Effects of drought on hay and feed grain prices

Journal Article

Author(s):
Schaub, Sergei; Finger, Robert

Publication date:
2020-03

Permanent link:
https://doi.org/10.3929/ethz-b-000388612

Rights / license:

Originally published in:
Environmental Research Letters 15(3), https://doi.org/10.1088/1748-9326/ab68ab

Environmental Research Letters

ACCEPTED MANUSCRIPT • OPEN ACCESS

Drought effects on hay and feed grain prices

To cite this article before publication: Sergei Schaub *et al* 2020 *Environ. Res. Lett.* in press https://doi.org/10.1088/1748-9326/ab68ab

Manuscript version: Accepted Manuscript

Accepted Manuscript is “the version of the article accepted for publication including all changes made as a result of the peer review process, and which may also include the addition to the article by IOP Publishing of a header, an article ID, a cover sheet and/or an ‘Accepted Manuscript’ watermark, but excluding any other editing, typesetting or other changes made by IOP Publishing and/or its licensors”

This Accepted Manuscript is **© 2019 The Author(s). Published by IOP Publishing Ltd**.

As the Version of Record of this article is going to be / has been published on a gold open access basis under a CC BY 3.0 licence, this Accepted Manuscript is available for reuse under a CC BY 3.0 licence immediately.

Everyone is permitted to use all or part of the original content in this article, provided that they adhere to all the terms of the licence https://creativecommons.org/licences/by/3.0

Although reasonable endeavours have been taken to obtain all necessary permissions from third parties to include their copyrighted content within this article, their full citation and copyright line may not be present in this Accepted Manuscript version. Before using any content from this article, please refer to the Version of Record on IOPscience once published for full citation and copyright details, as permissions may be required. All third party content is fully copyright protected and is not published on a gold open access basis under a CC BY licence, unless that is specifically stated in the figure caption in the Version of Record.

View the article online for updates and enhancements.

This content was downloaded from IP address 129.132.180.61 on 08/01/2020 at 13:40

Title: Drought effects on hay and feed grain prices

Authors: Sergei Schaub[a,b] and Robert Finger[a]

[a] Agricultural Economics and Policy Group, ETH Zürich

[b] Grassland Sciences Group, ETH Zürich

Abstract

Droughts represent a severe and increasing risk for the livestock sector as they can reduce hay and feed grain yields. Droughts are predicted to increase in frequency and magnitude under climate change. We here estimate the so far unexplored effect of drought shocks on feed prices. We use an empirical example from Germany and focus on the prices of hay as well as feed wheat and barley. Our results show that regional and national droughts substantially increase hay prices of up to 15%, start with a delay of about three months and last for about a year. In contrast, feed grain prices in our sample are not affected by regional or national droughts. These price responses can be linked to market integration, as the hay market are usually regionally organized while feed grains are traded transnationally. This knowledge is important to include into farm management and policy actions, especially considering climate change.

Keywords

Hay prices, feed grain prices, droughts, weather extremes, market integration

1. Introduction

Agriculture is highly vulnerable to droughts. This also holds for livestock production. Droughts can cause substantial reductions in yields of grassland and feed crops (e.g. Ciais et al. 2005; Smit et al. 2008; Webber et al. 2018). Yet, the implications for the feed markets are not well studied, even if, under climate change such droughts are predicted to increase in frequency and magnitude (Dai 2013; IPCC 2013; Spinoni et al. 2018).

We estimate effects of droughts occurring on regional and national levels on feed prices using an empirical example from South Germany and focusing on important feed prices, including hay and feed wheat and barley prices. These prices are expected to be affected differently by shocks, considering differences in transport and transaction costs, thus potential market integration. Transport costs are here defined as costs occurring due to transport, e.g. for fuel and loading. Transaction costs include other costs that occur due to the exchange of goods, e.g. finding sellers or buyers and verification of quality. Hay, as an important feed source for dairy and beef sector as well as for feeding horses (Vanselow et al. 2012; LfL 2018), is a bulky commodity with varying quality, has a low per ton protein unit, is usually not transported over great distances and relatively low quantities are traded (Rudstrom 2004; McCullock et al. 2014). Thus, hay markets are rather regional, with relatively low transparency and a lack of formal market exchanges.[1] In contrast, feed wheat and barley, which are the two most important feed grains in Germany (BLE 2019), have typically higher protein unit per ton than hay, are transported over longer distances, larger quantities are traded and trade occurs transnationally (Liefert et al. 2010; Taheripour et al. 2011; BLE 2019). Thus, the feed grain market is over-regionally organized and is assumingly more transparent than the hay market. Depending on the animal, wheat and barley can be good substitutes for each other whereas hay is only limited a substitute for them given animals feed roughage and grain/concentrate ration requirements (Flanders and Gillespie 2015).

While previous studies looked at general hay prices dynamics (e.g. Bazen et al. 2008; McCullock et al. 2014; Peake et al. 2019), no study investigated the drought effects on hay prices. For major grain prices some studies explored the reaction to drought (e.g. Sternberg 2012; Chung et al. 2014). Other studies showed that grain prices positively react to anomalies in the El Niño-Southern Oscillation, which are linked to extreme weather events such as droughts (e.g. Algieri 2014; Ubilava 2017).

