The Impact of Biofuel Mandates and Switchgrass Production on Hay Markets

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Abstract

The Renewable Fuel Standard mandate in the Energy Independence and Security Act of 2007 requires 16 billion gallons out of 36 billion gallons of ethanol be produced from cellulosic feedstocks in 2022, but the mandate was apparently enacted without critical assessments of the agricultural impacts of attempting to achieve energy independence. The feedstock production will likely compete with lands currently used for producing other traditional crops of which hay is likely to be affected the most since it has comparatively lower net returns. Thus ruminant production will consequently be affected greatly. This study uses ordinary least squares (OLS) to estimate and predict Oklahoma hay price which is used as objective value in linear programming (LP) model that determines the profitability options between hay and switchgrass production. The OLS results show that Oklahoma hay price is fairly stable, and hay is shipped across adjoining states. The LP results show that switchgrass production would be more profitable than hay and that switchgrass for biofuel production likely will bid land away from hay if biofuel production becomes fully operational.

Keywords: biofuel mandates, switchgrass production, hay production, hay markets.

Introduction

The wide support from most Americans for expansion of the ethanol industry led to expansion of the Renewable Fuel Standard (RFS) mandated in the Energy Independence and Security Act of 2007 (EISA 2007). This wide support was the result of the optimism associated with achieving energy independence and rural economic development (Herndon 2008), but was apparently enacted without critical assessments of the agricultural impacts of attempting to achieve the energy independence and rural economic development. In particular, reduced hay production will likely increase hay prices which would make hay less affordable to livestock farmers, with a secondary consequence of reduced livestock numbers. Reduced hay production may require livestock farmers to use substitutes such as corn, and this will consequently increase the demand for those substitutes, hence increasing the prices of those substitutes.

The Renewable Fuel Standard mandates in the Energy Independence and Security Act of 2007 (EISA 2007) require 36 billion gallons of ethanol to be produced in 2022, 16 billion gallons of which is to be produced from cellulosic feedstocks. To meet the mandate, 24.7 million acres would be used to produce 109 million tons of switchgrass in 2025. The majority of these acres would be converted from land currently producing hay (Dicks et al. 2009). Converting this land to biofuel feedstock would negatively impact the cattle industry since hay production and marketing would be affected, and hay prices would rise. A biofuel industry would bid resources (including land) from current use which would reduce output in other agricultural sectors.

Concerns about a potential reduction in hay production are important because of hay's significance to the agricultural sector. Hay production in the U.S. was 145.67 million tons valued at $18.78 billion (NASS 2008). It is an especially important crop on highly erodible soils (Bazen et al. 2008).

The commercialization of cellulosic-based ethanol (ethanol that comes from feedstocks such as switchgrass, corn stover, wheat straw, and wood products residues) could have an even greater impact on the agricultural industry (Epplin 1996). Potential conversion rate of 75 gallons or more from each ton of switchgrass coupled with expected switchgrass yields of 4-6 tons/acre have led to excitement over the future role of dedicated biofuel crops in the region's agriculture.

Dicks et al. (2009) predicted, using POLYSYS, that hay production would be reduced by 15.4 million acres (almost 20% of forage acres), leading to a 13.1-million-head reduction in beef cows. Their analysis described several areas that could benefit from further research including an estimate of the beef cow – hay price relationship.

Because reliable information on hay market price response was not available for the study by Dicks et al. (2009), the predicted effect on beef cows came from a simplistic estimate that, reduced beef cow numbers based solely on the tons of forage no longer produced – since each cow needs approximately 1,000 pounds of forage per month, replacing forage with switchgrass-for-ethanol would correspondingly reduce the number of cows that could be produced.

To fully understand the impacts of biofuel mandates on cattle markets, a linkage between cattle numbers and hay prices needs to be established. As a first step, this research estimates the effect of hay production on hay prices by estimating the (inverse) demand for hay, with hay price as a function of hay production, beef cow inventory, and price of substitutes for hay.

The objective of the analysis is to determine the impact of changes in hay production in Oklahoma and surrounding states on the price of hay in Oklahoma, and to further test the reliability of the model on other states.

The results will be used in ongoing research to determine the effects of increased switchgrass production on hay prices, and in turn on profitability of cattle production. Findings from this work will help policy makers consider the potential impact of biofuel mandates on the agricultural sector, and for livestock farmers to anticipate a potential changes in the price and quantity of hay.

Theoretical Framework

Agricultural producers and land owners will decide whether to produce switchgrass or hay, considering the net economic returns of each. The research assumes a profit maximizing firm chooses whether to produce switchgrass or other hay crops based on the economic returns of each.

Unconstrained profit maximizing formulation for a competitive, one product, single input firm would be expressed as:

$$\max_{x} E(\pi) = pE(y_i) - rx_i - b \quad (1)$$

$$s.t. E(y) = F(x) \quad (2)$$

where $E(y_i)$ is the expected yield per acre of ***i*** crop (either switchgrass or hay), ***r*** is the price of land (assumed to be the same for both switchgrass and hay), ***x*** is the acre of land required to produce ***y*** output, ***b*** is the fixed cost, and $E(\pi)$ is the expected profit from producing crop ***i***.

By differentiating the profit function with respect to x_i, gives:

$$\frac{\partial E(\pi)}{\partial x_i} = \frac{\partial E'(\pi)}{\partial x_i} - r = 0 \quad (3)$$

Equation (3) which implies

$$pMPP = r \iff MPP = \frac{r}{p} \quad (4)$$

From equation (4), profit maximizing level of x_i is obtained which is expressed in the equation below;

$$x^* = x^*(p, r) \quad (5)$$

The first part of the work modeled demand equation for hay using OLS estimates and in the second part, profitability decision on whether to produce hay or switchgrass is modeled using linear programming (LP). The demand equation is an inverse demand function with hay price as the dependent variable. The inverse demand equation is used to predict the hay price which used in the LP model as the objective value for hay.

Inverse demand function, $\boldsymbol{P} = f^{-1}(Q)$, is a function that maps the quantity of output demanded to the market price (dependent variable) for that output. Quantity demanded, ***Q***, is a function of price; the inverse demand function treats price as a function of quantity demanded, and is also called the price function. The inverse demand function is not the reciprocal of the demand function but refers to the mathematical concept of an inverse function as $f(\boldsymbol{P})$,in which ***P*** is price, so the value of the function is the quantity demanded (***Q***), then the inverse demand function is $f^{-1}(\boldsymbol{Q})$, whose value is the highest price that could be charged and still generate the quantity demanded ***Q***. This is to say that the inverse demand function is the demand function with the axes switched. This is useful because economists typically place price (***P***) on the vertical axis and quantity (***Q***) on the horizontal axis. To compute the inverse demand function, P is simply solved from the demand function. For example, if the demand function has the form $Q = \alpha - \beta P$, then the inverse demand function would be, $P = (\alpha - Q)/\beta$.

The inverse demand function for hay in this study is expresses as:

$$PHAY = f(TIME, HAYPROD, PSOYBEAN, BCOW)$$

The empirical form in a data generating process is specified as:

$$lnOKPHAY_t = \beta_0 + \beta_1 \ln(TIME_t) + \beta_2 \ln\left(\frac{OKHAYPROD_t}{OKBCOW_{t+1}}\right) + \beta_3 ln(OKPSOYBEAN_t) + \varepsilon_t$$

Variable names are defined under procedure.

Farmers would like to maximize profit based on the available resources. The emergence of switchgrass production will offer farmers the opportunity to produce alternative crops by comparing the profitability levels of each crop based on price and the opportunity cost of inputs. Therefore, producers will be able to select the crop unit that maximizes profit. Thus, the LP model would be used to determine the profit maximizing levels of hay and switchgrass subject to constraint resource(s).

