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# Water Constraints to Agricultural Productivity in Bhutan

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## Abstract

This paper uses two years of agriculture census data to build a panel dataset that consists of all the small towns in Bhutan. This dataset is used to estimate the impact of irrigation gaps and drought on the yields of paddy, maize, and other crops. The paper compares the estimated impacts from a panel fixed effects model and a spatial first differences model. The findings show that irrigation gaps reduce paddy yields and droughts reduce maize yields. Estimates from the spatial first differences model are found to be consistent relative to those from the panel fixed effects model. The paper further finds that water constraints reduce yields of vegetable crops, and other constraints, such as labor shortages, wild animals, insects, and diseases, also reduce the yields of cereal crops.


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*Background paper for the Bhutan Country Economic Memorandum*

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## 1. Introduction

Water is an essential input to agricultural production, and access to irrigation can have important impacts on agricultural productivity. Theoretically, irrigation can lead to improvements in productivity of cropping systems under rainfed conditions for which the amount of precipitation or the intra-seasonal variation constrains productivity, and it can also lead to cultivation where or when otherwise not possible, for example for more water-intensive crops or through an addition of another cropping season. The agronomic versus real-world improvements in productivity gains from irrigation are further determined by quality of access to irrigation, constraints to other complementary inputs, and differences between the socially and individually optimal use of water driven by whether or not farmers bear the true cost of water use (Dillon and Fishman, 2019). Gains in productivity lead to more food and higher incomes for farm households, lower prices for food products for net buyers, and multiplier effects on the non-farm rural economy (IFPRI, 2010). In this paper, we study the short to medium run impacts of irrigation and drought problems in Bhutan on the yields of cereals and other crops, using a novel panel of agricultural census data. The novelty of the structure of the data allows us to use rigorous estimation techniques to assess the impacts of irrigation in Bhutan.

The impacts of irrigation have been studied extensively in several contexts. In Rwanda, using plot-level spatial regression discontinuity design (RDD) on a sample of 969 cultivators over a four-year period, Jones et al. (2021) find that access to a hillside irrigation scheme enables dry season horticultural production (essentially adding a season focused on water-intensive crops), thereby boosting on-farm cash profits by 70 percent. However, incomplete land and labor markets lead to low adoption of irrigation, so much so that eliminating labor constraints would increase irrigation adoption by 21 percent.[1] Routine maintenance costs of irrigation are also found to be prohibitive, such that even for adopters, large profit gains do not compensate for these costs. In northern Mali, using propensity score matching and a matched diff-in-diff estimator on an eight-year panel, Dillon (2011) finds that small-scale community-level irrigation investments[2] increased household consumption by about 30 percent, and also led to positive impacts on savings and insurance, in particular through increased savings of tropical livestock units and engagement in informal risk-sharing. Much of the irrigation literature has also focused on documenting a variety of impacts in India. For example, larger irrigation dams decrease poverty in downstream districts but increase it in districts where the dams are built (Duflo and Pande, 2007), and access to groundwater via pumps reduces rural poverty and irrigation disputes (Sekhri, 2014).

Other work has focused on longer-term impacts and dynamics of access to water. Over a longer-time horizon, agricultural productivity gains could foster structural transformation, or overextraction of water resources could hamper the sustainability of the impacts of irrigation. Asher et al. (2021) study irrigation canals in India over 150 years and find that canal areas have higher land productivity and population density relative to neighboring non-canal areas, but that there is no long-run change in the share of the workforce outside of agriculture or even in agroprocessing. Instead, structural transformation occurs via higher growth rates in nearby towns, suggesting that the transformation is one that occurs in movement across space as opposed to across sectors (within the same area). Related work in India by Blakeslee et al. (2021) finds that large-scale irrigation increased agricultural output, population, and wealth in the program areas,

[1] In this study, financial and informational constraints to irrigation adoption were also tested for, but were not found to constrain adoption.
[2] These involved motorized pumps to redistribute water from the Niger River through small-scale canal systems.

but that nearby towns led to a decline in population, non-agricultural employment, and firm activity. Elsewhere, over abstraction and scarcity tend to be a binding constraint. Hornbeck (2014) shows that following the discovery of the Ogallala aquifer in the US in 1890, irrigation and crop yields increased, and drought sensitivity decreased in the short-run. In the long-run, farmers shifted to more water-intensive crops and yields became more sensitive to drought. Rising farm revenues and declining land values indicate that many will soon lose access to the aquifer. In Jordan, where production is mostly dependent on groundwater, farmers' decisions are affected by perception of water availability (Kafle and Balasubramanya, 2021).

