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Effects of drought on hay and feed grain prices

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Abstract

Droughts represent a severe and increasing risk for the livestock sector as they can reduce yields of hay and feed grain. Droughts are predicted to increase in frequency and magnitude under climate change. Here we 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 by up to 15%, starting with a delay of about 3 months and lasting 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 is usually regionally organized while feed grains are traded transnationally. It is important to include this knowledge into farm management and policy actions, especially considering climate change.

1. Introduction

Agriculture is highly vulnerable to drought. 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 feed markets are not well studied, even though, under climate change, droughts are predicted to increase in frequency and magnitude (Dai 2013, IPCC 2013, Spinoni *et al* 2018).

We estimate the effects on feed prices of droughts occurring on regional and national levels 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, and thus potential market integration. Transport costs are here defined as costs occurring due to transport, for example for fuel and loading. Transaction costs include other costs that occur due to the exchange of goods, for example finding sellers or buyers and quality verification. Hay, an important feed source for the dairy and beef sector as well as for horses (Vanselow *et al* 2012, LfL 2018), is a bulky commodity of varying

quality; it 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.[4] In contrast, feed wheat and barley, which are the two most important feed grains in Germany (BLE 2019), typically have a higher per ton protein unit 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 super-regionally organized and is assumed to be more transparent than the hay market. Depending on the animal, wheat and barley can be good substitutes for each other whereas hay is only a limited substitute for them given animals' feed roughage and grain/concentrate ration requirements (Flanders and Gillespie 2015).

While previous studies looked at general hay price dynamics (e.g. Bazen *et al* 2008, McCullock *et al* 2014,

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

Peake *et al* 2019), no studies have investigated the effects of drought on hay prices. Some studies have explored the reaction to drought of major grain prices (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 try to fill some of the 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 insurance businesses, as well as for public entities to improve management of the adverse effects of drought. 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 in section 2, followed by the description of the econometric framework in section 3 and the data in section 4. We then present our results for the baseline drought specification as well as robustness checks in section 5. Finally, we discuss our results and conclude in section 6.

2. Theoretical framework

The demand and supply functions for feed crops $Q_{D,t}$ and $Q_{S,t}$, are summarized as follows (see, e.g., Alam and Gilbert 2017):

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

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

P_t represents prices, for example wholesale prices, of the agricultural product, i.e. $P_t = [p_t^{wheat}, p_t^{barley}, p_t^{hay}]$, H_t is the transport costs and V_t the 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 state them explicitly in equations (1) and (2). $\gamma_{1,t,r}$ and $\gamma_{2,t,r}$ are vectors of variables: $\gamma_{1,t,r} = [Z_{1t}, k_{t,r}, \epsilon_{1,t}]$ and $\gamma_{2,t,r} = [Z_{2t}, k_{t,r}, \epsilon_{2,t}]$, where $Z_{1,t}$ and $Z_{2,t}$ are the respective demand and supply shifting variables. Note that we denote droughts separately from the other demand and supply shifting variables as $k_{t,r}$. We consider droughts at the regional level (i.e. in South Germany) or at the national level (i.e. in the whole of Germany)[5], i.e. $r = 1$ and $r = 2$, respectively. $\epsilon_{1,t}$ and $\epsilon_{2,t}$ are random shock variables.

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

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

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 drought on prices. Thus, using equation (3) we can obtain the inverse demand function, i.e. the price function (*sensu* Alam and Gilbert 2017),

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

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

How prices in one region react to (drought) shocks, depends amongst other things on costs for transport and transactions, as these costs affect market integration (Goodwin and Piggott 2001, Balcombe *et al* 2007), and thus how production and price shocks in one region can be balanced by other regions. Costs for transport and transaction depend on the distance between buyer and seller, Δs (for transaction costs, because closer markets are usually better known), and are affected by drought since droughts are systemic to a region. Additionally, transaction costs depend on the transparency of the market, ω. Furthermore, prices might not respond immediately but temporally 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

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

3. Econometric framework

To analyze the effect of drought on 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.[6] Using a SVAR model allows us to identify immediate and lagged effects of drought on feed prices; therefore, we allow that market participants can adjust their price expectations based on expected yields, and thus also expected drought-induced yield losses.[7] The SVAR is defined as

$$AX_t = A_1^* X_{t-1} + \dots + A_d^* X_{t-d} + B\varepsilon_t. \qquad (6)$$

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[5] We selected this resolution, because on the one hand we are interested in distinguishing the effects of drought 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).