The standard form of the LP model to maximize the production of hay and switchgrass subject to a land constraint is:

$$\max Z(H,S) = P_H H + P_S S$$

Subject to:

$$A_H H + A_S S \leq L$$

$$H \geq 0, S \geq 0$$

where $\boldsymbol{Z}$ is the value to be maximized (objective function value), $\boldsymbol{H}$ is optimal level of hay to be produced, $\boldsymbol{S}$ is optimal level of switchgrass to be produced, $\boldsymbol{P_H}$ is the marginal change in the value of the objective function $\boldsymbol{Z}$ resulting from a unit change in level of hay production, $\boldsymbol{P_S}$ is the marginal change in the value of the objective function $\boldsymbol{Z}$ resulting from a unit change in the level of switchgrass production, $\boldsymbol{A_H}$ is the amount of land required to produce a unit of hay, $\boldsymbol{L}$ is the acres of land, and $\boldsymbol{A_S}$ is the amount of land required to produce a unit of switchgrass. Haque et al. (2008) has reported that switchgrass production cost is lower than the production cost of hay in Oklahoma but for simplicity, this study assumes the production cost to be the same for switchgrass and hay so that the producer's choice will be based on the total revenue from producing either of these crops.

Data Sources.

Annual data from 1974 to 2009 on hay production, price of hay, and soybean price were obtained from USDA-NASS. Also annual data from 1975 to 2010 on beef cow inventory was obtained from USDA-NASS. The beef cow inventory data is reported on January first which reflects the activity of the previous year because beef cow reported on January first this year were grown last year. Hence beef cow data on January first was chosen to match the activities of the other variables in the preceding year. Figures 1 through 11 show upward trending in hay production and hay prices in Oklahoma and Texas, however, the fluctuations in the trend may result in unresponsiveness of both production and price to time.

The opportunity cost of land, and the expected yield and price per unit will determine the production options between hay and switchgrass for this study. Switchgrass yield is estimated to range from 2.23 tons per acre, as reported by Perrin et al. (2008) from field level studies in the northern plains to 6.45 tons per acre, as budgeted by Garland (2008) for Tennessee. Perrin et al. (2008) originally estimated production costs of $60 per ton based on field level studies but they reported a cost of $54 per ton based on extrapolated costs over a ten year stand life.

Epplin et al. (2007) reported a switchgrass yield from 3.75 tons per acre to 6.50 tons per acre, with an estimated farm gate production cost between $37 per ton and $53 per ton. The lowest cost of $37 per ton from their study depended critically on the assumption that harvest could extend over at least eight months. The extended harvest season allows for a substantially lower investment in harvest machines resulting in lower fixed costs per harvested ton and also lower storage costs.

Fuentes and Taliaferro (2002) reported switchgrass yields from variety trials conducted over seven years at two locations in Oklahoma. They found an average annual yield of 7.2 tons per acre from stands that included a combination of varieties Alamo and Summer. Haque et al. (2008) reported a mean annual yield of 5.5 tons per acre with one harvest per year and production cost of $47 per ton for switchgrass in Oklahoma. Based on their estimate of 5.5 tons per acre, 0.182 acre of land will be required to produce a ton of switchgrass. Table 1 includes a summary of switchgrass yield and production cost estimates from different studies.

The table indicates that yield estimates for switchgrass production in Oklahoma and Tennessee are higher than those from other states. Thus, Oklahoma and Tennessee are very promising for switchgrass production and can bid land away from some of the traditional crops including hay if expected price of switchgrass is high enough.

Determining the yield and acreage requirement for hay is difficult because hay is not as homogeneous as other crops. Grass hay can be produced from a variety of grasses which have different growth requirements and thus produce different yields. This characteristic makes it difficult to aggregate hay yield and acreage requirement as a single crop. USDA-NASS reports the annual aggregate yield per acre of hay as a single crop but this does not reflect the actual yield of the individual grass species used in producing the hay. USDA/NASS reports a mean annual all-hay yield of 1.8 tons per acre from 2000 to 2008. In 2008, USDA/NASS reported 2,600,000 harvested acres of hay (all-hay minus alfalfa). Haque et al. (2008) estimated the mean annual yield (dry tons per acre) of Burmudagrass, Lovegrass, and Flaccidgrass in Oklahoma to be 3.38, 3.53, and 4.5, respectively, for one harvest per year; and 4.8, 4.28, and 4.98, respectively, for two harvests per year. These figures are the means calculated from the means reported based on quantities of nitrogen per acre application. The respective costs of production ($/ton) are 57.00, 50.50, and 50.25 for one harvest per year; and 48.25, 48.75, and 48.25 for two harvests per year. If these grasses are produced as grass mix hay, they would have aggregate yields of 3.80 tons per acre for one harvest a year and 4.69 tons per acre for two harvests a year with production costs of $52.58 per ton for one harvest and $48.42 per ton for two harvests. Based on the yield from the two harvests a year, one ton of dried hay mix will require 0.213 acre of land.

Data and information on switchgrass prices are not currently available because markets for biomass are absent for much of the United States. Some studies including Bangsund et al. (2008) have estimated breakeven farm-gate switchgrass prices. However, for a switchgrass cropping systems to become commercially viable, the price paid to producers per ton of biomass must be high enough to bid land away from traditional farm enterprises, rather than simply offsetting production costs. Recent studies in Oklahoma indicate good switchgrass yields with comparatively lower production costs (table 1). Thus an attractive switchgrass price will likely bid away land currently used to produce some traditional crops including hay.

Oklahoma hay prices have been fairly stable over time, though there have been short-term fluctuations in response to production levels. USDA-NASS reports a mean annual all-hay price of $83.11 per ton from years 2000 to 2009. This study estimates the 2008 Oklahoma grass hay price to be $89.86 per ton.

Demand Procedure

Blake and Clevenger (1984) and Myer and Yanagida (1984) observed that an inverse demand function with hay price as the dependent variable is appropriate when supply is predetermined. Hay supply could be predetermined by the current year plantings, harvesting and weather. For this study, the inverse demand function was specified as:

$$lnPHAY = lnf(TIME, HAYPROD, PSOYBEAN, BCOW)$$

with the empirical form in a data generating process as :

$$lnOKPHAY_t = \beta_0 + \beta_1 \ln\,(TIME_t) + \beta_2 \ln\,(\frac{OKHAYPROD_t}{OKBCOW_{t+1}}) + \beta_3 ln(OKPSOYBEAN_t) + \varepsilon_t$$

and the model to test the effect of hay production to beef cow ratio of adjoining state on Oklahoma is specified as:

$$lnOKPHAY_t = \beta_0 + \beta_1 ln(TIME_t) + \beta_2 \ln(\frac{OKHAYPROD_t}{OKBCOW_{t+1}} + \beta_3\, ln\left(\frac{TXHAYPROD_t}{TXBCOW_{t+1}}\right) + \beta_4 ln(OKPSOYBEAN_t) + \varepsilon_t$$

Also, the Oklahoma model was used to estimate Texas hay price to find out how the model may work in other states and was specified as:

$$lnTXPHAY_t = \beta_0 + \beta_1 \ln\,(TIME_t) + \beta_2 \ln\,(\frac{TXHAYPROD_t}{TXBCOW_{t+1}}) + \beta_3 ln(TXPSOYBEAN_t) + \varepsilon_t$$

where $\boldsymbol{OKPHAY_t}$ is Oklahoma annual price of hay ($/ton) in year $\boldsymbol{t}$; $\boldsymbol{TXPHAY_t}$ is Texas annual price of hay ($/ton) in year $\boldsymbol{t}$; ***TIME*** is a time trend with 1974 = 1, 1975 = 2,…, 2009 = 36; ***OKHAYPROD*** is Oklahoma hay production other than alfalfa (1,000 tons); ***TXHAYPROD*** is Texas hay production other than alfalfa (1,000 tons); ***OKPSOYBEAN*** is Oklahoma soybean price ($/bu); ***TXPSOYBEAN*** is Texas soybean price ($/bu); ***OKBCOW*** is Oklahoma beef cow inventory (1,000 head) on January 1 of the following year; ***TXBCOW*** is Texas beef cow inventory (1,000 head) on January 1 of the following year; $\boldsymbol{\varepsilon_t \sim N(0, \delta_t^2)}$ is a random error term with mean zero and variance $\boldsymbol{\delta_t^2}$; $\boldsymbol{\beta_i}$ ($\boldsymbol{i}$ = 0,…, 5) and are parameters to be estimated; $\boldsymbol{t}$ is a subscript for the current year; and $\boldsymbol{t}$+1 is a subscript for the following year.