We contribute filling gaps in the literature by providing the first study on feed price dynamics, of different feed crops, in response to regional and national droughts. Our findings are important for private actors, such as farmers and insurances, as well as for public entities to improve management of adverse drought effects. We found that droughts substantially increased hay prices while feed grain prices were not affected. These price responses can be linked to market integration.

In the remainder of the paper, we present our theoretical framework (1), which is followed by the description of the econometric framework (2) and the data (3). Next, we present our results of the baseline drought specification as well as of the robustness checks (4), and finally, we discuss and conclude our results (5).

2. Theoretical framework

---

[1] Note that in this paper market transparency refers to the availability, accuracy, timeliness and reliability of market information and formal market exchanges the institutionalization and regularization of market exchanges.

The demand and supply function for feed crops Q_{Dt} and Q_{St}, are summarized as follows (see e.g. Alam and Gilbert 2017):

$$Q_{D,t} = Q_D(P_t, H_t, V_t, \gamma_{1,t,r}) \tag{1}$$

$$Q_{S,t} = Q_S(P_t, H_t, V_t, \gamma_{2,t,r}) \tag{2}$$

P_t represents prices, for example wholesale prices, of the agricultural product, i.e. $P_t = \left[p_t^{wheat}, p_t^{barley}, p_t^{hay}\right]$, H_t is transport costs and V_t is transaction costs. Whether buyers or sellers bear the transport and transaction costs depends on the market (power) of the different parties (e.g. Graubner et al. 2011), therefore, we stated them explicitly in equation (1) and (2). $\gamma_{1,t,r}$ and $\gamma_{2,t,r}$ are vectors of variables: $\gamma_{1,t,r} = \left[Z_{1t}, k_{t,r}, \epsilon_{1,t}\right]$ and $\gamma_{2,t,r} = \left[Z_{2t}, k_{t,r}, \epsilon_{2,t}\right]$, where $Z_{1,t}$ and $Z_{2,t}$ are the respective demand and supply shifting variables. Note that we denote separately from the other demand and supply shifting variables droughts as $k_{t,r}$. We consider droughts at the regional level (i.e. in South Germany) or at the national level (i.e. in whole Germany)[2], i.e. $r = 1$ and $r = 2$ respectively. $\epsilon_{1,t}$ and $\epsilon_{2,t}$ are random shock variables.

Using equation (1) and (2) the change in storage, δ_t, can be expressed as:

$$\delta_t = Q_S\left(P_t, H_t, V_t, \gamma_{2,t,r}\right) - Q_D(P_t, H_t, V_t, \gamma_{1,t,r}) \tag{3}$$

Note that while we assume intra-annual adjustments of these storage levels, we expect no changes in storage levels across periods. Moreover, storage can be seen as part of the market characteristics and the presence of storage tends to buffer price shocks (Serra and Gil 2012).

We focus here on the impact of droughts on prices. Thus, using equation (3) we can obtain the inverse demand function, i.e. price function (sensu Alam and Gilbert 2017):

$$P_t = f(k_{t,r}, H_t, V_t, \bar{\gamma}_{1,t}, \bar{\gamma}_{2,t}, \delta_t) \tag{4}$$

where $\bar{\gamma}_{1,t} = \left[Z_{1t}, \epsilon_{1,t}\right]$ and $\bar{\gamma}_{2,t} = \left[Z_{2t}, \epsilon_{2,t}\right]$.

How prices in one region react to (drought) shocks, depend amongst others on costs for transport and transactions, as these costs affect market integration (Goodwin and Piggott 2001; Balcombe et al. 2007), thus, how production and price shocks in one region can be balanced by other regions. Costs for transport and transaction depend on distance between buyer and seller, Δs (for transaction costs because closer markets are usually better known), and are affected by droughts since droughts are systemic to a region. Additionally, transaction costs depend on the transparency of the market, ω.

---

[2] We selected this resolution, because on the one hand we are interested in distinguishing drought effects on a smaller, i.e. regional, and larger, i.e. national, scale and on the other we consider the tendency of intra-national trade vis-à-vis cross-border trade of feed (McCallum 1995, Ghazalian 2012).

Furthermore, prices might not respond immediately but temporal delayed to shocks. The response time of a market to a shock, l_t, is assumed to depend on ω as well as on change in storage, δ_t. Hence, we can express the price function as:

$$P_t = f\left(k_{t,r}(H_t, V_t), H_t\left(\Delta s, k_{t,r}\right), V_t\left(\Delta s, k_{t,r}, \omega\right), l_t(\omega_t, \delta_t), \bar{\gamma}_{1,t}, \bar{\gamma}_{2,t}, \delta_t\right) \tag{5}$$