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

[7] Note that we assume that price expectations are connected to current prices as they shift the demand curve to the right.
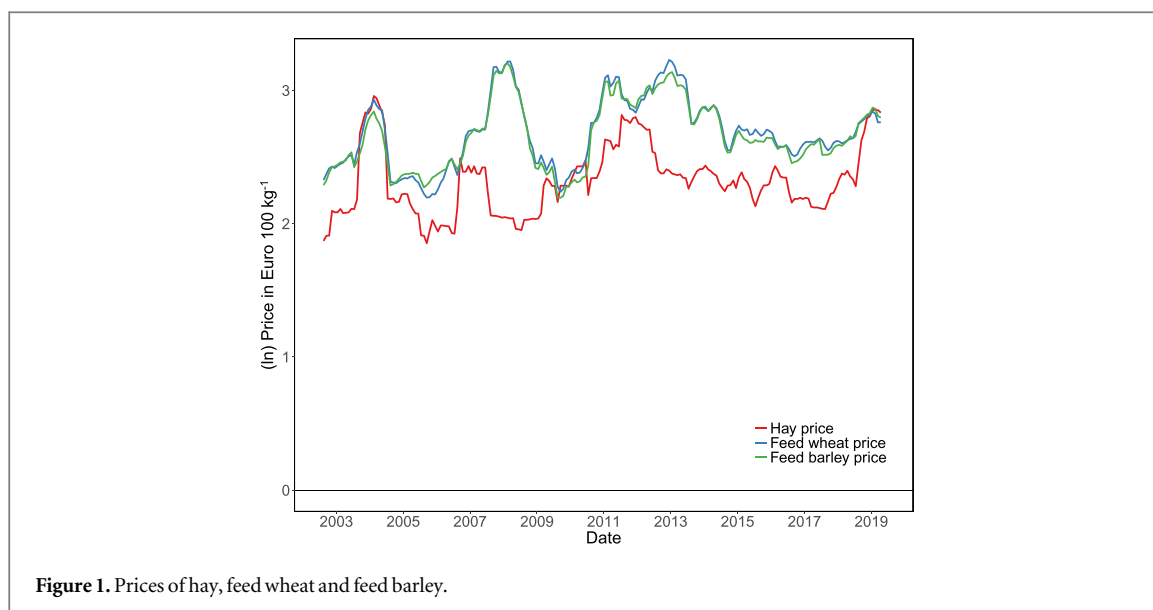
Figure 1. Prices of hay, feed wheat and feed barley.

Here X_t is the vector of n variables in period t including a drought variable and feed prices, i.e. $X_t = [k_{t,r}, p_t^{wheat}, p_t^{barley}, p_t^{hay}]$, and d is the number of lags. A_j^* for $j = 1, \ldots, d$ 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 in

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

(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 is available online at stacks. iop.org/ERL/15/034014/mmedia 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 because estimated SVAR coefficients alone are difficult to interpret. The shock to the impulse response function equals one standard deviation of the drought variable.[8] This empirical framework allows us to identify the different responses proposed in the theoretical framework, i.e. with respect to magnitude and timing of the response. Furthermore, the theoretical framework provides reasons why prices react differently to drought. Our analysis is conducted in R (R Core

Team 2018) using the R-packages 'vars' and 'urca' (Pfaff 2008, Pfaff *et al* 2016).[9]

4. Data

4.1. Price data

The price data include 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 were 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[10] (Destatis 2019). Hay prices (Euro $100 \, \text{kg}^{-1}$) were reported as a bi-weekly average wholesale price ex-farm including value added tax for high-pressure pressed hay.[11] Feed wheat and barley prices (Euro $100 \, \text{kg}^{-1}$) were reported as weekly average wholesale purchase prices from producers excluding value added tax. We converted prices into monthly natural long transformed real prices using the harmonized[12] index of consumer prices for Germany with the base year 2015 (Eurostat 2019; figure 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).