The coefficients of hay production to beef cow ratio were expected to be negative in order to be consistent with a negatively sloped industry demand curve (Blake and Clevenger 1984; Myer and Yanagida 1984). The higher the price of the commodity, the lower the quantity of the commodity to be demanded. An increase in the price of beef would act as an incentive for livestock producers to increase input use (Nicholson, 2005) as they build their herds. Thus beef cow producers would build their herds in anticipation of future profits which will consequently increase their demand for hay and thus increase the price of hay.

The coefficient of price soybean was hypothesized to be positive. Soybean price was considered in the model to represent the price of a substitute (protein supplement). Thus the price of soybeans is expected to be positively related to hay price. Prices of ingredients in feed rations tend to move together because the ingredients are generally good substitutes (Blake and Clevenger 1984).

A time trend was included in the model to capture the effects of other time-related variables not included in the model that have influenced hay prices. The trend variable also captures the positive trend in hay price over time.

The inverse demand equation with price of hay as the dependent variable; and time trend, ratio of hay production to beef cow inventory, and soybean price was estimated using ordinary least squares (OLS) with 36 observations from 1974 to 2009.

The Pearson correlation coefficients were estimated among independent variables and did not indicate problem with multicollinearity. However, the beef cow variable was not significant and assumed unexpected sign and so the data were transformed using a log-log specification. The residuals were checked for autocorrelation to see if the variables were serially correlated using Durbin-Watson statistics. The data were also checked for heteroskedasticity using Lagrangian multiplier (LM) test. The residuals were also checked for normality using the proc autoreg procedure to see whether the data were reliable. Texas hay production to Texas beef cow inventory ratio was included in the Oklahoma model to find out the direct effect of Texas hay production and beef cow inventory on Oklahoma hay price. The final model developed for Oklahoma hay demand was tested on Texas to find out the validity of the model in Texas and so the model was used to estimate Texas hay demand.

The LP Procedure

The LP model was used to determine the producer's choice between the production of hay or switchgrass based on maximum returns from production. Excel Solver was used to indicate the production of hay and switchgrass that will yield maximum profit based on the available resource (land) while holding all other factors constant. The objective function of the LP model was specified as:

$$max\ Z(H,S) = P_H H + P_S S$$

$$Subject\ to{:}\ A_H H + A_S S \leq L$$

$$H, S \geq 0$$

To produce one dry ton of switchgrass, 0.182 acre of land is required, while 0.213 acre of land is required to produce one dry ton of hay that is sold for $89.86. The study assumes total available land for production is 2,600,000 acres as reflected in the 2008 report from NASS-USDA as the harvested acres of hay (excluding alfalfa). Switchgrass price information is rarely available in Oklahoma and therefore, the price of switchgrass was parameterized in this modeling process. A switchgrass price that is lower than that of the hay price was used and then parameterized to find the point at which it will make switchgrass more profitable than hay (i.e. switch-over price of switchgrass)

FINDINGS

Demand Equation

The 0.27205 Pearson correlation coefficient between the ratio of hay production to beef cow inventory and the soybean price did not show any problem of multicollinearity, suggesting that the demand equation could be represented by a recursive model. However, the coefficient of the ratio of hay production to beef cow inventory had an unexpected sign, thus the data was transformed using log-log specification. Durbin-Watson statistic of 2.079, and 1.976 as shown in tables 2, and 3 respectively led to conclusion of no autocorrelation in each of the estimations. A test for autocorrelation on the Texas model using the Durbin-Watson statistics of 1.158 led into an inconclusive region, thus the Breusch-Godfrey Lagrangian Multiplier test result of 6.6841 with p-value of 0.0097 led to conclude that there is no autocorrelation. Heteroskedasticity test results from LM test were 7.128, 3.9888 and 1.6308 as shown in tables 2, 3, and 4 respectively did not indicate problem of heteroskedasticity in any of the estimations. Test results indicate that the data came from reliable source since normality tests of 0.7994, 2.5839 and 4.2077 with their respective p-values of 0.6705, 0.2747 and 0.1220 as shown in tables 2, 3, and 4 respectively.

All coefficients were significant at the 5% level with their expected signs. The negative sign of the coefficient for hay production to beef cow ratio confirms a negatively sloped demand curve in which quantity demanded increases as price decreases. Soybeans price was positively related to hay price because they are substitutes. An increase in the soybeans price relative to the hay price creates an incentive for beef cow producers to feed their cows more hay, thus increasing hay demand which will result in an increase in the price of hay. An increase in the beef cow inventory leads to an increase in demand for hay with a consequent increase in the price of hay.

The coefficients of the variables represent marginal changes in the price of hay with respect to a unit change in the respective variable. Therefore, a unit increase in the level of hay production to beef cow ratio will cause a $0.33 decrease in the price of hay, and hay price increases by $0.29 for one unit increases in the soybean price.

Price flexibilities (table 5) show the degree of responsiveness in the price of hay to a percentage change in hay production to beef cow ratio, and price of soybeans. It should be noted that the slopes of the log-log specifications are the direct estimates of (constant) elasticities (Johnston and DiNardo, 1997), but for inverse demand functions with log-log specifications, the coefficients of the independent variables are the price flexibilities as used in Bazen et al. (2008). Thus a one-percentage increase in the level of hay production to beef cow ratio will cause approximately a 0.32% decrease in the price of hay. A one-percent increase in soybeans price was associated with a 0.29% increase in the price of hay. Hay price is unresponsive to time, hay production to beef cow ratio, and soybeans price.

The ratio of Texas hay production to Texas beef cow inventory as added to the Oklahoma model and was more significant in the model than Oklahoma hay production to beef cow ratio (table 4) which indicates that Oklahoma hay price depends on the amount of hay and beef cow inventory in Texas.

The model developed for Oklahoma was used to estimate the inverse demand for Texas to find out the validity of the model in different states (table 4) and the model works for Texas hay demand with all variables significant at the 5% level.

LP Results

Analyses were based on only a land constraint, and prices while holding all other factors constant. Table 6 summarizes the results from the LP procedure using excel solver. At a price of $89.86/ton for hay and $75.50/ton for switchgrass, it would be profitable to produce hay instead of switchgrass. Parameterizing the price of switchgrass by adding $0.10 to $75.50 in alternate manner while holding hay price constant results in a switch-over point of $80.00/ton as switchgrass price. Thus switchgrass production becomes profitable over hay at the price of $80.00/ton for switchgrass and $89.86/ton for hay (predicted by the demand equation). Analysis was based on the assumption that switchgrass has lower cost of production than hay. At switchgrass price of $ 80/ton, hay must be sold for at least $93.7/ton in order for its production to be profitable over switchgrass, and at this point, parameterizing hay and switchgrass prices at the same rate in alternate manner switched production back and forth between hay and switchgrass. Switchgrass production appears to be profitable over hay production even when switchgrass price is placed $13.6 below the price of hay. The reason is that the land requirement/ton for switchgrass is far less than that of hay. It should be noted that this result could also have been obtained from a simple budgeting model but the excel solver made it easier because of the parameterization process.

CONCLUSION

Hay demand in Oklahoma can be represented by a recursive model of an inverse demand function with hay price as the dependent variable and time trend, level of hay production, soybean price, and beef cow inventory as independent variables.

Oklahoma hay price appeared to be unresponsive to the quantity of hay produced which may be attributed to a number of factors. The bulky nature of hay makes it less likely to be transported to far places where prices may be higher. Similarly, livestock farmers have less incentive to buy hay from far places, thus making it difficult for hay price to be adversely affected by the quantity of hay produced. The organization and the structure of the hay markets are not strong enough to control prices due to factors such as spatial intensity, and also there are no such organized markets like auctioning. Also hay is priced according to a number of factors such as species of grass, quality, and size of bale, thus it makes it difficult to keep track of its price as a single commodity. Also some livestock farmers may produce their own hay to feed their herd and the value of such levels of production may not be perfectly reflected in the overall price of hay. Furthermore, the unresponsiveness of the hay price to a change in the quantity of hay produced is an indication that the Oklahoma hay price is fairly stable.