While Bhutan is unique, its agriculture sector faces similar challenges and opportunities around irrigation and water access. Yield growth in the South Asia region has been attributed to an extent to the expansion of irrigation (Morita, 2021). But the impacts of climate change threaten yield gains. Farming in Bhutan is already naturally constrained by its mountainous topography. The impacts of climate change in Bhutan include erratic rainfall, windstorms, hail storms, droughts, flash floods, and landslides (Chhogyel and Kumar, 2018). Rice is known to require a significant amount of water, and delays or changes in rain will impact the amount of irrigation water and the flow of snow and glacial-fed rivers.

Using the 2009 Bhutan census for the renewable and natural resources (RNR) sector, IFPRI (2010) notes that the self-reported top constraints to farming are wildlife insects/plant diseases, irrigation, and labor shortage. Using propensity score matching techniques, this work finds that access to rural roads and improved quality of land (i.e. irrigation) are strongly related to productivity. Cursory policy simulations indicate that irrigation investment programs provide larger returns, compared to rural roads and wetland protection.

We build on this work of IFPRI by matching the RNR census 2009 with the RNR census 2019, to build a chiwog-level panel dataset over this 10-year period. We study the immediate impacts of irrigation and drought problems on yields for cereals and other crops, and we compare estimates from a spatial first differences (SFD) and a panel fixed effects (panel FE) approach. We find that irrigation problems cause a substantial reduction in yield for paddy rice, but only minimally so for maize. On the other hand, drought leads to lower yields for maize, but has insignificant impacts on rice yield. This is expected as paddy rice is mostly produced in irrigated land as opposed to maize, which relies on rainfall. We also find that the two estimators, SFD and panel FE, yield different estimates, with SFD providing more robust estimates. We argue that this is due to the fact that the chiwog-specific unobservables are changing over time, which leads to the estimates from the panel FE to be inconsistent. On the contrary, SFD captures the time-varying chiwog-specific unobservables as long as they are similar across adjacent chiwogs.

We also find that irrigation and drought problems lead to negative impacts on the yields of other crops, for example, for vegetables such as spinach, radish and cabbage. Other constraints also matter. For example, unproductive land, labor shortages, landslides, wild animals, and insects/diseases lead to yield reductions for paddy.

Our work contributes to the literature on the impacts of small-scale irrigation on productivity, building on the work of IFPRI (2010) in Bhutan, and providing evidence on the importance of access to water. In particular, this paper makes contributions to the empirical evidence on the role of water constraints in crop productivity, particularly by leveraging a relatively recent identification strategy, the SFD approach, made possible by the novelty of the census structure of our data. Our work also differs in context to that of Jones et al. (2021) in

Rwanda and of Dillon (2011) in northern Mali, as our focus is directly on the impacts of water-related constraints, as opposed to on interventions to alleviate these constraints.

## 2. Data and Estimation

### *Data Source*

Our primary source of data is the renewable resources (RNR) census collected by the Bhutan Ministry of Agriculture and Forests at ten-year intervals. We use two rounds of RNR census data from 2009 and 2019 that cover nearly all the agricultural and livestock holdings in the country at that given point in time. This totaled about 57,600 and 66,600 holdings in 2009 and 2019 respectively. The standardized questionnaire was largely consistent between the rounds and includes modules that collected self-reported data on asset ownership, farm characteristics, access, major constraints as well as crop-wise estimates of acreage and production. To allow us to exploit temporal variation between the two census rounds, we aggregated the data at the Chiwog level, which is a third-tier administrative unit consisting of a cluster of villages. Chiwogs were then matched between the two rounds to construct a panel.

### *Variables*

We focus on a partial productivity measure, crop yields, as our outcome variable. For paddy rice (irrigated) and maize separately, we compute the chiwog-level yields by dividing total quantity produced in a chiwog with total planted acres in the chiwog, i.e. $Yield_{it} = \frac{Quantity_{it}}{Acres_{it}}$, where $Quantity_{it}$ and $Acres_{it}$ are the quantity produced and the acres planted in chiwog $i$ in year $t$. For the holding-level analyses in the annex, the yields are simply the quantity produced by a holding with the planted acres of the holding. In the annex, we provide the analyses for yields of other crops: spinach and sags, radish, chili, beans, cabbages, cauliflower, potatoes, ginger, mandarin, and cardamom.

