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Influence of climate factors on spatial distribution of Texas cattle breeds

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Abstract This paper investigates the spatial distribution of cattle breeders in Texas to quantify how climate factors influence cattle breed selection. A multivariate probit model is employed to examine the county-level binary choices of *Bos taurus*, *Bos indicus* and composite breeds derived from cattle breed association membership data. The estimation results suggest that summer heat stress is a significant factor for breed selection: positive for *Bos indicus* and negative for *Bos taurus* and composite breeds, with the average marginal effects on breed membership probability being 9.7 %, −26.5 % and −7.9 %, respectively. The intensity of the summer heat impacts can lead to noteworthy changes in spatial distributions of Texas cattle breeds in the event of climate change.

A changing climate can alter agricultural production patterns, as crop and livestock producers have long been engaged in adapting their production practices to the changing natural, market, and policy environments (Rose and McCarl 2008). For livestock production, climate change can impose its influence principally via two channels: one is to directly impact animal performance, and the other is to alter feed production and thus indirectly affect animal production (Adams et al. 1999). Among many other climate factors, high temperatures and humidity are found to have detrimental effects on reproductive efficiency and performance of

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cattle (St-Pierre et al. 2003), and rising temperature and decreasing precipitation can negatively influence forage availability and quality (Craine et al. 2010) that cattle production rely on.

For Texas, the future hotter and drier climates—projected by U.S. Global Change Research Program (2009)—will be an issue as heat stress is estimated to have already resulted in an annual economic loss of about $180 million in the beef industry (St-Pierre et al. 2003). Thereupon, adaptation to climate change may be needed for cattle production and one possible adaptation is switching livestock breeds (Mader et al. 2009; Craine et al. 2010). In fact, the abatement of heat stress on cattle production through selection of cattle breed has been done by U.S. cattlemen in history as they deal with different climates across the country (Paschal 2011). Here we study that quantitatively in Texas using a spatial analogue method. The underlying assumption in the spatial analogue method is that, on the margin, relatively colder areas will adopt practices of relatively warmer areas as climate warms (Schimmelpfennig et al. 1996). An understanding of how climate factors alter cattle breed selection may reveal adaptation strategies for cow-calf producers.

1 Background

Reproductive and physical performance of cattle is influenced by environmental factors, largely climate and forage conditions (Hammack 2010a). The extent to which cattle would be affected is biologically determined by their genetic traits. Some breeds, like Brahman of *Bos indicus*, are more adapted to a hot and humid environment (Hammack 2010c). On the other hand, *Bos taurus* breeds, for example the Angus breed, are not as well suited to a hotter climate as Brahman (Paschal 2011), though they typically yield better quality beef (Turner 1980), and higher prices (Hammack 2010b; Meyer 2010).

Baker et al. (1993) simulated the U.S. grassland and cattle production under climate change and they suggested that a northward migration of range-based feeder calves production may occur due to animal performance declines in the southern regions. They pointed out that if the simulated animal response were based on heat tolerant *Bos indicus* rather than *Bos taurus*, the simulated declines would be milder. The latter argument implies the adaptation opportunity of switching breeds and corresponds to the aforementioned breed selection in hot and humid areas.

Nonetheless, beef cattle producers consider more than climate and forage conditions. Generally, cow-calf breeders would select the breed that delivers the profit maximizing combination of market-desired and production-suitable traits (Hawkes et al. 2008). As described in Winder et al. (1992), producers have to decide whether "the increase in animal productivity stemming from the use of *Bos indicus* [Brahman] breeds outweigh the [price] discounts seen from the resulting calves [that] Southwest cow-calf producers sell." Such a tradeoff between using *Bos indicus* and receiving price discounts may be even more intensely manifested in Texas in the event of climate change, as the hotter and drier climates can cause producers to take adaptive measures to shift to *Bos indicus* breeds amidst the price discrimination against *Bos indicus*.