3. Econometric framework

To analyse the effect of droughts on the feed prices we use a structural vector autoregressive model (SVAR; see e.g. Lütkepohl 2005). SVAR models can be used to model the effect of an exogenous drought shock on endogenous feed prices using time series data.[3] Using a SVAR model allows identifying immediate and lagged drought effects on feed prices, therefore, we allow that market participants can adjust their prices expectation based on expected yields, thus also expected drought induced yield losses.[4] The SVAR is defined as:

$$AX_t = A_1^* X_{t-1} + \cdots + A_d^* X_{t-d} + B\varepsilon_t \tag{6}$$

X_t is the vector of n variables in period t including a drought variable and feed prices, i.e. $X_t = \left[k_{t,r}, p_t^{wheat}, p_t^{barley}, p_t^{hay}\right]$, and d is the number of lags. A_j^* for $j = 1, \dots, d$ are the coefficient matrices $(n \times n)$. B is an identity matrix, I_n, and ε_t is the structural error, which is assumed to be white noise. Multiplying equation (6) by the inverse of A results:

$$X_t = A^{-1}A_1^* X_{t-1} + \cdots + A^{-1}A_d^* X_{t-d} + A^{-1}B\varepsilon_t \tag{7}$$

where $u_t = A^{-1}B\varepsilon_t$ is the vector of reduced form residuals and $\sum_u A^{-1}BB'A^{-1\prime}$ its variance-covariance matrix. We restrict the model by using the 'canonical form' (see Appendix 1 for details).

To identify the optimal length, d^*, we employ the Akaike information criterion (AIC). Furthermore, we used an Augmented Dickey–Fuller (ADF) unit root test with a constant to test for stationarity of the different price time series and without a constant to test for stationarity of the different drought time series (see e.g. Pfaff et al. 2016). Based on the estimated coefficients, we use impulse response functions to analyze the effect of drought shocks, i.e. 'drought effects', on prices. The impulse response functions show the effect over time of an exogenous impulse, here drought shock, on endogenous variables, here feed prices. They are useful as estimated SVAR coefficients alone are difficult to

---

[3] Previously, SVAR models were for example used to model effect of El Niño-Southern Oscillation or policy shocks (Alam and Gilbert 2017; Bastianin et al. 2018).

[4] Note that we assume that price expectations are connected to current prices, as they shift the demand curve to the right.

interpret. The shock to the impulse response function equals one standard deviation of the drought variable.[5] This empirical framework allows deducting the different responses proposed in the theoretical framework, i.e. with respect to magnitude and timing of the response. Furthermore, the theoretical framework provides reason why prices react differently to droughts. Our analysis is conducted in R (R Core Team 2018) using the R-packages ´vars´ and ´urca´ (Pfaff 2008, Pfaff et al. 2016).[6]

4. Data

4.1 Price data

The price data contains prices of hay, feed wheat and barley from August 2002 to April 2019 from the German states of Bavaria and Baden-Württemberg, together referred to as 'South Germany' and was provided by the Bavarian Association of Farmers. South Germany represents about 30% of Germany's hay production and 20% of its wheat and barley production[7] (Destatis 2019). Hay prices (Euro $100kg^{-1}$) were reported as a bi-weekly average wholesale price ex-farm including value added tax for high-pressure pressed hay.[8] Feed wheat and barley prices (Euro $100kg^{-1}$) were reported as weekly average wholesale purchasing prices from producers excluding value added tax. We converted prices into monthly natural long transformed real prices using the harmonized[9] index of consumer prices for Germany with base year 2015 (Eurostat 2019; Fig. 1, see Table A1 for summary statistics). These prices are henceforth indicated as hay, feed wheat and feed barley prices. The optimal lag length, d^*, of the price time series is 3 months based on the AIC and the ADF unit root test indicates that all price time series are stationary (Table A2).

4.2 Drought information

For identifying droughts, we used the Standardized Precipitation Evapotranspiration Index (SPEI) as a standardized drought index. The SPEI incorporates information about precipitation and potential evapotranspiration (Vicente-Serrano et al. 2010). Thus, the SPEI also accounts for the impact of high temperature on drought intensity as temperature strongly affects evapotranspiration (Vicente-Serrano et al. 2010; Beguería et al. 2014). We used different SPEI lengths that comprise information

---

[5] We can obtain the coefficients of the impulse response functions from the following matrices (Lütkepohl 2005): $\Theta_j = \phi_j A^{-1} B, j = 1, \ldots, d$

[6] We used for the SVAR estimation the BFGS algorithm.

[7] Including all wheat and barley.

[8] Note that in Germany it is common that intensive grasslands are harvested four to five times per year (Socher et al. 2013).

[9] 'Harmonized' indicates that the index of consumer prices follows an EU-wide methodology (see e.g. Eurostat 2019 for definitions).

about the last *X* months (SPEI-X). The drought variable were defined as drought, i.e. as $k_t = |\text{SPEI-X}|$, when the SPEI-X was below a specific threshold and otherwise as $k_t = 0$.

We focus on drought occurrence during the entire main vegetation period[10] (April – October). In the robustness checks, we also separately considered droughts in spring (April-May) and summer (June – August).[11]

We used monthly potential evapotranspiration and precipitation data from January 1991 to April 2019 provided by German Meteorological Office as 1km x 1km gridded data (DWD 2019). The SPEI-X[12] was calculated for every 1km x 1km grid of the agricultural area in i) South Germany and ii) whole Germany. For identifying the agricultural area[13] we used the 2012 'CORINE Land Cover 10 ha' data (BKG 2019). For both regions, South Germany and whole Germany, we calculated then the monthly average SPEI-X over all grid cells and the drought variable. The spatial aggregation of droughts are in line with its systemic nature, i.e. droughts usually affect larger areas (Miranda and Glauber 1997), and that market prices are an expression of the aggregated market supply and demand. All drought time series are stationary (Table A2).