Also, Oklahoma hay price is dependent on the quantity of hay produced in adjoining state. Oklahoma hay price appeared to be dependent on Texas hay production. There is a myth that the bulky nature of hay makes it very difficult to transport across states but this study has shown that hay could be transported across adjoining states. An increase in the quantity of Texas hay production causes a decrease in the price of Oklahoma hay price. The inverse demand function for Oklahoma can also be used to model Texas hay demand using the same variables used for Oklahoma, indicating that a reasonable model was arrived at and may be assumed as a regional model if it works for other adjoining states as well.

Switchgrass production could possibly be more profitable than hay production even if the switchgrass price is below the hay price because switchgrass requires less land per unit of production. It is therefore likely that farmers who produce hay for sale may switch their land currently used for hay production to switchgrass production when the federal mandate of biofuel production becomes fully operational, thus creating strong markets for feedstock. The consequent effect would be that hay production would be reduced, causing an increase in the hay price, thus making it less affordable to beef cow farmers. Beef cow numbers would be reduced causing increases in beef prices overtime. It is unlikely that all lands currently used to produce hay would be shifted to switchgrass production because some livestock farmers will still produce hay to feed their own herds.

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Table 1. Estimates of Switchgrass Yield and Farm Gate Production Costs

Source	Location	Matured Yield	Farm Gate Cost
Bangsund et al.[d] (2008)	ND	3.06	37.78
Brechbill and Tyner (2008)	IN	5.00	45
Duffy (2007)	IA	4.00	82
Epplin (1996)	OK	4.00	23
Epplin et al. (2007)	OK	3.75-6.50	37-53
Garland (2008)	TN	6.45	62[e]
Khanna et al. (2008)	IL	2.58	82
Haque et al. (2008)	OK	5.5 and 6.2[a]	46 and 47[b]
Mooney et al. (2009)	TN	6.2-7.9	42-63
Perrin et al. (2008)	ND,SD	2.23	54
Vadas et al. (2008)	WI	4 .84	53
Wang (2009)	TN	6.0-7.8	66-77 [c]

[a] 5.5 tons/acre yield estimate is based on one harvest per year and 6.2 tons per acre yield estimate is based on two harvests per year.
[b] $46/ton cost estimate is based on two harvests and $47/ton cost estimate is based on one harvest per year.
[c] Estimates include delivery cost.
[d] Estimates are averages from soil productivity classes, described as low, average, and high.
[e] Cost excludes land charge.
Farm gate cost is in $/ton.
Matured yield is in tons/acre.

Table 2. OLS Estimates of an Inverse Demand Function for Oklahoma Hay Production

Variables	Estimates	Standard Errors	t-values	P-values
INTERCEPT	3.04439	0.16715	18.21	0.0001
LNTIME	0.29821	0.04121	7.24	0.0001
LNOKHC	-0.32705	0.09317	-3.51	0.0014
LNPSOYBEAN	0.29437	0.08499	3.46	0.0015
Normality	0.7994			0.6705
D-Watson	2.079			
R^2	0.7606			
LM	7.128			

Note: Hay price ($/ton) is the dependent variable and the ratio of Oklahoma hay to beef cow inventory (OKHC, ton/head), time (1974=1, …, 2008=35), and Oklahoma soybean price (PSOYBEAN, $/bu) are independent variables.

Table 3. OLS Estimates of an Inverse Demand Function for Oklahoma Hay Production

Variables	Estimates	Standard Errors	t-values	P-values
INTERCEPT	3.00314	0.15685	19.15	0.0001
LNTIME	0.33549	0.04145	8.09	0.0001
LNOKHC	-0.16934	0.16934	-1.56	0.1300
LNPSOYBEAN	0.26686	0.08009	3.33	0.0022
LNTXHC	-0.25171	0.10469	-2.40	0.0224
Normality	2.5839			0.2747
R^2	0.7982			
DW	1.976			
LM	3.9888			

Note: Oklahoma hay price ($/ton) is the dependent variable and the ratio of Oklahoma hay to Beef cow inventory (OKHC, ton/head), time (1974=1, …, 2009=36), Oklahoma soybean price (PSOYBEAN, $/bu) and the ratio of Texas hay production to Texas beef cow inventory (TXHC, ton/head) are the independent variables.

Table 4. OLS Estimates for Inverse Demand for Texas Hay Production

Variables	Estimates	Standard Errors	t-values	P-values
INTERCEPT	2.76356	0.21678	12.75	0.0001
LNTIME	0.30957	0.05465	5.66	0.0001
LNTXHC	-0.21444	0.12129	-1.77	0.0866
LNTXPSOYBEAN	0.43256	0.11105	3.90	0.0005
Normality	4.2077			0.1220
Breusch-Godfrey LM	6.6841			0.0097
R^2	0.7404			
LM	1.6308			
D-Watson	1.158			

Note: Price of hay ($/ton) is the dependent variable and time trend (TIME, 1974=1, …, 2009=36), ratio of hay production to beef cow (TXHC, ton/head), and soybean price (TXPSOYBEAN, $/bu) are the independent variables.

Table 5. Hay Price Flexibilities among Independent Variables.

Variables	Price flexibilities
Time	0.30
OKHC	-0.33
BCOW	0.29

Table 6. The LP Results

Price of Hay	Optimal Value of Hay	Price of Switchgrass	Optimal Valueof Switchgrass	Ojective Function Value
89.86	12206572.77	75.5	0	1,096,882,629
89.86	12206572.77	75.6	0	1,096,882,629
89.86	12206572.77	75.7	0	1,096,882,629
89..86	12206572.77	75.8	0	1,096,882,629
89.86	12206572.77	75.9	0	1,096,882,629
89.86	0	80	14285714.29	1,142,857,143
89.96	0	80	14285714.29	1,142,857,143
90.06	0	80	14285714.29	1,142,857,143
93.6	0	80	14285714.29	1,142,857,143
93.7	12206572.77	80	0	1,143,755,869
93.7	0	80.1	14285714.29	1,144,285,715
93.8	12206572.77	80.1	0	1,144,976,526
93.8	0	80.2	14285714.29	1,145,714,286
93.9	12206572.77	80.2	0	1,146,197,183
93.9	0	80.3	14285714.29	1,147,142,857
94	12206572.77	80.3	0	1,147,417,840

Note: Price of hay ($/ton), optimal value of hay (tons), price of switchgrass ($/ton), optimal value of switchgrass (tons), and objective function value ($).