The literature above indicates the noteworthy climate effects on livestock performance and introduced the dilemma that producers might encounter when adapting to climate change by switching breeds. Other literature on climate change and livestock find that climate factors can have significant influence on agricultural land allocation, livestock species choice, and the spatial pattern of livestock production. In Africa Seo et al. (2009) predict climate change would cause a move toward livestock and away from crops. They also predict a shift among livestock species away from cattle to goats. In South America Seo et al. (2010) find a similar shift away from beef and dairy cattle to sheep. In the U.S. Adams et al. (1999) find mild future climate change impacts on livestock production, though this mild effect is at national level and it probably masks the underlying regional production shifts. Mu and McCarl (2011) find climate change shifts land from cropland to pasture as well as decreases cattle stocking rate. However in these studies, no “within species”, breed shift examinations have been carried out. The research presented in this paper investigated climate influences on beef cattle breed selection. This was done by statistically analyzing breed choice across Texas counties using data on breed association membership.

2 Analytical approach

Prior climate change adaptation research has employed the multinomial choice model (Seo et al. 2009; Seo et al. 2010) to explore the statistical relationships between climate factors and livestock species choices. However the multinomial choice model may not be appropriate here since the breed choices are not necessarily mutually exclusive at the county level. Following Zilberman et al. (2004), a simplified conceptual graphic analysis of cattle breed selection is presented in Fig. 1. There, we assume that each kind of breed performs differently across a range of temperatures, and that the value potential associated with each breed is unimodal. In other words, when the temperature goes beyond the point where the value potential for keeping a breed reaches its optimum, another breed may become dominant.

A multivariate probit model (MPM) is employed to examine the choices of cattle breeds across Texas counties. The MPM is selected to estimate the climate impacts on the probabilities of selecting three major types of cattle breeds being used at any location in Texas. Following Greene (2003) and Cappellari and Jenkins (2003), the MPM is as follows.

$$y_{i,j}^{*} = X_{i,j}^{'}\beta_j + \varepsilon_{i,j}$$

$$y_{i,j} = \begin{cases} 1, & if\ y_{i,j}^{*} > 0 \\ 0, & otherwise \end{cases}$$

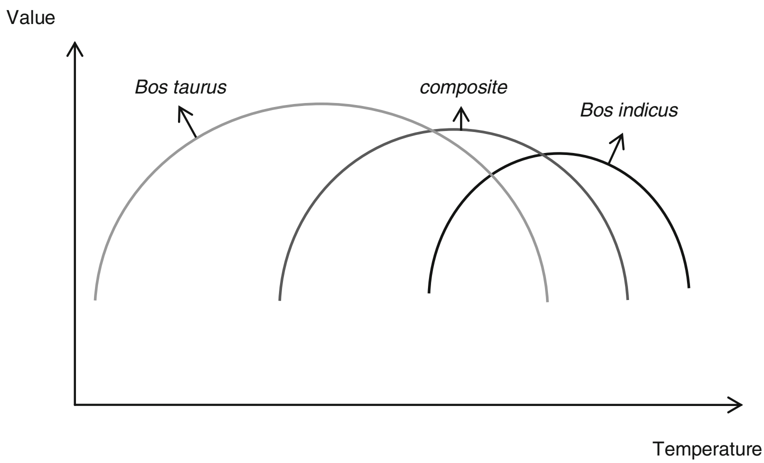


Fig. 1 Value potentials of raising *Bos taurus*, composite, and *Bos indicus* breeds as temperature changes

where i denotes the Texas county and $j=1, 2, 3$, representing *Bos taurus*, composite, and *Bos indicus*, respectively. Also, y indicates the observed outcome—that is if the breed of interest is used in the location, y=1, otherwise y=0. X is the vector of explanatory variables that represent county-level characteristics including climate items. In addition, the error terms ε are assumed to follow a trivariate normal distribution.