The drought specification mainly used here reflects a 'severe drought', i.e. threshold = -1.5 (Yu et al. 2014), based on the SPEI-3. Fig. 2 shows severe droughts for South Germany and whole Germany for the different drought periods using SPEI-3. For this specification, the correlation between South Germany and whole Germany of the SPEI and severe droughts were 0.90 and 0.84, respectively (see Fig. A1 for more details). See Table 1 for additional specifications.

Table 1: Variation in drought specification.

Region	Drought period	SPEI length	Threshold
South Germany	Main vegetation period (MVP)	3 months (SPEI-3)	-1.5 (Severe drought)
Whole Germany	*Spring*	*2 months (SPEI-2)*	*-1.0 (Moderate drought)*
	Summer	*4 months (SPEI-4)*	

In italic are the variation used only for the robustness checks.

---

[10] In fact, while wheat and barley are usually winter crops, i.e. are planted in autumn, rainfall levels in autumn and winter are not limiting factors for yields (see e.g. Dalhaus et al. 2018).

[11] Droughts can cause at different times of the vegetation period losses for grain and hay yields (see e.g. Daryanto et al. 2017; Wilcox et al. 2017). The robustness checks also account for grains being more valuable to droughts in spring and grasslands in summer (see e.g. Denton et al. 2017; Dalhaus et al. 2018).

[12] For calculating the SPEI we used the R-packages ´SPEI´ (Beguería and Vicente-Serrano 2017).

[13] The agricultural area considered includes the categories 'non-irrigated arable land', 'pasture, meadows and other permanent grasslands under agricultural use', 'complex cultivation patterns', 'land principally occupied by agriculture, with significant areas of natural vegetation' and 'natural grassland'. Note that we consider natural grasslands as they can be extensively grazed (Kosztra et al. 2019).

Figure 1: Prices of hay, feed wheat and feed barley.