As we are interested in how water-related constraints of farms can affect productivity, the two main explanatory variables of interest are the share of holdings in a chiwog that responded "irrigation" was a major constraint for agricultural production (*Irrigation*) and the share of holdings that responded "drought" was a major constraint (*Drought*). These are constructed as,

$$Irrigation_{it} = \frac{Number\ of\ holdings\ reported\ irrigation\ as\ a\ constraint_{it}}{Number\ of\ holdings_{it}},$$

and

$$Drought_{it} = \frac{Number\ of\ holdings\ reported\ drought\ as\ a\ constraint_{it}}{Number\ of\ holdings_{it}}.$$

Each constraint, including irrigation and drought, is a categorical variable, recorded as being in place if the respondent chooses it as one of the most relevant from a pre-defined list. While this list is largely consistent between the two rounds of censuses, the respondent was restricted to choose up to a maximum of three most relevant constraints in 2019, while no such restriction was in place in 2009.

We explicitly control for two sets of possible confounders in identifying the relationship between crop yields and water constraints. The first set is the shares of holdings that responded to having other constraints to agricultural production, including unproductive land, shortage of land, shortage of labor, limited market access, excessive rain, hailstorm or wind, wild animals, and insects or diseases. Also, as the holdings reported different numbers of major constraints, we also control for the average number of constraints reported by the holdings in a chiwog.

The second set of a controls is a set of other constraints. This includes land owned by the holding, the proportion of land that is left fallow in the season, and whether a water pump was used. In addition, we control for agroecological variables, including elevation, distance to closest water body, total monthly precipitation, monthly minimum, and monthly temperature.

***Empirical Approach***

The primary goal of the paper is to identify the relationship between the water constraints and crop yields. We first estimate the following equation:

$$y_{jt} = \alpha + \mathrm{B}D_{jt} + \Gamma X_{jt} + \epsilon_{jt} \quad (1)$$

where $y_{jt}$ is yield of a crop in chiwog $j$ in year $t$, $D$ is the vector of the two water-related constraint variables, namely irrigation and drought. As described in the earlier section, the constraint variables are defined as the number of holdings in a chiwog which report that they face a given constraint over the total holdings in a chiwog. Finally, $X$ denotes the vector of other controls.

The consistent estimation of the coefficients of the two key variables of interest requires that these two be orthogonal to the error term. If there are omitted variables that are correlated with the two key variables and affect the outcome, orthogonality is violated. One example is the factors that can affect the overall infrastructure of the agriculture (including irrigation infrastructure) in each chiwog, which can affect both the water-related constraints and the yields. These can be chiwog or time-specific as they can be related to the wealth of the chiwogs or the national or chiwog-level economic growth. Climates of the chiwogs also can be a possible source of the omitted variable bias as they can affect the constraints and yield variables.

To minimize the risk of omitted variable bias, we consider two empirical strategies: i) chiwog-level panel fixed effect (Panel FE) estimation, and ii) spatial first-difference (SFD) estimation, adapted from Druckenmiller and Hsiang (2018).

First, consider chiwog-level panel fixed effects estimation. We can rewrite the error term of (1) as

$$\epsilon_{jt} = v_j + \mu_t + u_{jt} \quad (2)$$

where $v_j$ and $\mu_t$ are chiwog-specific and round-specific fixed effects, and $u_{jt}$ is the remaining error term. The identifying assumption is, therefore, $E\left(D'_{jt}u_{jt}\right) = 0$. While the fixed effects estimation can control for chiwog-specific time-invariant unobservable factors or factors that are round-specific but common across chiwogs, it cannot mitigate the possible bias from chiwog-specific time-varying unobservable factors.

Second, consider the SFD estimator of Druckenmiller and Hsiang (2018):

$$\Delta y_{jt} = \alpha + \mathrm{B}\Delta D_{jt} + \Gamma\Delta X_{jt} + \Delta\epsilon_{jt} \quad (3)$$

where $\Delta$ denotes the spatial first difference operator. The SFD design relies on the Local Conditional Independence Assumption (LCIA), which implies that the adjacent neighbors have identical expected potential outcomes if the "treatment" is identical. One can denote the identifying assumption as $E\left(\Delta D'_{jt}\Delta\epsilon_{jt}\right) = 0$. If we follow the error structure of (2), we have $\Delta\epsilon_{jt}$= $\Delta v_j + \Delta u_{jt}$.

To compare the credibility of the two identification strategies, suppose the identifying assumption of the panel FE estimator, which is $E\left(D'_{jt}u_{jt}\right) \neq 0$, is violated. This can occur when there are chiwog-specific and time-varying unobservable factors that affect both the constraints and the outcome. The question is under which condition can the SFD estimator provide more credible estimates if the panel FE identification assumption is violated. One can rewrite the LCIA as $E\left(\Delta D_{jt}'(\Delta v_j + \Delta u_{jt})\right) = 0$. From this representation, we see that the sufficient conditions for SFD estimation to provide consistent estimates are a) $E(\Delta D_{jt}'\Delta v_j) = 0$ and b) $E(\Delta D_{jt}'\Delta u_{jt}) = 0$. If the first condition is satisfied and the panel FE assumption is violated, the SFD estimator would provide better estimates if $E(D_{jt}'u_{jt}) = E(D_{j-1t}'u_{j-1t})$ where $j-1$ is the adjacent chiwog for chiwog $j$ . In words, the degree to which the constraints are correlated with the error term is identical between chiwog *j* and the adjacent chiwog. On the other hand, suppose the panel FE assumption is valid, i.e. $E(D_{jt}'u_{jt}) = 0$, which implies $E(\Delta D_{jt}'\Delta u_{jt}) = 0$. That is, if the first sufficient condition of the SFD identification assumption fails, i.e. $E(\Delta D_{jt}'\Delta v_j) \neq 0$, then the panel FE provides more credible estimates.