3 Data

3.1 Binary choice data

The Angus and Hereford breeds of *Bos taurus*, Brahman breed of *Bos indicus*, and Brangus and Braford, composite breeds having traits of both *Bos taurus* and *Bos indicus*, are among the most prevalent cattle breeds in Texas (Hammack 2010c; Paschal 2011). Hence, the membership data from the respective breeders' associations were used to generate the observable binary choice data. The 2010 membership data are used in this paper. The county-level y would have a 1 for a county if there is at least one member of the breed of interest there and 0 otherwise.

3.2 Explanatory variables

Breed has a significant impact on the economic viability of cow-calf operations (Greiner 2009) and breed selection primarily involves consideration of production and market conditions—where the key production factors are related to climate and forage (Hammack 2010a). Explanatory variables in this study thus include climate factors that have direct impacts on cattle performance and forage factors that indirectly influence on cow-calf operations, as well as market prices for calves and other county characteristics. For the purpose of this analysis, the explanatory variables selected are the ones whose value would vary across Texas counties.

Specifically, as shown in Table 1, summer heat stress measured by temperature-humidity index (THI) and winter minimum temperature that impose heat or cold stresses on cattle (Hoffmann 2010; Mader et al. 2010) are included as climate factors. Spring precipitation that is essential for annual forage growth and summer precipitation are included as forage factors. In particular, spring precipitation has a determining effect on forage vs. supplemental feed ratio that directly affects feed cost (Baker et al. 1993). And feed cost is the most critical control point for the profitability of cow-calf enterprise (Miller et al. 2001). Besides, precipitation influences forage quality, especially in the event of climate change (Craine et al. 2010). The areas of natural range and managed pasture lands are also included as they indicate the availability of grazing resources that influence grazing (feed) costs (Falconer et al. 1999).

Hay yield that reflects the general vegetation productivity and farming efforts involved is considered as a forage factor too. Moreover, land surface variation—ranging from flat plains to high mountains—is considered, as it affects the ease of access to forage and summer forage productivity (Smith et al. 2011).

Furthermore, market prices for different breeds, and county characteristics such as cattle inventory that implies the market demand for feeder calves and household income levels are included.

As introduced earlier, compared to *Bos taurus*, breeds with *Bos indicus* traits are more heat-tolerant and less demanding on forage quality (Paschal 2011). Therefore we expect that

Table 1 Variable definitions

Variable	Unit	Description
Climate Conditions		
thisum	1	Average summer (July and August) temperature-humidity index, derived from maximum temperature and dew point temperature data
tminwin	°C	Average of winter (December and January) minimum temperature
Forage Conditions		
prepspr	mm	Average spring (March and April) precipitation
prepsum	mm	Average summer precipitation
range	1000 acres	Rangeland acreage in the county
pasture	1000 acres	Pasture acreage in the county
hay	dry ton/acre	Average county hay yield per acre of land
topo	1	Indicator of topographic variation, where 1 indicates flat regions (the lower bound) and 21 indicates high mountains (the upper bound)
Market Conditions		
angusbsp	$100/head	Average Angus bull calf price for spring transactions
angusfmsp	$100/head	Average Angus heifer calf price for spring transactions
hfbsp	$100/head	Average Herford bull calf price for spring transactions
hffmsp	$100/head	Average Herford heifer calf price for spring transactions
taurusbsp	$100/head	Average lot size-weighted Angus and Hereford bull calf price for spring transactions
taurusfmsp	$100/head	Average lot size-weighted Angus and Hereford heifer calf price for spring transactions
brangusbsp	$100/head	Average Brangus bull calf price for spring transactions
brangusfmsp	$100/head	Average Brangus heifer calf price for spring transactions
County Characteristics		
cattle	1000 heads	Total number of cattle in the county
income	$1000	Median household income in the county

warmer and drier climates would increase the probability of adopting *Bos indicus* whereas counties with abundant and relatively high quality forages would prefer *Bos taurus*. The effects of climate and forage factors on selecting composite breeds may fall in between those for *Bos taurus* and *Bos indicus*.