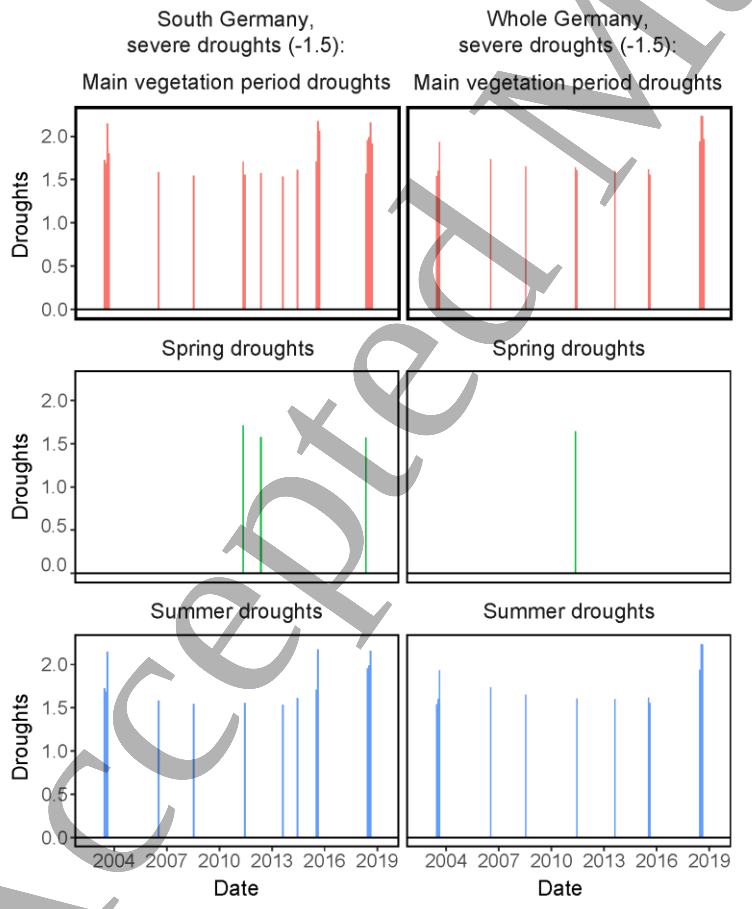
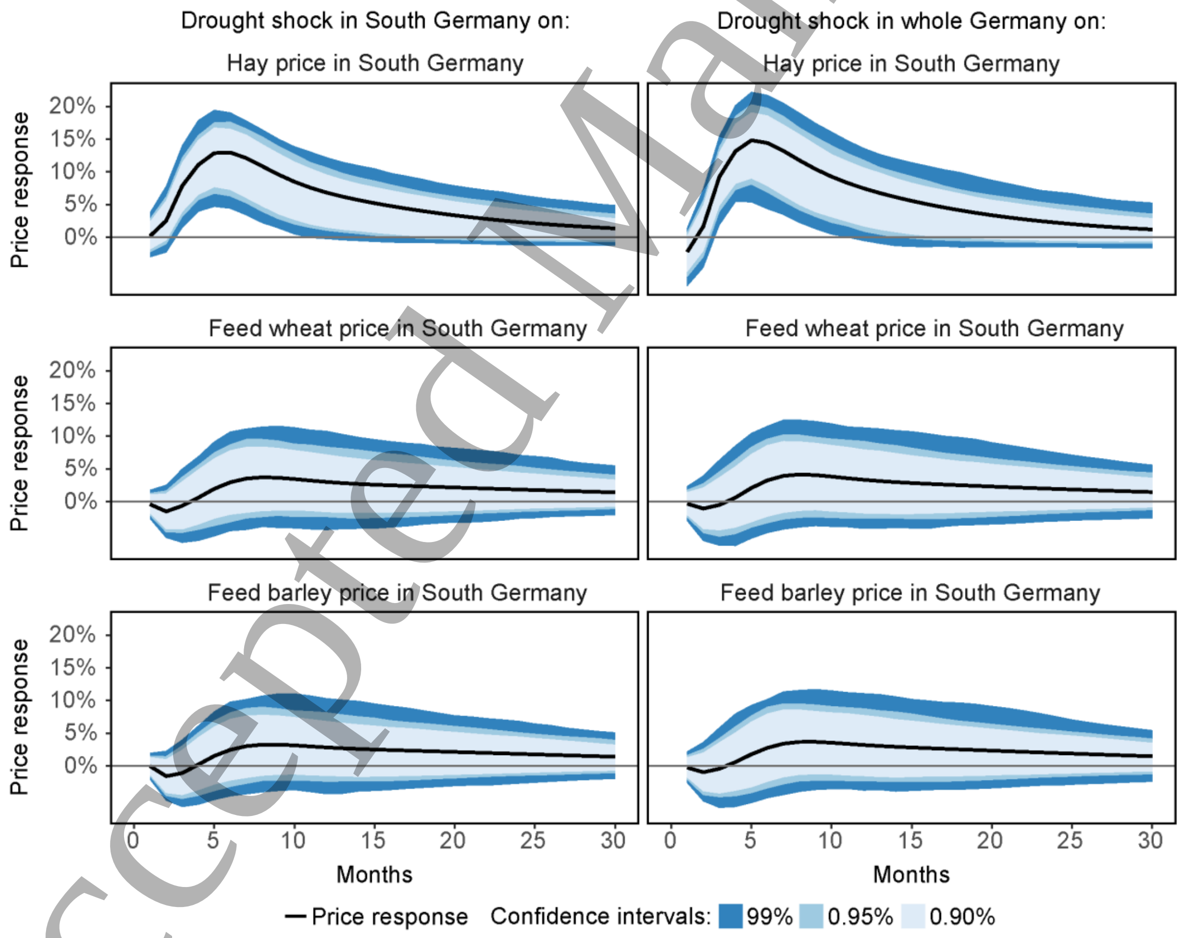


Figure 2: Severe droughts (threshold = -1.5) in South Germany and whole Germany for SPEI-3 and different drought periods. The bold frame indicates the baseline drought specification. See Fig. A2 to A7 for other drought specifications.

5. Results

5.1 Main results

We found that a drought shock, i.e. 'drought effects', in South Germany led to a substantial increase in hay prices, up to +13% in month five after the shock (Fig. 3 and Table 2).[14] The hay price increase lasted from month 3 to 16 after the drought shock (see Figure 3 and Table 2, A4 and A5 for details on other than the 5% significance level). Germany-wide drought shocks resulted in similar effects on hay prices, which peaked +15% and lasted from month 3 to 14 after the drought shock Differently to this, we found no significant drought effects on feed grain prices, independent if droughts occurred in South Germany or whole Germany.



---

[14] Coefficients estimates are available upon request.

Figure 3: Impulse response functions of the hay, feed wheat and feed barley price in percent to a drought shock (baseline scenario) for South Germany and whole Germany.

5.2 Robustness checks

In our robustness checks we varied the drought specification with respect to timing of drought, SPEI length and drought threshold (Table 2). Considering only droughts in spring or summer, we found that summer droughts (at regional and national level) caused increases in hay prices. In contrast, we found no effects of spring droughts on hay prices. Drought effects on feed grain prices remained absent in South Germany for spring or summer droughts in almost all cases. On the national level, we also found no generally spring or summer drought effect on feed grain prices (Table 2). When altering SPEI length from SPEI-3 to SPEI-2 or SPEI-4, drought effects on hay prices remained similar. For feed grain prices, we discovered in some cases drought effects when drought specification was based on SPEI-2, whereas for the other SPEI lengths no drought effects were present (Table 2). Decreasing the threshold for drought severity from -1.5 (severe drought) to -1.0 (moderate drought) decreased the magnitude and duration of the drought effects on hay prices. The threshold choice did not impact the drought effects on feed grain prices.[15]

---

[15] Note that results were also similar when droughts are computed for all area of South Germany and Germany and not only for the agricultural area.