Finally, we consider including an additional set of control variables in the vector, $X_{jt}$. This set of control variables includes land size, used chemical fertilizer, used manuare, proportion of land left fallow, access to water pump, elevation, distance to river, monthly precipitation, and monthly minimum and maximum temperature. The inclusion of the control variables assists in exploring the validity of identifying assumptions of the two estimators. The identifying assumptions of the two estimators hinge on the correlation structures between chiwog-specific factors, either time-varying or time-invariant, and the self-reported constraints. Assuming that the set of control variables is exogenous and represents the unobservable variables well, examining the difference in the estimated coefficients from the models with and without the control variables helps the discussion on the identifying assumptions.

## 3. Summary Statistics

Table 1 presents the means and standard deviations of the chiwog-level production variables for irrigated paddy rice and maize for the chiwogs that produce the crop. Overall, the average of the chiwog-level production areas are 29.3 and 38.2 acres for irrigated paddy and maize with the average yields being 1,309kg/acre and 909kg/acre respectively. Comparing 2009 to 2019, the average area increased and the average yield decreased for irrigated paddy over time. Also, the number of chiwogs that produced irrigated paddy rice increased between the two rounds from 678 chiwogs to 755 chiwogs indicating that the irrigated paddy production has been expanding. The average chiwog-level acres of maize production and the average yield decreased over the two rounds but the number of chiwogs increased similar to irrigated paddy. In 2019, there were a total of 1,041 Chiwogs in Bhutan that engaged in RNR activity, and 837 in 2009.[3,4]

Annex Table A1 also shows statistics for other commonly grown crops. In 2019, over 90 percent grew some spinach, radish, chili, beans, and potato, and 62 percent grew ginger, 74 percent cardamom, and 75 percent mandarin. These proportions remained largely stable for most crops for the ten year period we study, with a few trends that stand out. There was a marked rise in cardamon

[3] The data collection of the 2009 RNR census preceded the official declaration of Chiwogs as a third level administrative unit in Bhutan, and therefore Chiwogs in the 2009 data did not correspond to officially allotted titles in this round. Consequently, we matched available Chiwog strings in 2009 to their best match against the official list from 2019. The matching exercise yielded a success rate of approximately 80% (837 Chiwogs).

[4] For paddy, there is a 28% drop from 2009 to 2019 in common Chiwogs (those that harvested paddy in both 2009 and 2019). This is not explained by cultivated area (which remains stable), but rather by a fall in production. In addition, Chiwogs that dropped in 2019 are more productive than Chiwogs that entered in 2019. For maize, for common Chiwogs, both area and production fall proportionately, and yields are stable over time. (See Annex Table A3). For paddy, there is regional heterogeneity in yield changes from 2009 to 2019 for common Chiwogs. Decline in yields are concentrated in South-East and South-West regions. Districts in the West (i.e. Paro) experienced rising yields. Similarly for maize, decline in yields were concentrated in the southern regions, while the rest of the country saw rising yields. (See Annex Table A4). Also (See Annex Table A5) for the incidence of paddy and maize growing in different regions.

growers, which has become a popular export crop in Bhutan. Cardamom growers increased from 21 percent in 2009 to 74 percent in 2019. Cabbages and cauliflower also grew in popularity between the two census periods, with proportions increasing by 29 and 44 percentage points respectively. Meanwhile, irrigated paddy fell in popularity, with the proportion of growers dropping from 81 percent to 73 percent in 2019.