The climate data used were drawn from the PRISM Climate Group, Oregon State University. The monthly averages of maximum temperature, minimum temperature, dew point temperature and precipitation over the period of 1980–2009 for the 254 Texas counties were utilized. The summer temperature-humidity indices (THI) are calculated based upon formulas $t_{dew} = B_1\left[\ln\left(\frac{RH}{100}\right) + \frac{A_1 t}{B_1+t}\right] / \left[A_1 - \ln\left(\frac{RH}{100}\right) - \frac{A_1 t}{B_1+t}\right]$ and $THI = 0.8t + \left[\left(\frac{RH}{100}\right)(t - 14.3)\right] + 46.4$ provided in Lawrence (2005) and Mader et al. (2010) respectively, where *RH* stands for relative humidity and A_1 and B_1 are given parameters. Following the argument in Mendelsohn et al. (1994) and Schlenker et al. (2006), the long-term 30-year average climate values—instead of the short-term annual weather data typically featured by intense variation—are employed for this study, since our interests are in understanding how breeders have incorporated the lasting climate effects into their decision making.

Data on forage conditions including acreages of managed pastureland and native rangeland, hay yield, and topographic variation are obtained from a variety of sources. The grazing land data were assembled from the Texas A&M Institute of Renewable Natural Resources (IRNR), using 2007 data. Hay yields were based on the county-level hay acres and production quantities data from the 2007 Census of Agriculture, USDA National Agricultural Statistics Service (NASS). Topography code data used were from the Natural Amenities Scale program, USDA Economic Research Service.

The price data were drawn from the year 2009 sale reports from the online databases of the American Angus Association and the American Hereford Association, plus the Brangus Journal. The county-level price averages for bull calves and heifers are used, where the bull and female prices in the sale reports are assumed to largely reflect the prices for bull calves and heifers. Spring prices are used because the Brangus data were only available for spring. The average *Bos taurus* price is a weighted average of Angus and Hereford prices, where weights are the breed-specific sums of the lot size associated with each price in the sale reports.

Cattle inventory data were collected from the USDA NASS for 2010. County-level median household income data were obtained from the Small Area Income and Poverty Estimates, the U.S. Census Bureau for 2007.

4 Results and discussion

4.1 Spatial allocation of cattle breeders

To take a first investigation of the effects of summer climates on breed selection, displays of the spatial allocations of *Bos taurus*, composite, and *Bos indicus* breeders across the Texas landscape—against the 30-year average summer heat stress background—are provided (Figs. 2 and 3). The "*i*" dots in the figures indicate the presence of breeder(s) raising the breed of interest.

Figure 2 portrays the spatial distributions of *Bos taurus* (including Angus and Hereford) and *Bos indicus* (Brahman) breeders overlaid on a map of heat stress. In that figure the darker the background color, the more severe the summer heat stress is. It shows *Bos taurus* breeders spread across Texas, but are not common in hot South Texas. *Bos indicus* breeders are shown to be concentrated in the relatively hotter and humid coastal areas, and again, not common in South Texas, suggesting that *Bos indicus* breeds are adapted to hot and humid environments.

Figure 3 presents the spatial allocation of breeders joining composite breed (including Brangus and Braford) associations. The geographic coverage of composite breeders is between that of *Bos taurus* and *Bos indicus*, and most dominantly in the hotter and more humid areas. The presence of composite breeders in the most southern Texas corresponds to the fact that (commercial) cattle herd in South Texas is mostly crossbred (Paschal 2011), reflecting both the production constraints that favor the heat-tolerant *Bos indicus* traits there and the market demand preferring beef with better quality that is related to *Bos taurus* traits. In sum, the spatial allocations of cattle breeds in Texas are a product of environmental and market configurations.