Table 2: Drought effects (peak and duration) for different drought specification. *Remark:* Drought effects in South Germany and in whole Germany derived from the impulse response function (Figure 3). %-Numbers indicate the peak effects and numbers in parentheses the start and end month of the effects. We only report values when effects were significant at 5% level (for other significance levels see Table A4 and A5). Grey shaded cells indicate the baseline drought specification and NAs specification without drought observation. We note that results were similar when droughts are computed for all area of South Germany and Germany and not only for the agricultural area.

			SPEI-3		SPEI-2		SPEI-4	
			-1	-1.5	-1	-1.5	-1	-1.5
Droughts in South Germany	Hay price	Main vegetation period	11% (4-14)	13%% (3-16)	8% (3-12)	13% (3-14)	12% (4-11)	16% (3-14)
		Spring	-	-	-	-	-	-
		Summer	10% (4-12)	14% (3-14)	10% (3-12)	12% (3-13)	9% (4-8)‡	15% (4-14)
	Feed wheat price	Main vegetation period	-	-	-	-	-	-
		Spring	-	-	8% (1-6)	-	-	-
		Summer	-	-	-	-	-	-
	Feed barley price	Main vegetation period	-	-	-	-	-	-
		Spring	-	-	4% (1-2)	2% (1-1)	-	-
		Summer	-	-	-	-	-	-
Droughts in whole Germany	Hay price	Main vegetation period	12% (3-13)	15% (3-14)	8% (4-13)	12% (3-12)	12% (3-12)	17% (3-13)
		Spring	-	-	-	-	-	NA
		Summer	10% (4-11)	15% (3-14)	10% (3-13)	12% (3-12)	10% (4-10)	16% (3-13)
	Feed wheat price	Main vegetation period	-	-	-	6% (9-9)	-	-
		Spring	-	-	-	-	-	NA
		Summer	-	-	-	-	-	-
	Feed barley price	Main vegetation period	-	-	-	6% (8-10)	-	-

Spring	-	-	2% (1-1)	-	-	NA
Summer	-	-	-	-	-	-

6. Discussion and conclusion

We showed that droughts at the regional and national level caused substantial increases in hay prices (up to +15%), while feed grain prices were, in our case study, not affected by droughts. This indicates that feed grain markets are – in contrast to hay markets – organized at higher than regional or national levels and thus react less to regional or national drought shocks. These responses confirm with our theoretical and market assumptions, i.e. that prices of markets with relatively low market integration due to high transport and transaction costs respond stronger to drought shocks. Furthermore, hay prices did not react immediately to droughts, but drought responses occurred with a delay (about three months), and drought-induced price shocks were long lasting (usually for over a year). These observations are in line with our theoretical model and the assumption of relatively low transparency of the hay market. Therefore, our analysis highlights the importance of considering transport and transaction costs with respect to their value to understand the price sensitivity to regional shocks, such as droughts. In general regional and national droughts were highly correlated, which is in line with the systemic nature of droughts and explains similar reaction to regional and national droughts. Climate change will increase to occurrence probability and magnitude of droughts. The here identified price sensitivity of the hay market represents an additional severe risk to the agricultural and livestock sector, next to the risk of yield loss. Farmers may suffer from low feed production and exceptionally high prices for the additional feed bought. Similar argumentation about responses to droughts can also hold true for other markets with low-value-to-weight products, low market transparency, low trade quantities and/or with a lack of formal market exchanges, and particularly for agricultural markets in developing countries that often exhibit high national and international trade costs, i.e. transport and transaction costs, thus, low market integration (Porteous 2019). The knowledge about feed price responses to droughts is important to include into farm management and policy actions, especially under future climatic scenarios. Here, for example, online feed price exchanges might contribute to reduce price shocks as they increase market transparency.

Droughts based on SPEI cover important events of low precipitation and high temperature, which together increase intensity of droughts and often occur together (Trenberth and Shea 2005; Estrella and Menzel 2013). Next to these events also other extreme weather events, as solely extreme high/low temperature and precipitation as well as other interactions than high temperature and low precipitation might be important (e.g. Rosenzweig et al. 2002; Schlenker and Roberts 2009; Barlow et al. 2015; Tack et al. 2017) for feed and other agricultural prices and remain an important area for future research.

Data availability

The data that support the findings of this study are openly available at Schaub and Finger (2019; https://doi.org/10.3929/ethz-b-000385361).

Code availability

The R-code for replication of this study is available in the supplementary information.

References

Alam MR, Gilbert S (2017) Monetary policy shocks and the dynamics of agricultural commodity prices: evidence from structural and factor-augmented VAR analyses. Agric Econ 48:15-27. https://doi.org/10.1111/agec.12291

Algieri B (2014) A roller coaster ride: an empirical investigation of the main drivers of the international wheat price. Agric Econ 45:459-475. https://doi.org/10.1111/agec.12099

Balcombe K., Bailey A, Brooks, J (2007) Threshold effects in price transmission: the case of Brazilian wheat, maize, and soya prices. Am J Agric Econ 89:308-323. https://doi.org/10.1111/j.1467-8276.2007.01013.x

Barlow KM, Christy BP, O'leary GJ, Riffkin PA, Nuttall JG (2015) Simulating the impact of extreme heat and frost events on wheat crop production: A review. Field Crops Res 171:109-119. https://doi.org/10.1016/j.fcr.2014.11.010

Bastianin A, Lanza A, Manera M (2018) Economic impacts of El Niño southern oscillation: evidence from the Colombian coffee market. Agric Econ 49:623-633. https://doi.org/10.1111/agec.12447

Bazen EF, Roberts RK, Travis J, Larson JA (2008) Factors Affecting Hay Supply and Demand in Tennessee. Annual Meeting Southern Agricultural Economics Association, Dallas, February 2–6, 2008.