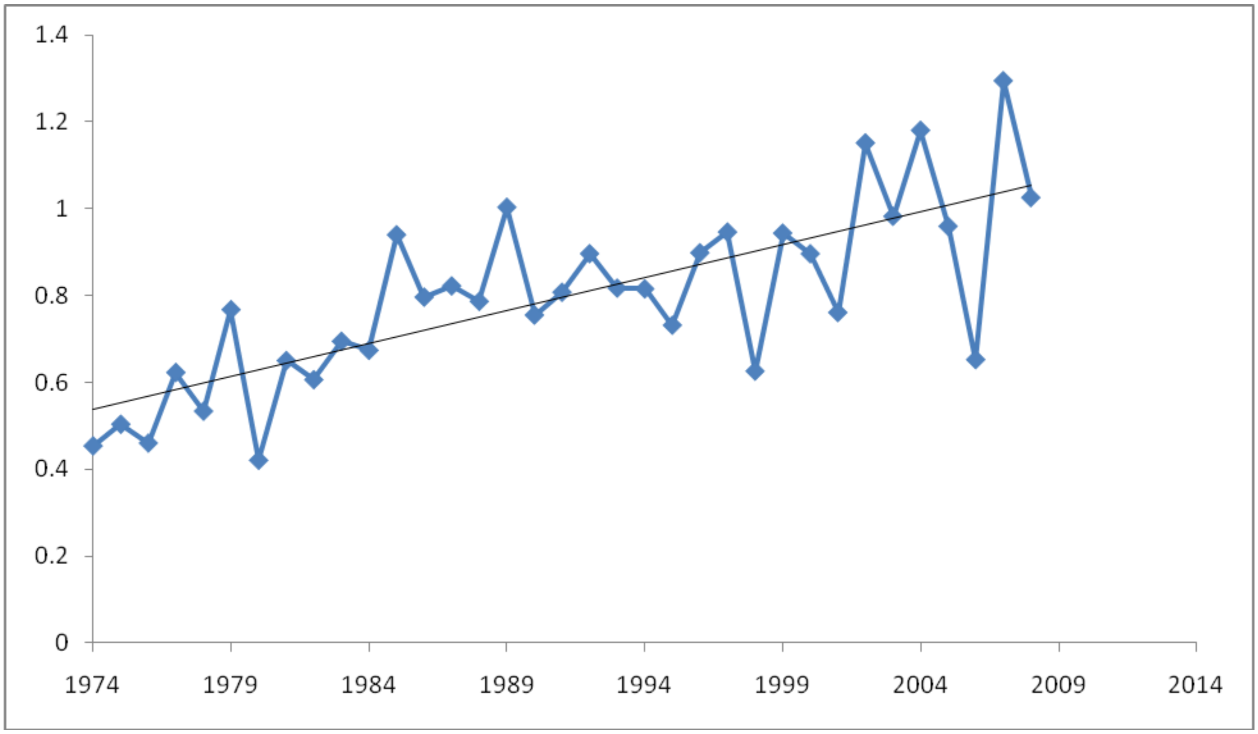

Figure 1. The ratio of Oklahoma all hay production to all cattle inventory (ton/head).

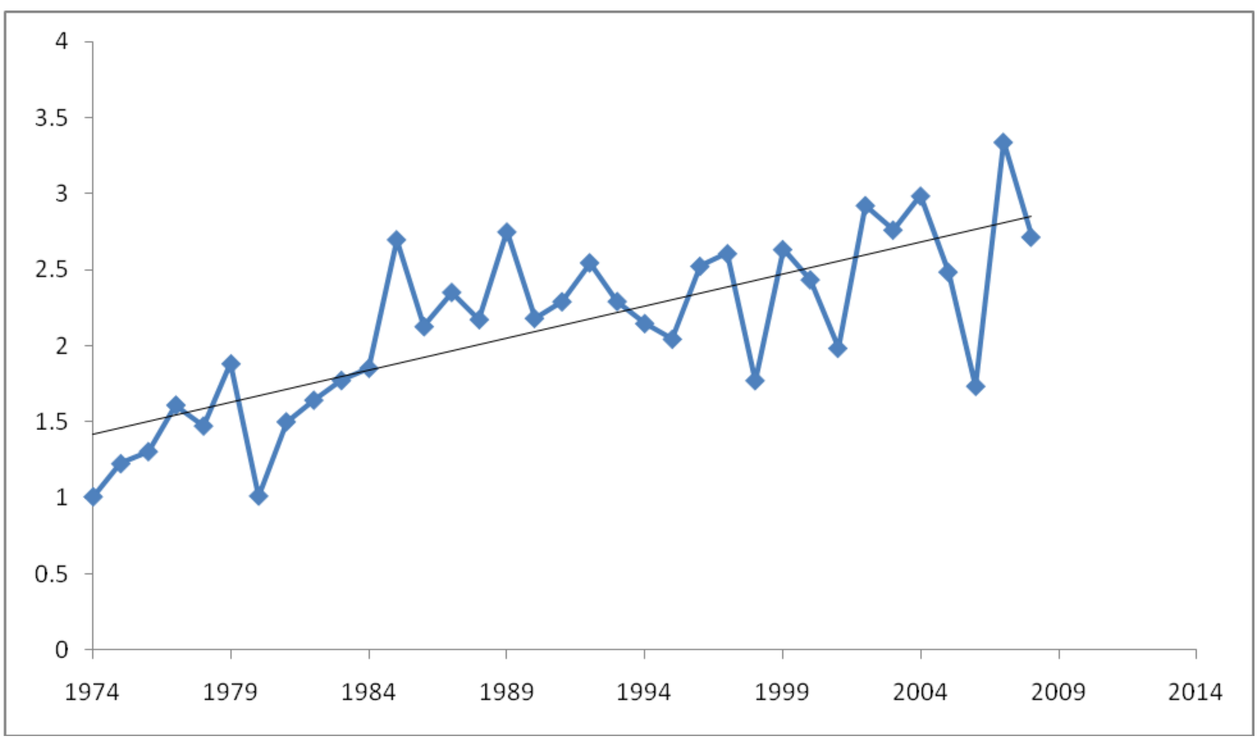

Figure 2. The ratio of Oklahoma all hay production to beef cow inventory (ton/head).

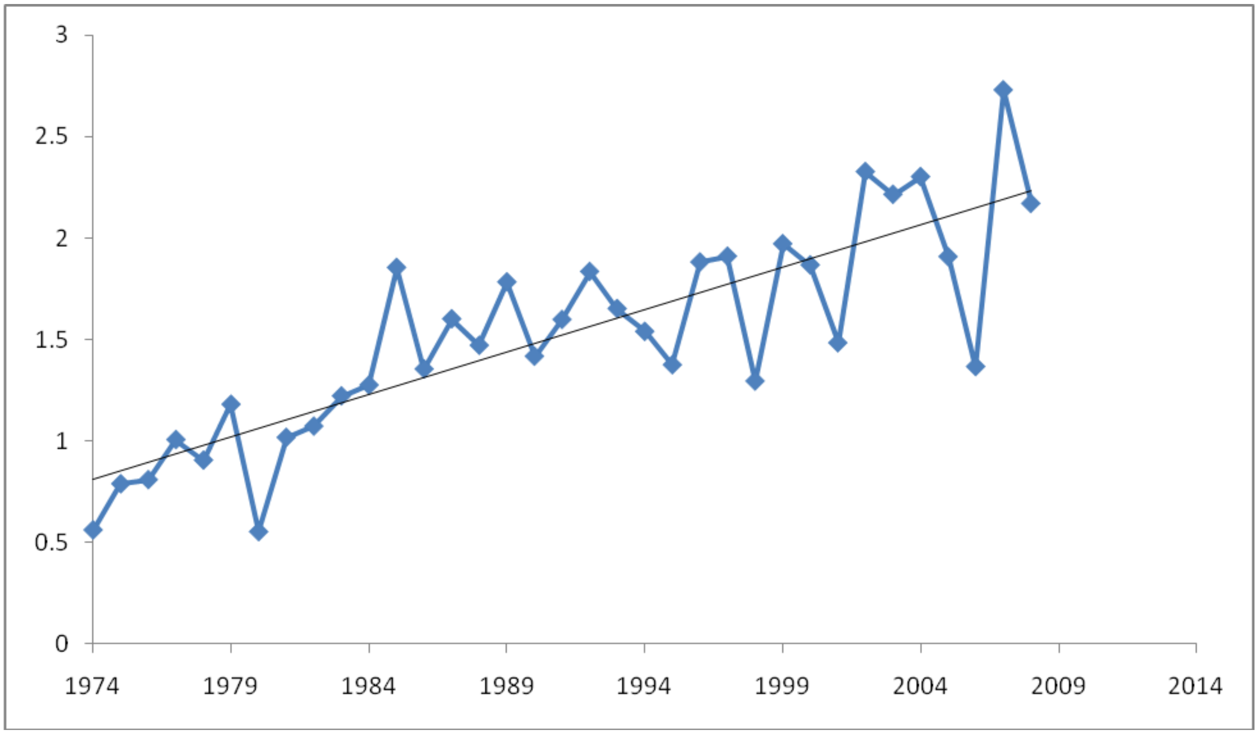

Figure 3. The ratio of Oklahoma other hay production to beef cow inventory (ton/head).