4.2 Determinants of spatial cattle breed distribution

The results of estimated probit model (Table 2) show that summer heat stress has significant effects on the occurrence of breeder presence—positive for *Bos indicus* and negative for *Bos*

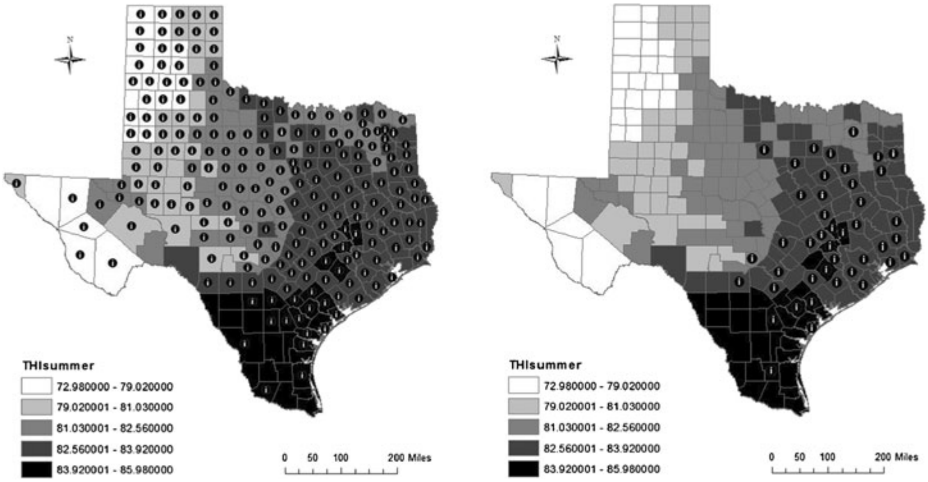
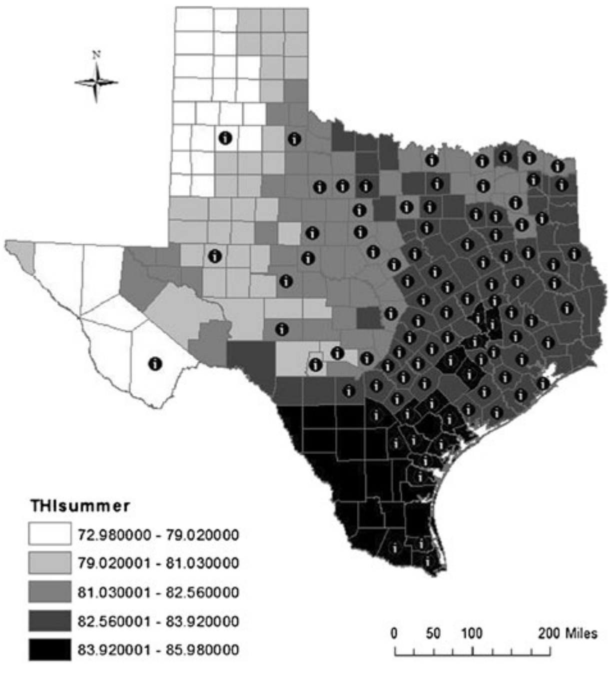


Fig. 2 Spatial allocation of *Bos taurus* (left) vs. *Bos indicus* (right) breeders against the background of summer heat stress (THIsummer) in Texas, 2010

taurus. This meets the expectation that *Bos indicus* breeds are more common for adapting to hot and humid environments. Meanwhile, summer heat stress has a negative impact on the presence of composite breeders, albeit smaller than that of *Bos taurus*, reflecting that composite breeds are more adapted to heat stress than *Bos taurus*. While the occurrences of *Bos taurus* and *Bos indicus* breeders are significantly influenced by summer heat stress only, the presence of composite breeders is also affected by minimum winter temperature, positively. This indicates the dual aspects about composite breeds—on the one hand, their

Fig. 3 Spatial allocation of composite breeders against the background of summer heat stress (THIsummer) in Texas, 2010



Bos indicus traits allow them to be less negatively affected by summer heat stress; on the other hand, they are less adapted to cold stress compared with *Bos taurus* and thus are more likely to be located in counties with warmer winters.

