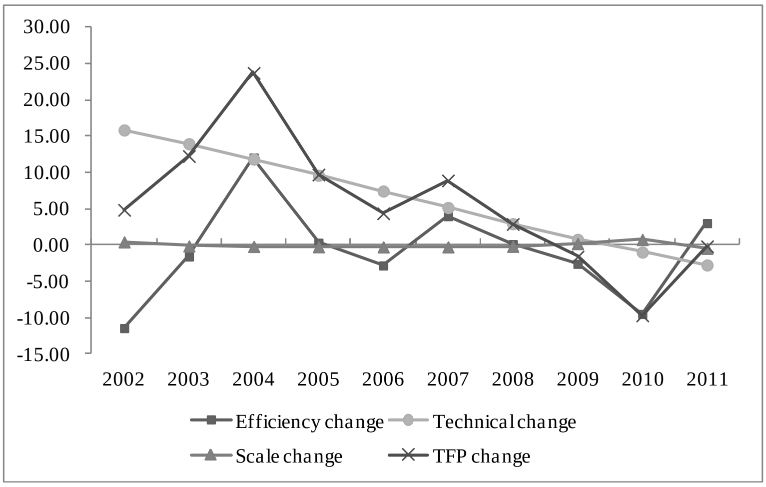
Furthermore, access to electricity reduces inefficiency. Having access to electricity may imply that herders are able to get more information about weather and markets through televisions or other electronic devices. Electricity may also reduce the time to prepare food and livestock products.

The result that fodder per livestock increases inefficiency may be unusual for livestock farms in other countries. However, in the case of Mongolia, this is very likely because animals graze almost exclusively on natural pastureland, while commercial fodder is rare. Fodder production has fallen dramatically since the collapse of state farms. Currently, there are considerable constraints for herders to produce fodder due to the restrictions on public pastureland. Herders often encounter difficulties to obtain permission to cultivate fodder crops and conflicts arise with other herders on the use of land. In addition, herders lack working equipment, machinery, skills, and experience to cultivate land and sow fodder crops. Therefore, only a small amount of natural fodder is prepared for winter. In the case of natural disasters, fodder is often distributed by the state free of charge as disaster support. Therefore, increasing fodder concentration may indicate the time of a natural disaster.

Finally, having an auto vehicle increases inefficiency whereas animal fences have no statistical significance on inefficiency. It should be noted that our data on these two variables do not distinguish between type, quality and capacity of vehicles and fences; rather they just provided as an aggregate number. If such data was available, it could be interesting to analyze the effects of different types of vehicles and fences on farm efficiency. With the current data, the statistically significant positive coefficient on auto vehicle may imply that holding an auto vehicle is associated with distance to markets. In addition, poor road infrastructure in rural areas makes it difficult for herders living far away from markets to commercialize.

Using the results of the stochastic frontier analysis, we construct the Malmquist TFP index to measure changes in TFP and its decomposition over time. The results are presented in Figure 1.

Figure 1. Annual percentage changes in TFP and its decomposition



Source: Author's computation

The TEC is quite stochastic, which is common to the agricultural sector because of its dependence on random variables, such as weather. The TFP change mostly follows the technical efficiency change, as it is the most important component contributing to the TFP. On average, the TFP grew by 5.5% annually during 2001–2011. However, its growth has been declining by approximately 2% annually. Therefore, TFP growth has become smaller over time. Peaks in TEC correspond to recovery periods from the *dzud* of 2000–2003, foot and mouth disease of 2006, and *dzud* of 2009–2010. The results also indicate that the recovery after each disaster has become smaller over time. The scale change component shows almost no change during the period. The technical change was progressive until 2009, subsequently turned regressive, which indicates there is pressing need to invest in technology change in the sector.

5. Conclusion

An important challenge facing the Mongolian livestock sector is to transform into a more commercialized production system and compete in world markets. Therefore, it has become inevitable to invest in technology and productivity improvement in the sector. This study, to the best of the author's knowledge, is the first study to measure productivity and efficiency of the livestock sector in Mongolia. Furthermore, this study aims to contribute to the empirical literature regarding the link between trade openness and technical inefficiency in the agricultural sector.

Our findings suggest that labor, capital livestock, and fodder are important production inputs, whereas pastureland does not add to output. This result indicates that the sector may be operating in stage 3 of the production function; adding land to production activities does not affect the output level. Moreover, overstocking to increase output could have resulted in degradation of pastureland, while the public nature of pastureland discourages herders to invest in land productivity. To improve land productivity and avoid desertification, which further decreases productivity of the livestock sector, proper land tenure rights or land titles should be implemented.

Results from the inefficiency model show that farm efficiency increases with herd size, access to electricity, and greater exposure to trade. Therefore, our results demonstrate that trade openness is associated with greater efficiency in the Mongolian livestock sector. This may also indicate that herders have increasing incentive to commercialize, if there are markets for their production.

Meanwhile, efficiency is reduced with auto vehicle ownership and fodder per livestock. The result on the fodder per animal may indicate the free distribution of fodder by the state during disaster times, whereas in regular times, animals graze on natural pasture and commercial fodder is rare. To become fully commercialized producers, herders should have access to input markets and credits to obtain working equipment, machinery, and supplementary fodder. Furthermore, they should be trained to gain skills to sow fodder crops as to decrease the dependence on natural forage and reduce risks. Infrastructure development in rural areas is also crucial to help herders to access markets.

The technical efficiency change is quite stochastic because the sector is subject to random shocks such as weather. The TFP change largely follows the technical efficiency change, as it is the most important component of the TFP. During 2001–2011, the TFP grew by 5.5% annually, but at a decreasing rate. Recovery after each disaster has become smaller over time. The technical change was progressive until 2009 and turned regressive, which indicates there is pressing need to invest in technology change in the sector.

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