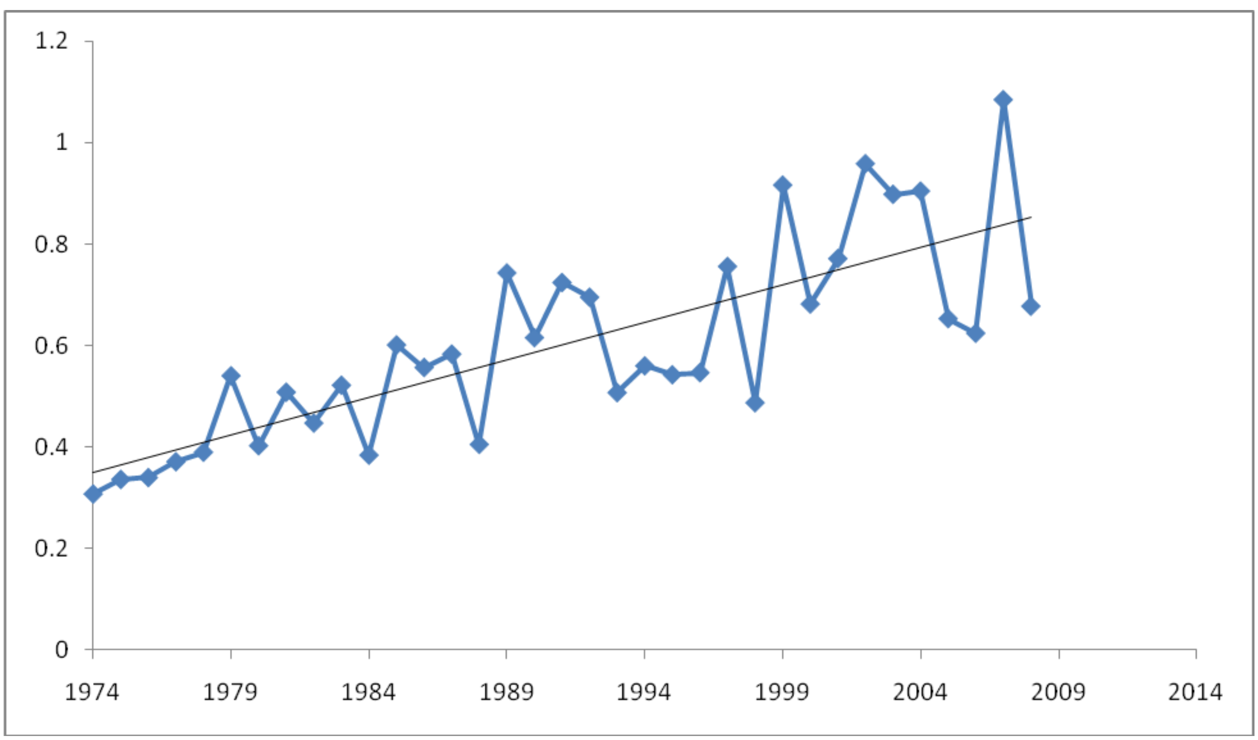

Figure 4. The ratio of Texas all hay production to Texas all cattle inventory (ton/head).

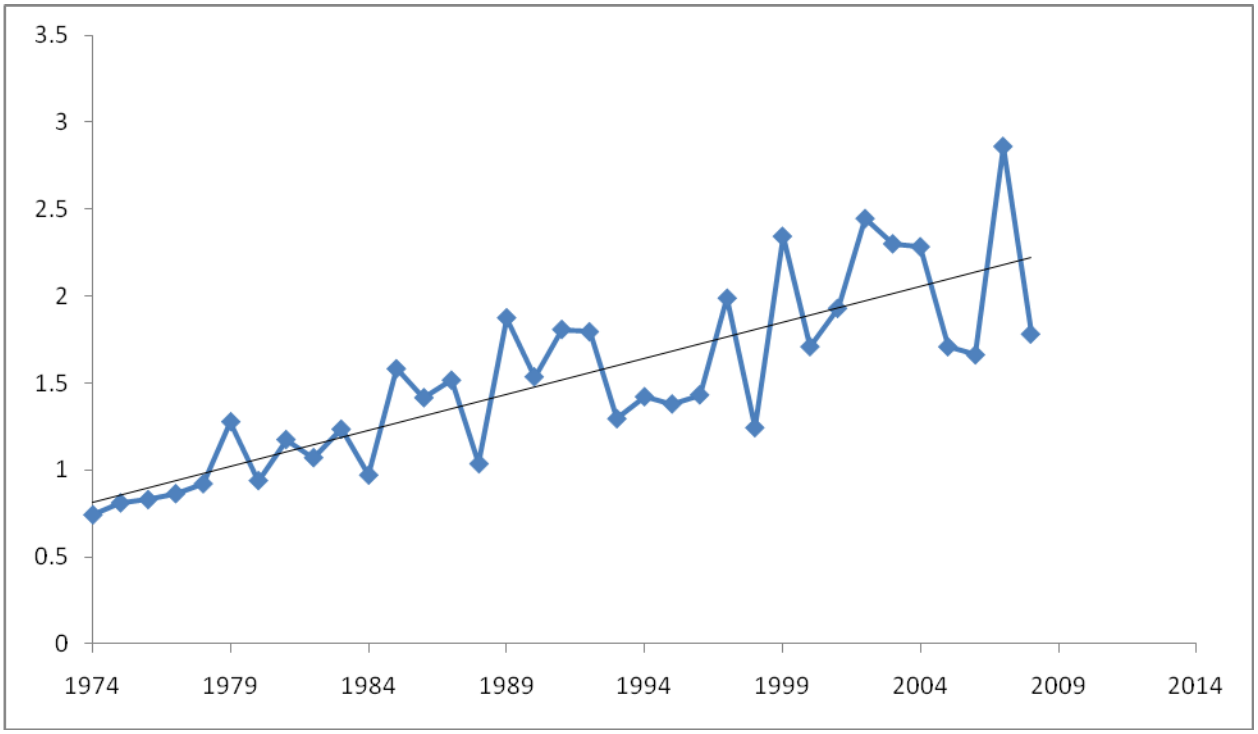

Figure 5. The ratio of Texas all hay production to Texas beef cow inventory (ton/head).

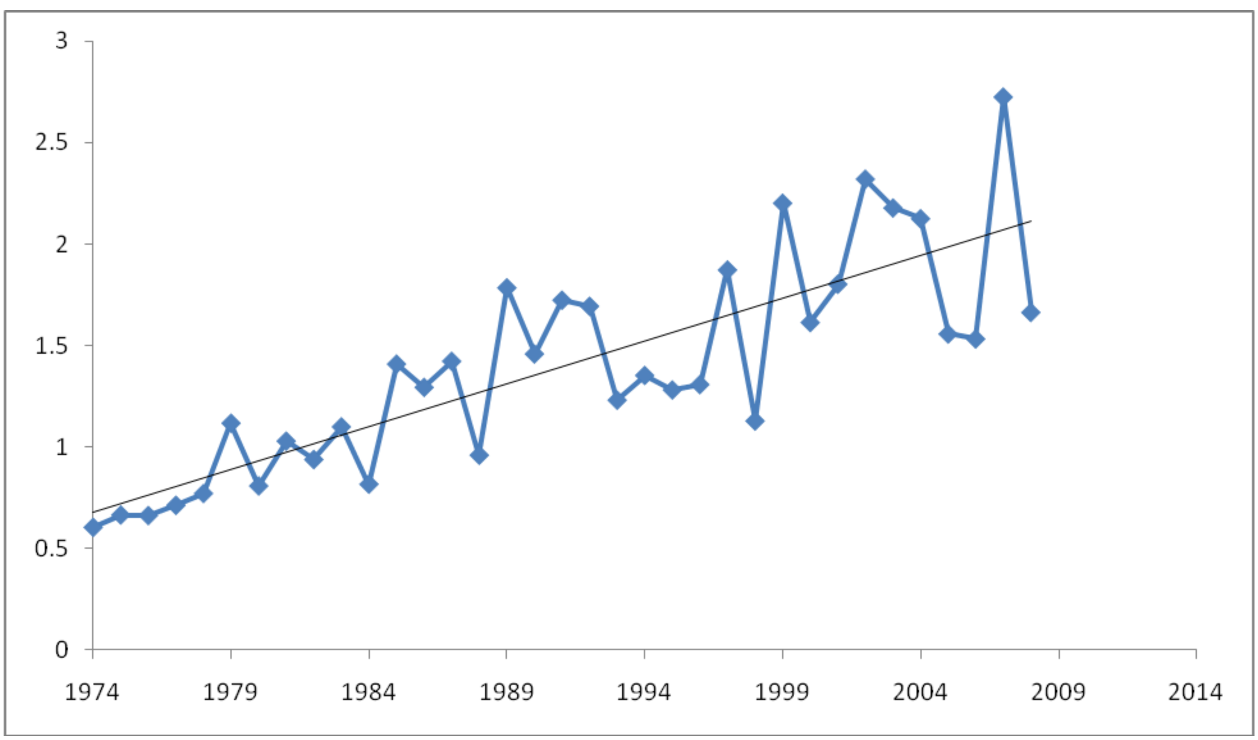

Figure 6. The ratio of Texas other hay production to Texas beef cow inventory (ton/head).