Spring precipitation, *prepspr*, is estimated to contribute positively to the presence of *Bos taurus* breeder, suggesting that *Bos taurus* breeds are more likely to be raised in counties with greater spring precipitation having more abundant forage supply (Baker et al. 1993) with generally higher forage quality (Bade 1998). The effects of spring precipitation on composite and *Bos indicus* are insignificant, implying less dependence on spring rainfall and the associated forage growth and quality. Summer precipitation, *prepsum*, turns out to have negative effects on the likelihood of selecting *Bos taurus* breeds as higher summer precipitation would increase the growth of summer forage that has lower quality (Bade 1998).

Counties with greater areas of pasture land, which represented managed grazing, are estimated to be more likely to include breeders who select composite breeds. Considering the geographic coverage of composite breeds, this estimate implies the prevalent use of composite breeds and the relatively intensive grazing needed in the hotter and more humid areas. In addition, counties with larger land surface variation, measured by *topo*, tend to have *Bos indicus* breeds that can adapt to harsh environments. Recall that the slope of the rangeland can affect the access to forage and summer forage productivity (Smith et al. 2011).

The market conditions, represented by spring prices of *Bos taurus* and composite breeds, are in general insignificant factors influencing the distribution of cattle breeds. This result corresponds to the finding that the cow-calf enterprise in Texas is financially underperforming compared to many alternatives (Falconer et al. 1999) and thus the price factors cannot be easily translated into significant incentives that affect breed selection, at cow-calf operation level. However, the *Bos taurus* bull calf price, *taurusbsp*, is found to have positive effects on *Bos indicus* membership. One possible explanation is that the expensive investment associated with *Bos taurus* breeding could make breeders turn to other breeds, in particular raising the probability of choosing *Bos indicus* breeds.

Regarding county characteristics, the estimation results suggest that after controlling climate, forage, and market factors, counties having larger cattle inventories are more likely to see composite and *Bos indicus* breeds, with greater effects on the latter. This indicates that the beef industry having demand for feeder calves does give consideration to breeds with *Bos indicus* traits, as is the case in South Texas (Paschal 2011). Moreover, counties with relatively high household income levels are more likely to have *Bos taurus* and *Bos indicus* breeds.

4.3 Marginal effects of summer heat stress

The marginal effects of summer heat stress, *thisum*, on the marginal incidence probabilities of *Bos taurus*, composite, and *Bos indicus* breeder membership are calculated by scaling the marginal success probabilities (the unconditional probability of $y=1$) with *thisum* coefficient estimates in each equation.

As summarized in Table 3, on average, a 1 unit increase in summer THI value will reduce *Bos taurus* membership by over 26 %. The negative effects on composite membership are lesser—about 8 %. On the other hand, a marginal increase in summer heat stress measured by THI can raise the marginal incidence rate of *Bos indicus* membership by about 10 %. Thus, when climate gets warmer, breeders initially adopting *Bos taurus* and composite breeds may turn to *Bos indicus* breeds.

Figure 4 presents the spatial pattern of marginal effects of summer heat stress on *Bos indicus* breeder membership probability. Note that the darker the color, the higher the

Table 2 Estimation results for the *Bos taurus*, composite, and *Bos indicus* group (*N*=254)