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

[9] We used the Broyden–Fletcher–Goldfarb–Shanno (BFGS) algorithm for the SVAR estimation.

[10] Including all wheat and barley.

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

[12] 'Harmonized' indicates that the index of consumer prices follows an European Union-wide methodology (see, e.g., Eurostat 2019 for definitions).
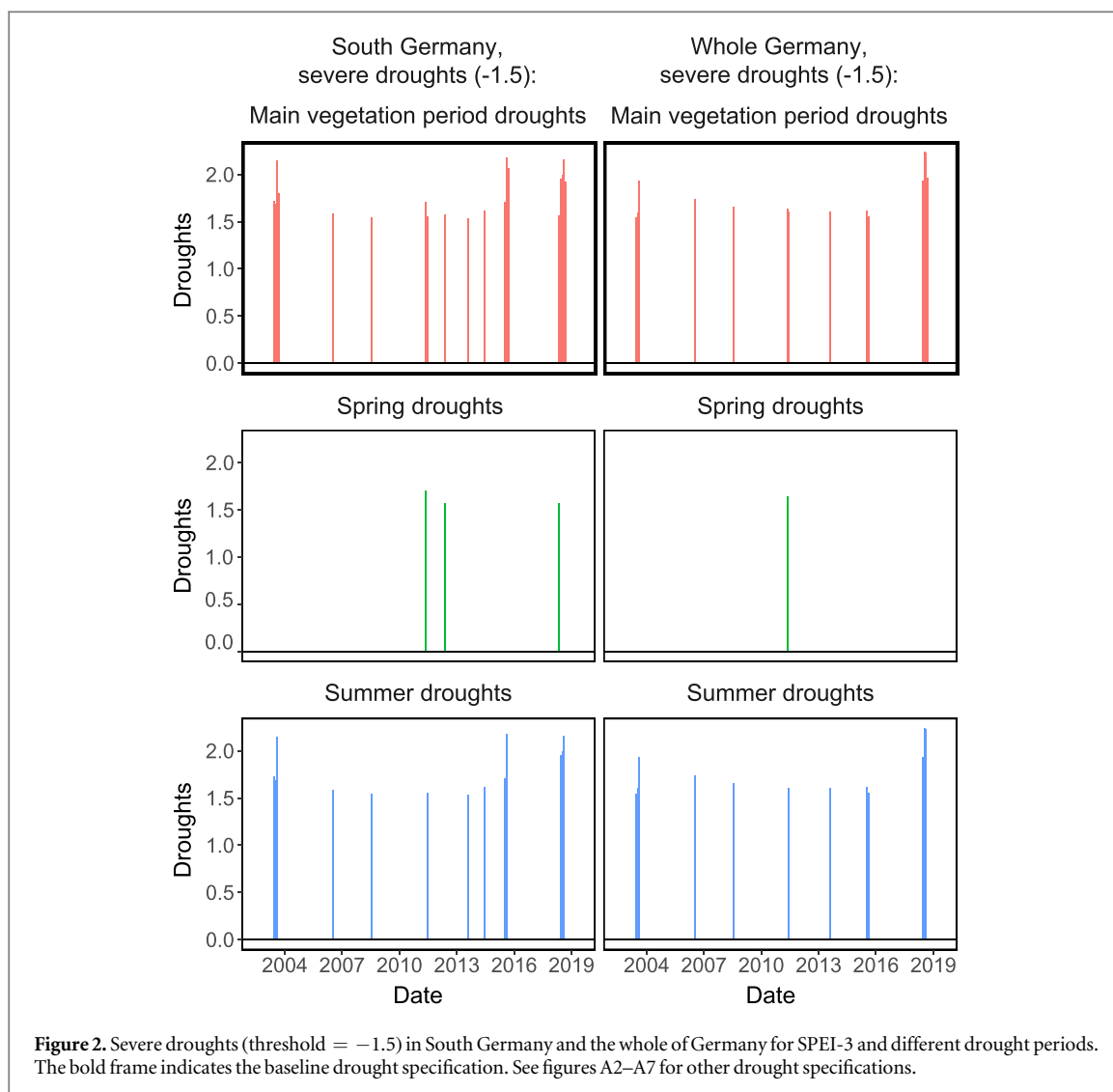
Figure 2. Severe droughts (threshold = −1.5) in South Germany and the whole of Germany for SPEI-3 and different drought periods. The bold frame indicates the baseline drought specification. See figures A2–A7 for other drought specifications.