*Table 1 Means and Standard Deviations of Chiwog-level Production, Planted Area, and Yields for Irrigated Paddy and Maize*

| | *Chiwog level (pooled)* | | *Chiwog level (2009)* | | *Chiwog level (2019)* | |
|---|---|---|---|---|---|---|
| | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** |
| | | | **Panel A: Paddy (Irrigated)** | | | |
| Proportion that grew | 0.76 | 0.42 | 0.81 | 0.39 | 0.73 | 0.45 |
| Area (acres) | 29.3 | 38.9 | 28.3 | 36.9 | 30.2 | 40.5 |
| Production (kg) | 38,992.6 | 57,759.7 | 47,063.8 | 66,159.5 | 32,503.1 | 49,072.3 |
| Yield (kg/acre) | 1,308.7 | 616.9 | 1,585.7 | 411.1 | 1,060.3 | 663.4 |
| Total holdings | 39,415 | | 15,398 | | 24,017 | |
| N | 1,433 | | 678 | | 755 | |
| | | | **Panel B: Maize** | | | |
| Proportion that grew | 0.86 | 0.34 | 0.87 | 0.34 | 0.86 | 0.35 |
| Area (acres) | 38.2 | 45.7 | 41.6 | 50.2 | 35.4 | 41.6 |
| Production (kg) | 34,897.3 | 47,066.0 | 40,753.1 | 51,637.1 | 30,189.0 | 42,483.8 |
| Yield (kg/acre) | 909.0 | 460.1 | 935.8 | 226.8 | 887.2 | 583.9 |
| Total holdings | 64,367 | | 21,984 | | 42,383 | |
| N | 1,619 | | 726 | | 893 | |

Table 2 presents the means and the standard deviations of the chiwog-level constraint variables for irrigated paddy rice and maize. Panel A reports the averages among the chiwogs that grow any irrigated paddy and Panel B reports the averages among the chiwogs that grow any maize. On average among the rice-producing chiwogs, about 40% of holdings in a chiwog face irrigation as a constraint and the share is similar across two rounds. About 6% of holdings reported drought as a constraint. For the maize-producing chiwogs, the shares are slightly lower for the irrigation constraint (35% – 37%) and for the drought constraint (4% – 6%). Note that the correlation across constraints is low (Annex Table A6).

*Table 2 Means and Standard Deviations of Chiwog-level Constraint Variables for Chiwogs Producing Irrigated Paddy or Maize*

| | *Chiwog level (pooled)* | | *Chiwog level (2009)* | | *Chiwog level (2019)* | |
|---|---|---|---|---|---|---|
| | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** |
| | **Panel A: Chiwogs that Produce Irrigated Paddy** | | | | | |
| Irrigation problem | 0.40 | 0.29 | 0.40 | 0.30 | 0.40 | 0.29 |
| Drought | 0.06 | 0.13 | 0.06 | 0.12 | 0.05 | 0.13 |
| Unproductive land | 0.10 | 0.13 | 0.13 | 0.16 | 0.07 | 0.10 |
| Shortage of land | 0.17 | 0.17 | 0.22 | 0.19 | 0.13 | 0.14 |
| Labor shortage | 0.47 | 0.24 | 0.51 | 0.23 | 0.44 | 0.24 |
| Limited access to market | 0.15 | 0.23 | 0.23 | 0.27 | 0.08 | 0.16 |
| Excessive rain | 0.02 | 0.06 | 0.03 | 0.08 | 0.01 | 0.04 |
| Hailstorm / wind | 0.06 | 0.14 | 0.08 | 0.14 | 0.05 | 0.13 |
| Landslides / soil erosion | 0.03 | 0.06 | 0.04 | 0.07 | 0.02 | 0.04 |
| Crop damage by wild animals | 0.66 | 0.26 | 0.63 | 0.27 | 0.68 | 0.25 |
| Crop damage by insects /diseases | 0.38 | 0.29 | 0.55 | 0.26 | 0.23 | 0.24 |
| Total no. of constraints reported | 2.66 | 0.69 | 3.04 | 0.66 | 2.32 | 0.50 |
| N | 1,425 | | 673 | | 752 | |
| | **Panel B: Chiwogs that Produce Maize** | | | | | |
| Irrigation problem | 0.36 | 0.29 | 0.35 | 0.30 | 0.37 | 0.29 |
| Drought | 0.05 | 0.12 | 0.06 | 0.13 | 0.04 | 0.12 |
| Unproductive land | 0.10 | 0.14 | 0.14 | 0.16 | 0.07 | 0.11 |
| Shortage of land | 0.16 | 0.17 | 0.21 | 0.19 | 0.12 | 0.13 |
| Labor shortage | 0.47 | 0.24 | 0.51 | 0.23 | 0.44 | 0.24 |
| Limited access to market | 0.17 | 0.24 | 0.25 | 0.28 | 0.10 | 0.17 |
| Excessive rain | 0.02 | 0.06 | 0.03 | 0.08 | 0.01 | 0.05 |
| Hailstorm / wind | 0.08 | 0.16 | 0.10 | 0.18 | 0.06 | 0.15 |
| Landslides / soil erosion | 0.03 | 0.07 | 0.05 | 0.10 | 0.01 | 0.04 |
| Crop damage by wild animals | 0.68 | 0.25 | 0.64 | 0.26 | 0.71 | 0.25 |
| Crop damage by insects /diseases | 0.38 | 0.29 | 0.56 | 0.26 | 0.24 | 0.24 |

| | | | |
|---|---|---|---|
| Total no. of constraints reported | 2.64 0.69 | 3.05 0.67 | 2.32 0.52 |
| N | 1,614 | 720 | 894 |