Variable	*Bos taurus*			*Composite*			*Bos indicus*		
	Est.	Std. Err.	p-value	Est.	Std. Err.	p-value	Est.	Std. Err.	p-value
thisum	−0.301**	(0.131)	0.021	−0.206*	(0.123)	0.094	0.57**	(0.281)	0.043
tminwin	0.0509	(0.0733)	0.487	0.23***	(0.0694)	0.001	0.132	(0.143)	0.354
prepspr	0.0292***	(0.0113)	0.01	0.0111	(0.00758)	0.142	0.0234	(0.0151)	0.121
prepsum	−0.0334**	(0.0137)	0.015	−0.0133	(0.00898)	0.139	0.00603	(0.0134)	0.652
range	0.000458	(0.000338)	0.176	−0.00037	(0.000409)	0.362	−0.00078	(0.000552)	0.16
pasture	0.00223	(0.00375)	0.551	0.00396*	(0.00223)	0.076	0.00311	(0.00194)	0.109
hay	0.167	(0.189)	0.377	−0.155	(0.165)	0.347	0.197	(0.341)	0.564
topo	−0.0196	(0.0403)	0.627	0.037	(0.0319)	0.247	0.0888*	(0.0474)	0.061
taurusbsp	0.0202	(0.0949)	0.831	−0.0539	(0.0606)	0.374	0.164**	(0.0715)	0.022
taurusfmsp	0.021	(0.0796)	0.792	0.064	(0.0529)	0.226	−0.0412	(0.0356)	0.247
brangusbsp	−0.0743	(0.0781)	0.341	−0.125	(0.0772)	0.105	0.0576	(0.0984)	0.558
brangusfmsp	0.00407	(0.04)	0.919	0.0266	(0.0349)	0.446	−0.0477	(0.0353)	0.177
cattle	0.00542	(0.0039)	0.165	0.00294**	(0.00135)	0.029	0.00761**	(0.00372)	0.041
income	0.0763***	(0.0254)	0.003	0.0132	(0.0119)	0.265	0.0318**	(0.0135)	0.018
_cons	23.829**	(10.834)	0.028	18.471*	(10.092)	0.067	−57.04**	(24.427)	0.02
Correlation	Est.	Std. Err.	p-value						
ρ_{21}	0.197	(0.157)	0.21						
ρ_{31}	0.0989	(0.210)	0.637						
ρ_{32}	−0.0679	(0.168)	0.685						

See Table 1 for variable definitions. Log pseudo likelihood=−253.233, Wald χ^2 (42)=182.75, Probability>χ^2 =0

The likelihood ratio test of $\rho_{21}=\rho_{31}=\rho_{32}=0$, χ^2 (3)=1.132, Probability>χ^2 =0.769

* denotes significance at 10 % level, ** at 5 % level, and *** at 1 % level

positive marginal effects are. As shown in the figure, a marginal increment in summer heat stress will further increase the probability of adopting *Bos indicus* in the coastal area. The positive marginal effects are smaller in East Texas however. And, the expansion of the colored area indicates potential expansion of *Bos indicus* presence.

The spatial pattern of marginal effects of summer heat stress on *Bos taurus* and composite breeds are shown in Fig. 5, mapped against the distributions of 2010 *Bos taurus* and composite breeders respectively. Note that this time, the darker the color, the greater the negative effects are. As shown on the left, as summer heat stress gets more severe, the incidence of *Bos taurus* membership in most counties decreases by at least 20 %, and most current *Bos taurus* breeding sites would be affected—implying potential contraction of *Bos taurus* presence. For composite breeds, the marginal rise in summer heat stress decreases the marginal probability by at least 9 % in much of the East Texas. And again, many of the current composite breeds breeding sites would be affected.

Given the intensity of the summer heat impacts suggested by the estimated marginal effects above, the spatial distributions of Texas cattle breeds may experience noticeable changes under future climate change where the temperature rises would be at least a couple Celsius degrees by 2050 (U.S. Global Research Program 2009)—and the magnitude will be further amplified if the related THI values are calculated.

5 Conclusions

The selection of more heat tolerant cattle breeds is one way of adapting to climate change. In particular, *Bos indicus* breeds or composite breeds with *Bos indicus* traits are often selected in the Southern U.S. principally because of their heat-tolerance characteristic (Hawkes et al. 2008). Under future climate change—projected by IPCC WGI (IPCC WGI 2007) as inevitable—further selection for heat-tolerant breeds may be necessary (Hoffmann 2010).

The estimation results of this research suggest that summer heat stress, measured by temperature-humidity index (THI), reduces the likelihood of producers electing to raise *Bos taurus* and composite breeds, especially the former one. On the other hand, summer heat stress increases the incidence of *Bos indicus* breeds. Also, the results suggest that compared with *Bos indicus* breed, *Bos taurus* and composite breeds are more sensitive to factors that influence forage quantities and/or quality—whether naturally endowed or actively managed. In addition, the impacts of market factors are found to be insignificant in general, implying an amelioration of the future tradeoff between switching to *Bos indicus* breeds and receiving price discounts under climate change.