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 of Germany	*Spring*	*2 months (SPEI-2)*	*−1.0 (moderate drought)*
	Summer	*4 months (SPEI-4)*	

Italics indicate the variation used only for robustness checks.
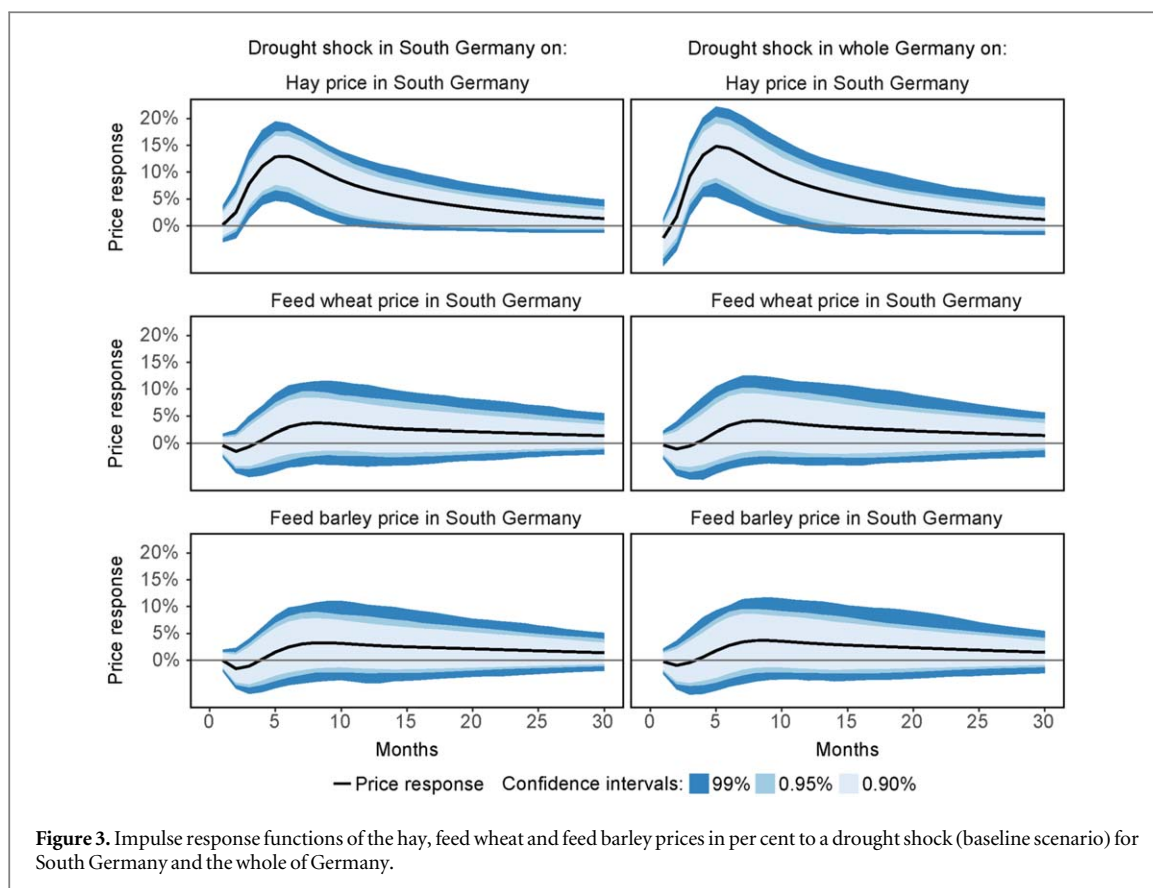
4.2. Drought information

To identify droughts we used the Standardized Precipitation Evapotranspiration Index (SPEI). 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 about the last X months (SPEI-X). The drought variables were defined as drought, i.e. as $k_t = |$SPEI-$X|$, when SPEI-X was below a specific threshold and otherwise as $k_t = 0$.