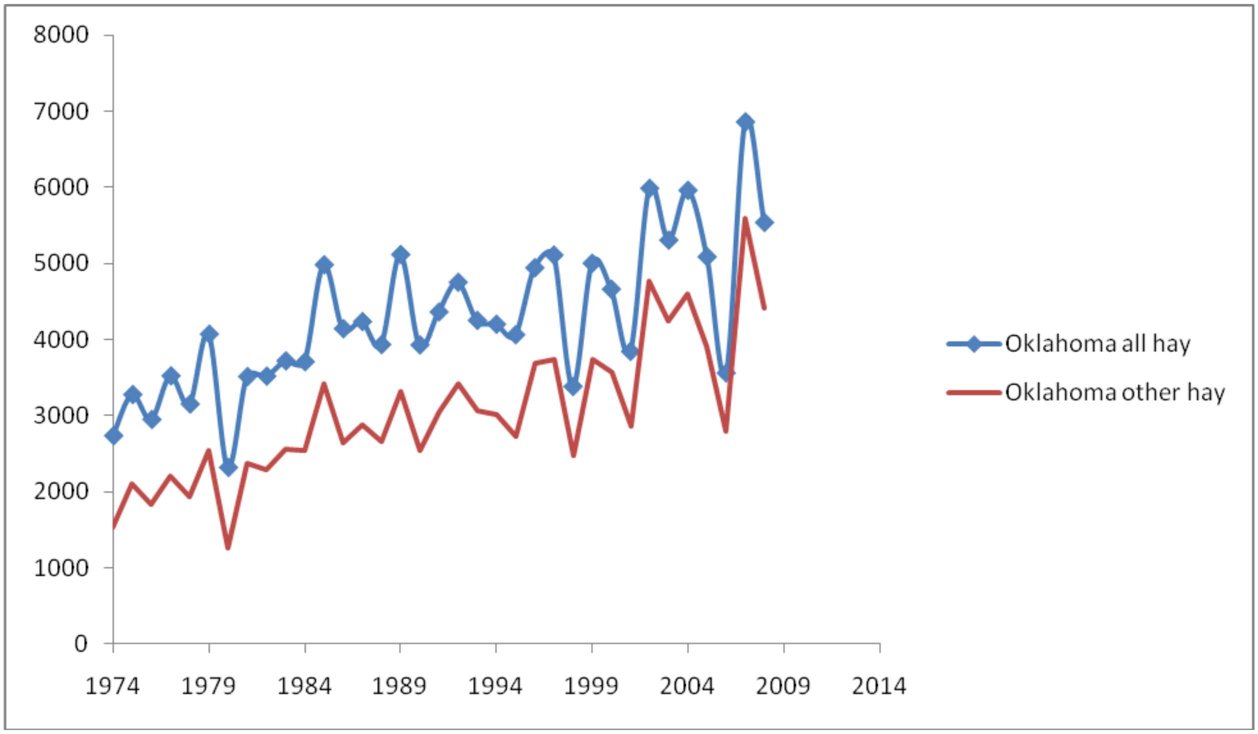

Figure 7. Oklahoma hay production (1000 tons).

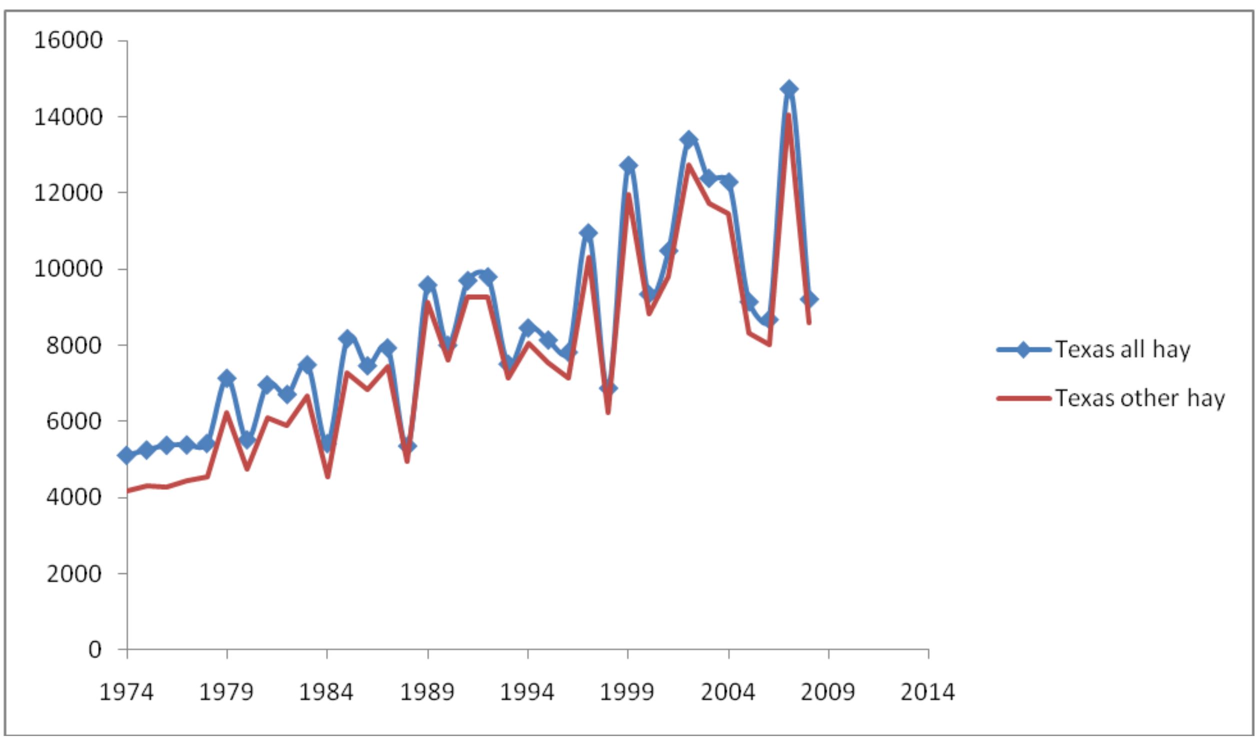

Figure 8. Texas hay production (1000 tons).