Beguería S, Vicente-Serrano SM (2017) Package ´SPEI´ Calculation of the Standardised Precipitation-Evapotranspiration Index. R package version, Version 1.7.

Beguería S, Vicente-Serrano SM, Reig F, Latorre B (2014) Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. Int J Climatol 34:3001-3023. https://doi.org/10.1002/joc.3887

BKG (Federal Agency for Cartography and Geodesy) (2019) CORINE Land Cover 10 ha (CLC10) https://gdz.bkg.bund.de/index.php/default/open-data/corine-land-cover-10-ha-clc10.html. Accessed 3 December 2019

BLE (Federal Office for Agriculture and Food) (2019) Futteraufkommen im WJ 2017/18 (vorläufige Zahlen). https://www.bmel-statistik.de/fileadmin/user_upload/monatsberichte/DFT-0601010-2018.xlsx. Accessed 14 October 2019

Chung U, Gbegbelegbe S, Shiferaw B, Robertson R, Yun JI, Tesfaye K, Hoogenboom G, Sonder K. (2014) Modeling the effect of a heat wave on maize production in the USA and its implications on food security in the developing world. Weather and Climate Extremes 5-6:67-77. https://doi.org/10.1016/j.wace.2014.07.002

Ciais P et al (2005) Europe-wide reduction in primary productivity caused by the heat and drought in 2003. Nature 437:529-533. https://doi.org/10.1038/nature03972

Dai A. (2013) Increasing drought under global warming in observations and models. Nat Clim Chang 3:52-58. https://doi.org/10.1038/nclimate1633

Dalhaus T, Musshoff O, Finger R, (2018) Phenology information contributes to reduce temporal basis risk in agricultural weather index insurance. Sci Rep 8:46. https://doi.org/10.1038/s41598-017-18656-5

Daryanto S, Wang L, Jacinthe PA (2017) Global synthesis of drought effects on cereal, legume, tuber and root crops production: A review. Agric Water Manage 179:18-33. https://doi.org/10.1016/j.agwat.2016.04.022

Denton EM, Dietrich JD, Smith MD, Knapp AK (2017) Drought timing differentially affects above-and belowground productivity in a mesic grassland. Plant Ecol 218:317-328. https://doi.org/10.1007/s11258-016-0690-x

Destatis (German Federal Statistical Office) (2019) Land- und Forstwirtschaft, Fischerei - Fachserie 3, R 3.2.1, Feldfrüchte 2018. Destatis, Wiesbaden

DWD (German Meteorological Office) (2019) DWD Climate Data Center ftp://ftp-cdc.dwd.de/. Accessed 12 December 2019

Estrella N, Menzel A (2013) Recent and future climate extremes arising from changes to the bivariate distribution of temperature and precipitation in Bavaria, Germany. Int J Climatol 33:1687-1695. https://doi.org/10.1002/joc.3542

Eurostat 'Eurostat data' (2019). https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=prc_hicp_midx&lang=en. Accessed 14 October 2019

Flanders F, Gillespie JR (2015) Modern livestock & poultry production, 9th edn. Cengage Learning, Clifton Park

Ghazalian PL (2012) Home bias in primary agricultural and processed food trade: Assessing the effects of national degree of uncertainty aversion. J Agric Econ 63:265-290. https://doi.org/10.1111/j.1477-9552.2011.00329.x

Graubner M, Balmann A, Sexton RJ (2011) Spatial price discrimination in agricultural product procurement markets: a computational economics approach. Am J Agric Econ 93:949-967. https://doi.org/10.1093/ajae/aar035

Goodwin BK, Piggott NE (2001) Spatial market integration in the presence of threshold effects. Am J Agric Econ 83:302-317. https://doi.org/10.1111/0002-9092.00157

IPCC (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker TF, Qin D, Plattner GK, Tignor M., Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM edn. Cambridge University Press, Cambridge and New York City

Kosztra B, Büttner G, Hazeu G, Arnold S (2019) Updated CLC Illustrated Nomenclature Guidelines. Environment Agency Austria, Vienna

Liefert WM, Serova E, Liefert O (2010) The growing importance of the former USSR countries in world agricultural markets. Agric Econ 41:65-71. https://doi.org/10.1111/j.1574-0862.2010.00489.x

Lütkepohl H (2005) New Introduction to Multiple Time Series Analysis. Springer, Berlin

LfL (Bavarian State Research Center for Agriculture) (2018) Gruber Tabelle zur Fütterung der Milchkühe, Zuchtrinder, Schafe, Ziegen, 43th edn. LfL, Freising-Weihenstephan

McCallum J (1995) National borders matter: Canada-US regional trade patterns. AER 85:615-623.