We focus on the occurrence of drought during the entire main vegetation period[13] (April—October). In the robustness checks, we also separately considered droughts in spring (April–May) and summer (June—August).[14]

We used monthly potential evapotranspiration and precipitation data from January 1991 to April

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

[14] Droughts at different times of the vegetation period can cause 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 vulnerable to droughts in spring and grasslands in summer (see, e.g., Denton *et al* 2017, Dalhaus *et al* 2018).

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

2019 provided by the German Meteorological Office as 1 km × 1 km gridded data (DWD 2019). SPEI-X[15] was calculated for every 1 km × 1 km grid of the agricultural area in (i) South Germany and (ii) the whole of Germany. To identify the agricultural area[16] we used the 2012 'CORINE Land Cover 10 ha' data (BKG 2019). For both regions, South Germany and the whole of Germany, we then calculated the monthly average SPEI-X over all grid cells and the drought variable. The spatial aggregation of droughts is in line with their systemic nature, i.e. droughts usually affect larger areas (Miranda and Glauber 1997), and market prices are an expression of the aggregated market supply and demand. All drought time series are stationary (table A2).

The main drought specification used here reflects a 'severe drought', i.e. threshold $= -1.5$ (Yu *et al* 2014), based on SPEI-3. Figure 2 shows severe droughts for South Germany and the whole of Germany for the different drought periods using SPEI-3. For this specification, the correlation between South Germany and the whole of Germany of the SPEI and severe droughts

were 0.90 and 0.84, respectively (see figure A1 available online at stacks.iop.org/ERL/15/034014/mmedia for more details). Additional specifications are given in table 1.

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 (figure 3 and table 2).[17] The hay price increase lasted from month 3 to month 16 after the drought shock (see figure 3 and tables 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 at +15% and lasted from month 3 to month 14 after the drought shock However, we found no significant effects of drought on feed grain prices, independent of whether the drought occurred in South Germany or the whole of Germany.

5.2. Robustness checks
In our robustness checks we varied the drought specification with respect to the 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)

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[15] To calculate the SPEI we used the R-package 'SPEI' (Beguería and Vicente-Serrano 2017).

[16] 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).

[17] Coefficients estimates are available upon request.

Table 2. Drought effects (peak and duration) for different drought specifications.

			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 of 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	—	—	—	—	—	—

Remark: The effects of drought in South Germany and the whole of Germany are derived from the impulse response function (figure 3). Percentages 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 the 5% level (for other significance levels see tables A4 and A5). Gray shaded cells indicate the baseline drought specification and NA the specification without drought observation. We note that results are similar when droughts are computed for all areas of South Germany and Germany and not only for the agricultural areas.

caused increases in hay prices. In contrast, we found no effects of spring droughts on hay prices. The effects of drought 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 generally no effect of spring or summer droughts on feed grain prices (table 2). When altering SPEI length from SPEI-3 to SPEI-2 or SPEI-4, the effects of drought on hay prices remained similar. For feed grain prices, we discovered drought effects in some cases when drought specification was based on SPEI-2, whereas for the other SPEI lengths no effects of drought 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 effects of drought on hay prices. The choice of threshold did not influence the effects of drought on feed grain prices.[18]

6. Discussion and conclusion

We have shown that droughts at regional and national levels 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 our theoretical and market assumptions, i.e. that prices of markets with relatively low market integration due to high transport and transaction costs respond more strongly to drought shocks. Furthermore, hay prices did not react immediately to droughts, but drought responses occurred with a delay (about 3 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 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 the similar reaction to regional and national droughts. Climate change will increase the probability of occurrence and the magnitude of droughts. The price sensitivity of the hay market identified here 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 arguments about responses to drought 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, and thus low market integration (Porteous 2019). Knowledge about the responses of feed price to drought is important to include in 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 the SPEI cover important events of low precipitation and high temperature, which together increase the intensity of droughts and often occur together (Trenberth and Shea 2005, Estrella and Menzel 2013). Next to these events other extreme weather events, for example extreme high/low temperature and precipitation on their own as well as interactions other than high temperature and low precipitation, might also 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; this remains an important area for future research.

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

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