## 4. Results

Table 3 and Table 4 report the estimation results for the effects of water constraints on the yields for irrigated paddy rice and maize. Column (1) is the estimation results of equation (1) with chiwog- and round-level fixed effects. Columns (2) and (3) are the results from estimating equation (2), i.e. the spatial first difference specification. Column (3) includes round-level fixed effects.

The first two rows of Table 3 present the estimates of the key coefficients, the coefficients of the water constraints, for irrigated paddy production. The estimated coefficient for the irrigation constraint ranges from -400kg/acre to -169kg/acre as a response to moving from none of the holdings in a chiwog facing the irrigation constraint to all of them facing. As we see that about 40% of the holdings are facing the irrigation constraint (panel A, Table 2), eliminating the irrigation problem for these 40% of holdings would increase the yield of irrigated paddy by about 68kg/acre (169*0.4) to 160kg/acre (400*0.4).[5]

The estimated magnitude of the effect is substantially smaller for the SFD estimations (columns 2 and 3) than that of the panel FE (column 1). The estimated effect is significantly different from zero at 1% for the chiwog-level fixed effects estimations and at 10% for the SFD estimations. We do not find significant effects of the drought constraint on the yield of irrigated paddy, yet the estimated coefficients are also substantially different between the panel FE and the

[5] Note that the constraints are reported by holdings and not crop-specific. Hence, the more nuanced interpretation would be the effect of eliminating the constraint faced by a holding as a whole, not for a specific crop.

SFD. The differences in the estimated coefficients between the panel FE and the SFD estimations suggest that at least one of the two estimators is facing a violation in its identifying assumptions. We further discuss the stability of the estimates and the identifying assumptions when we compare the results of Table 3 and Table 4 with those of Table 5 and Table 6, which are the estimation results with the additional control variables in the model.

*Table 3 Estimated Effects of Various Constraint on Yield of Irrigated Paddy*

| Outcome: Yield | OLS | SFD | SFD |
|---|---|---|---|
| | (1) | (2) | (3) |
| Irrigation problem | -400.1*** | -169.74* | -169.45* |
| | (133.9) | (100.58) | (101.25) |
| Drought | -252.4 | -53.86 | -53.8 |
| | (202.5) | (130.2) | (130.26) |
| Unproductive land | -41.45 | -275.58** | -275.16** |
| | (203.3) | (133.25) | (133.82) |
| Shortage of land | -561.8*** | -88.26 | -88.08 |
| | (170.9) | (124.29) | (124.54) |
| Labour shortage | -408.9*** | -124.25 | -123.78 |
| | (144.8) | (98.1) | (98.52) |
| Limited access to market | -131.1 | -85.43 | -85.09 |
| | (163.2) | (107.13) | (107.45) |
| Excessive rain | 49.01 | -512.46 | -511.88 |
| | (365.6) | (330.25) | (329.88) |
| Hailstorm / wind | 272.2 | 181.13 | 181.75 |
| | (343.9) | (200.21) | (201.14) |
| Landslides / soil erosion | 446.7 | -357.81* | -357.31* |
| | (338.0) | (182.7) | (182.98) |
| Crop damage by wild animals | -528.4*** | -149.22 | -149.14 |
| | (190.3) | (96.91) | (97.11) |
| Crop damage by insects /diseases | -483.2*** | -234.61** | -234.31** |
| | (149.8) | (100.79) | (101.31) |
| Total no. of constraints reported | 335.5*** | 107.21 | 106.94 |
| | (110.3) | (80.75) | (81.12) |
| Constant | 1,686*** | -9.97 | -12.48 |
| | (145.9) | (17.14) | (22.41) |
| Observations | 1,082 | 1,163 | 1,163 |

| Outcome: Yield | OLS | SFD | SFD |
| --- | --- | --- | --- |
| | (1) | (2) | (3) |
| Year fixed effects | Yes | No | Yes |
| Chiwog fixed effects | Yes | No | No |

Note: Robust standard errors clustered at the chiwog level are given in the parentheses (*** p<0.01, ** p<0.05, * p<0.1).