The marginal effects of summer heat stress on breed selection are also calculated. −26.5 % on average for *Bos taurus* and −7.9 % on average for composite breeds. The marginal effects on *Bos indicus* membership probability are estimated to be 9.7 % on average, implying a reinforcement of choices made by breeders in coastal areas if heat stress gets more severe.

Table 3 Marginal effects of summer heat stress on marginal incidence probability of Breeder Membership

	Mean	Std. Dev.
Bos taurus (*thitaurus*)	−0.265	0.051
Composite (thicomposite)	−0.079	0.058
Bos indicus (*thisindicus*)	0.097	0.128

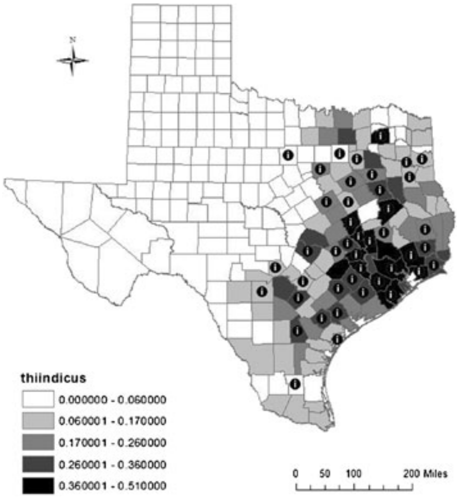


Fig. 4 Spatial pattern of marginal effects of summer heat stress on *Bos indicus* breeder membership probability in Texas

Given the intensity of the summer heat impacts suggested by the marginal effects, future climate change in Texas could induce noteworthy changes in spatial allocations of cattle breeds—where the more northern areas in Texas would turn to *Bos indicus* breeds. As argued in Mader et al. (2009), though animals can adapt to small increases in ambient temperature, more severe changes may dictate interventions that go beyond usual modifications—such as changing herd genetic base.

The research is subject to several limitations, largely due to the paucity of data. First we could not obtain data on population by breed and so breed association membership was used as a proxy, which may be subject to the problem of underreporting. Second we did not have county-varying data that can better represent forage conditions. Third the market data were limiting. In particular, a more complete collection of breed-specific price data may improve the quality of the estimation results.

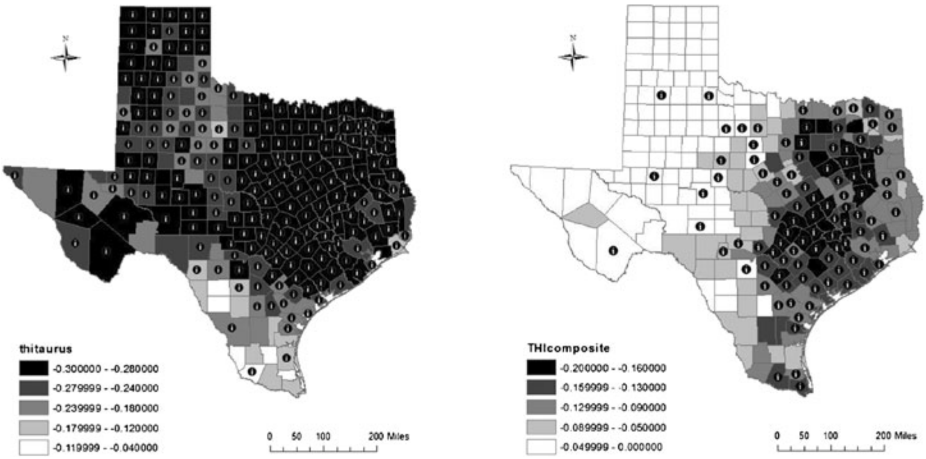


Fig. 5 Spatial pattern of marginal effects of summer heat stress on *Bos taurus* (left) and composite (right) breeder membership probabilities in Texas

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