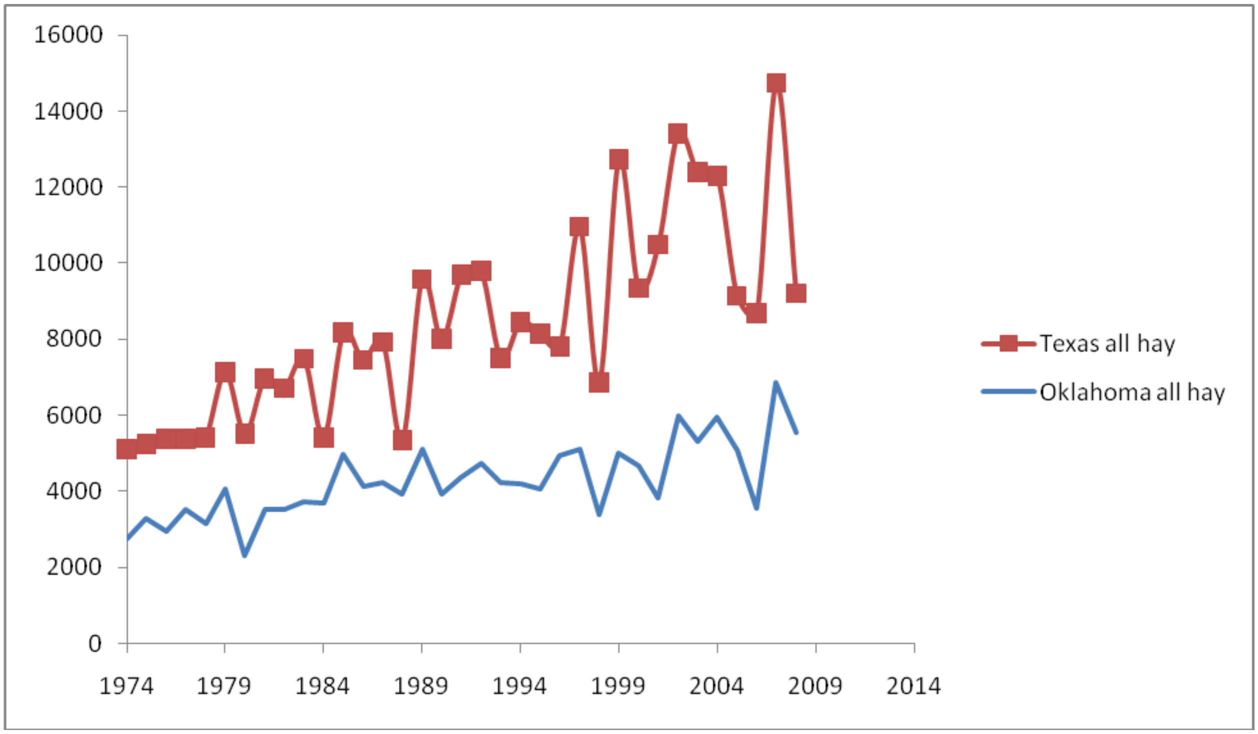

Figure 9. Texas and Oklahoma hay production (1000 tons).

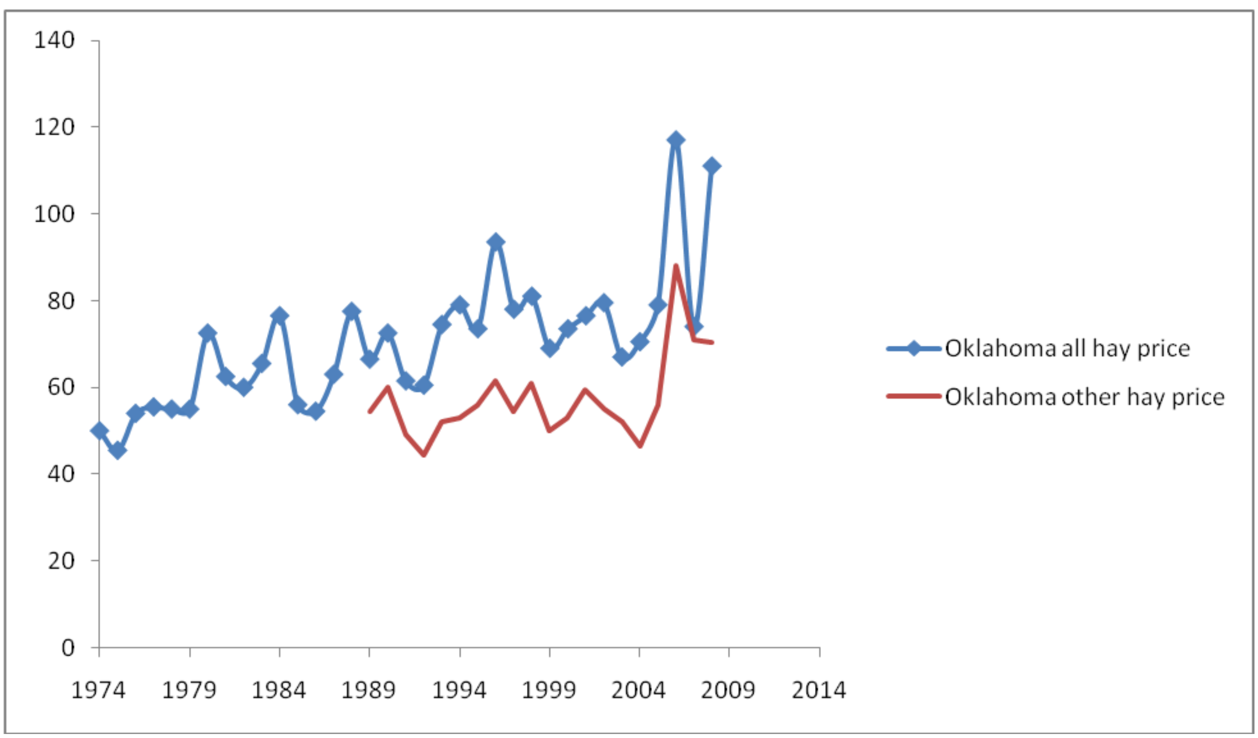

Figure 10. Oklahoma hay price ($/ton).

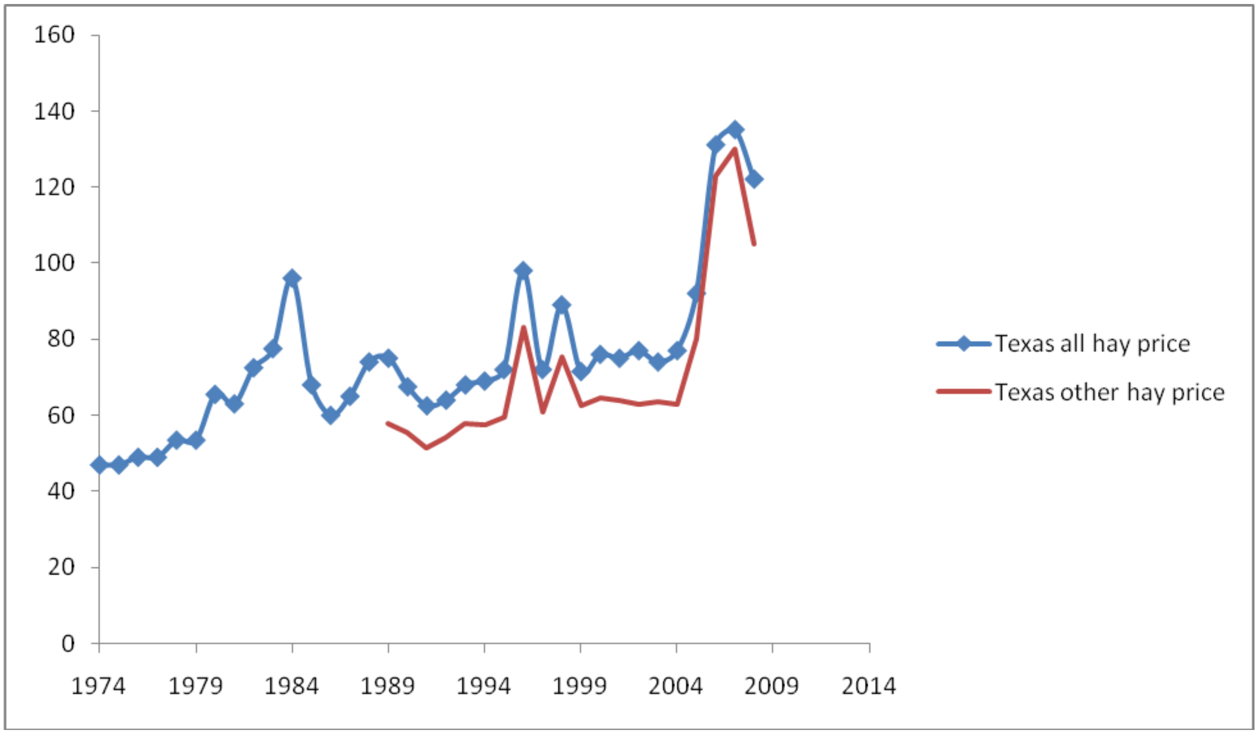

Figure 11. Texas hay price ($/ton).