In Table 4, we observe the larger magnitudes of the effects of the drought constraint for maize production. The estimated coefficient ranges from -606kg/acre to -414/acre as a response to moving from none of the holdings in a chiwog facing the drought constraint to all of them facing. Using the average share of 5% in table 2, eliminating the drought constraint in a chiwog implies an increase of about 21kg/acre to 30kg/acre. While the magnitudes are smaller with the SFD estimations, the estimated effects are statistically significant at 1%. The estimated coefficients for the irrigation constraint are statistically significant only with the SFD estimations.[6] On the contrary to the case of irrigated paddy, maize yields respond much more to the drought constraint compared to the irrigation constraint.

We present panel FE, SFD, and SFD with year FE for a range of other crops in Tables A7, A8, and A9. The panel FE results show that problems of irrigation lead to reductions in yield for radish, chili, cabbage, and potato, while droughts lead to reductions in yield for radish, chili, beans, potato, and ginger. The results from SFD with year FE show that problems of irrigation lead to reduction in yields for radish and cabbage, while droughts lead to reductions in yield for spinach and cardamom. In addition, in Table A10, we present holding-level SFD regresssions for all other crops using 2019 data. While the results remain largely consistent with our main findings, we see

[6] As the constraints are not crop-specific, one needs to be cautious in the interpretation. While maize is mostly rainfed and it is possible that the maize-growing holdings report irrigation as a constraint for other crops, we would have observed insignificant effects of the irrigation constraint if that were the case. Hence, the results may suggest a possible positive effect of irrigation on maize production.

smaller magnitudes for the estimated impacts of the constraints. The difference can be driven by either changes in productivity and technology in the sector as we are looking at the cross-sectional data of the more recent year, or simply the difference in the unit of observations (holdings instead of Chiwogs).

*Table 4 Estimated Effects of Various Constraints on Yield of Maize*

| Outcome: Yield | OLS<br>(1) | SFD<br>(2) | SFD<br>(3) |
|---|---|---|---|
| Irrigation problem | -140.8 | -149.16* | -149.08* |
| | (131.8) | (87.39) | (87.41) |
| Drought | -606.0*** | -415.07*** | -414.34*** |
| | (186.3) | (127.13) | (127.34) |
| Unproductive land | 317.3* | -21.41 | -20.9 |
| | (180.0) | (94.32) | (94.19) |
| Shortage of land | -558.1*** | -68.58 | -68.65 |
| | (202.2) | (102.87) | (102.95) |
| Labour shortage | -83.23 | -38.43 | -38.09 |
| | (149.6) | (87.26) | (87.35) |
| Limited access to market | 56.14 | -74.84 | -74.61 |
| | (145.8) | (94.1) | (94.22) |
| Excessive rain | -254.7 | 177.01 | 177.01 |
| | (367.8) | (162.37) | (162.33) |
| Hailstorm / wind | -270.2* | -192.59** | -192.65** |
| | (148.0) | (87.08) | (87.15) |
| Landslides / soil erosion | 276.1 | -298.99** | -297.17** |
| | (244.6) | (120.91) | (120.85) |
| Crop damage by wild animals | -357.6** | -196.2** | -195.91** |
| | (147.1) | (85.16) | (85.11) |
| Crop damage by insects /diseases | -404.4*** | -166.63* | -166.24* |
| | (143.8) | (88.19) | (88.27) |
| Total no. of constraints reported | 153.2 | 78.98 | 78.7 |
| | (111.8) | (74.24) | (74.23) |
| Constant | 1,140*** | 8.17 | .99 |
| | (102.8) | (11.71) | (11.09) |
| Observations | 1,334 | 1,400 | 1,400 |
| Year fixed effects | Yes | No | Yes |
| Chiwog fixed effects | Yes | No | No |

Note: Robust standard errors clustered at the chiwog level are given in the parentheses (*** p<0.01, ** p<0.05, * p<0.1).

To assess whether the inclusion of the measures on the realization of the constraints affect the estimated effects, we replicate Table 3 and Table 4 with the expanded set of the control variables. The additional control variables are land size, proportion of land left fallow, access to water pump, elevation, distance to river, monthly precipitation, and monthly minimum and maximum temperature. Table 5 and Table 6 are the replications of Table 3 and Table 4 with these additional control variables.

Table 5 and Table 6 show that the estimated effects from the SFD estimation are robust to the inclusion of the realization of the constraints whereas the effects change substantially for the estimates from the fixed effects estimation. As discussed earlier, the difference in the changes of the estimated coefficients with respect to the inclusion of the control variables between the panel FE and the SFD estimations provides insights on the robustness of the identifying assumptions. Assuming that the set of the control variables is orthogonal to the error terms, we argue that the identifying assumptions of the SFD estimations are more reliable compared to those of the panel FE as we observe small changes in the estimated coefficients for the SFD estimations when we include additional control variables. Similar patterns are observed in both estimation results for irrigated paddy and maize.