McCullock K, Davidson C, Robb J (2014) Price Characteristics at a Hay Auction. Agron J 106:605-611. https://doi.org/10.2134/agronj2013.0369

Miranda MJ, Glauber JW (1997) Systemic risk, reinsurance, and the failure of crop insurance markets. Am J Agric Econ 79:206-215. https://doi.org/10.2307/1243954

Peake MD, Burdine KH, Mark TB, Goff BM (2019) Factors Affecting Hay Prices at Auction: A Hedonic Analysis', Agron. J. 111:736-740. https://doi.org/10.2134/agronj2018.08.0524

Pfaff B (2008) VAR, SVAR and SVEC models: Implementation within R package vars. J Stat Softw 27:1-32. https://doi.org/10.18637/jss.v027.i04

Pfaff B, Zivot E, Stigler M (2016) Package 'urca'. Unit root and cointegration tests for time series data. R package version, Version 1.3.

Porteous O (2019) High trade costs and their consequences: An estimated dynamic model of African agricultural storage and trade. Am Econ J: Appl Econ 11:327-66. https://doi.org/10.1257/app.20170442

Rosenzweig C, Tubiello FN, Goldberg R, Mills E, Bloomfield J (2002) Increased crop damage in the US from excess precipitation under climate change. Glob Environ Chang 12:197-202. https://doi.org/10.1016/S0959-3780(02)00008-0

Rudstrom M (2004) Determining implicit prices for hay quality and bale characteristics. Agric Econ Res Rev 26:552-562. https://doi.org/10.1111/j.1467-9353.2004.00199.x

R Core Team (2018) R: a language and environment for statistical computing. Version 3.5.0.

Schaub S. Finger R (2019) Dataset: Feed price and SPEI data of South Germany and whole Germany. ETH Zurich Research Collection. https://doi.org/10.3929/ethz-b-000385361

Schlenker W, Roberts MJ (2009) Nonlinear temperature effects indicate severe damages to US crop yields under climate change. Proc Natl Acad Sci 106:15594-15598. https://doi.org/10.1073/pnas.0906865106

Serra T, Gil JM (2012) Price volatility in food markets: can stock building mitigate price fluctuations?. Eur Rev Agric Econ 40:507-528. https://doi.org/10.1093/erae/jbs041

Smit HJ, Metzger MJ, Ewert F (2008) Spatial distribution of grassland productivity and land use in Europe. Agric Syst 98:208-219. https://doi.org/10.1016/j.agsy.2008.07.004

Socher SA et al (2013) Interacting effects of fertilization, mowing and grazing on plant species diversity of 1500 grasslands in Germany differ between regions. Basic Appl Ecol 14:126-136. https://doi.org/10.1016/j.baae.2012.12.003

Spinoni J, Vogt JV, Naumann G, Barbosa P, Dosio A (2018) Will drought events become more frequent and severe in Europe?. Int J Climatol 38:1718-1736. https://doi.org/10.1002/joc.5291

Sternberg T (2012) Chinese drought, bread and the Arab Spring. Appl Geogr 34:519-524. https://doi.org/10.1016/j.apgeog.2012.02.004

Taheripour F, Hertel TW, Tyner WE (2011) Implications of biofuels mandates for the global livestock industry: a computable general equilibrium analysis. Agric Econ 42:325-342. https://doi.org/10.1111/j.1574-0862.2010.00517.x

Tack J. Barkley A, Hendricks N (2017) Irrigation offsets wheat yield reductions from warming temperatures. Environ Res Lett 12:114027. https://doi.org/10.1088/1748-9326/aa8d27

Trenberth KE, Shea DJ (2005) Relationships between precipitation and surface temperature. Geophys Res Lett 32. https://doi.org/10.1029/2005GL022760

Ubilava D (2017) The ENSO effect and asymmetries in wheat price dynamics. World Development 96:490-502. https://doi.org/10.1016/j.worlddev.2017.03.031

Vanselow R, Wahrenburg W, Teichner T, Behrens C, Gutsmiedl I (2012) Pferd und Heu: ein Handbuch für Pferdehalter und Heuproduzenten über die wichtigste Nahrungsquelle der Pferde. VFD, Twistringen

Vicente-Serrano SM, Beguería S, López-Moreno JI (2010) A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. J Clim 23:1696-1718. https://doi.org/10.1175/2009JCLI2909.1

Webber H et al. (2018) Diverging importance of drought stress for maize and winter wheat in Europe. Nat Commun 9:4249. https://doi.org/10.1038/s41467-018-06525-2

Wilcox KR et al. (2017) Asymmetric responses of primary productivity to precipitation extremes: a synthesis of grassland precipitation manipulation experiments. Glob Chang Biol 23:4376-4385. https://doi.org/10.1111/gcb.13706

Yu M, Li Q, Hayes MJ, Svoboda MD, Heim RR (2014) Are droughts becoming more frequent or severe in China based on the standardized precipitation evapotranspiration index: 1951–2010?. Int J Climatol 34:545-558. https://doi.org/10.1002/joc.3701