*Table 5 Estimated Effects of Various Constraint on Yield of Irrigated Paddy (with Controls)*

| Outcome: Yield | OLS<br>(1) | SFD<br>(2) | SFD<br>(3) |
|---|---|---|---|
| Irrigation problem | -60.52 | -198.67* | -197.65* |
| | (138.14) | (101.24) | (101.95) |
| Drought | 61.33 | -64.01 | -64.17 |
| | (172.34) | (131.85) | (131.9) |
| Unproductive land | -14.34 | -302.51** | -301.18** |
| | (181.01) | (131.74) | (132.31) |

| Outcome: Yield | OLS | SFD | SFD |
|---|---|---|---|
| | (1) | (2) | (3) |
| Shortage of land | -199.5 | -151.39 | -151.16 |
| | (202.01) | (131.04) | (131.1) |
| Labour shortage | -182.56 | -173.08* | -171.54* |
| | (146.95) | (99.29) | (99.8) |
| Limited access to market | -56.72 | -64.47 | -63.57 |
| | (163.02) | (109.05) | (109.41) |
| Excessive rain | 247.77 | -525.59 | -522.39 |
| | (369.29) | (339.25) | (338.26) |
| Hailstorm / wind | 542.78 | 213.02 | 214.57 |
| | (340.62) | (201.94) | (202.78) |
| Landslides / soil erosion | -47.13 | -357.92* | -355.93* |
| | (261.13) | (189.41) | (189.54) |
| Crop damage by wild animals | -255.26 | -163.42* | -163.1 |
| | (198.07) | (99.09) | (99.43) |
| Crop damage by insects /diseases | -275.22* | -253.4** | -252.28** |
| | (147.33) | (98.14) | (98.67) |
| Total no. of constraints reported | 160.93 | 119.07 | 118.27 |
| | (114.69) | (79.32) | (79.74) |
| Total land owned (acres) | -16.38 | -5.43 | -5.45 |
| | (14.93) | (12.08) | (12.09) |
| Used chemical fertilizer | 39.75 | 17.66 | 17.29 |
| | (114.55) | (75.9) | (76.14) |
| Used manure | 141.88 | -62.11 | -60.98 |
| | (102.57) | (80.89) | (80.7) |
| Proportion of land left fallow | -127.46 | -116.35 | -116.37 |
| | (231.08) | (158.97) | (158.99) |
| Used water pump | 56.92 | 216.87 | 214.31 |
| | (404.17) | (479.2) | (481.81) |
| Elevation (meters) | - | -.09 | -.09 |
| | | (.11) | (.11) |
| Distance to river (meters) | - | .01 | .01 |
| | | (.01) | (.01) |
| Constant | -53,919.6 | -15.69 | -24.18 |
| | (36,305.87) | (17.52) | (23.56) |
| | | | |
| Observations | 1,082 | 1,163 | 1,163 |
| Year fixed effects | Yes | No | Yes |
| Chiwog fixed effects | Yes | No | No |

Robust standard errors clustered at the chiwog level are given in the parenthesis.
*** p<0.01, ** p<0.05, * p<0.1
Additional controls include monthly precipitation, and monthly minimum and maximum temperature

*Table 6 Estimated Effects of Various Constraints on Yield of Maize (with controls)*

| Outcome: Yield | OLS<br>(1) | SFD<br>(2) | SFD<br>(3) |
|---|---|---|---|
| Irrigation problem | 64.19 | -163.56* | -163.22* |
| | (116.89) | (88.2) | (88.16) |
| Drought | -241.37 | -422.23*** | -420.98*** |
| | (181.03) | (124.75) | (124.9) |
| Unproductive land | 208.02 | -10.3 | -9.11 |
| | (137.89) | (99.1) | (98.85) |
| Shortage of land | -260.08 | -60.25 | -60.4 |
| | (176.97) | (107.13) | (107.17) |
| Labour shortage | 113.6 | -77.05 | -76.55 |
| | (127.49) | (87.17) | (87.2) |
| Limited access to market | 14.74 | -91.96 | -91.33 |
| | (122.45) | (94.66) | (94.78) |
| Excessive rain | -208.07 | 173.73 | 174.43 |
| | (315.9) | (155.97) | (155.93) |
| Hailstorm / wind | -77.38 | -197.75** | -197.92** |
| | (123.04) | (89.03) | (89.11) |
| Landslides / soil erosion | -42.66 | -291.28** | -288.13** |
| | (226.11) | (131.27) | (131.13) |
| Crop damage by wild animals | -202.97* | -209.87** | -209.27** |
| | (117.76) | (88.11) | (87.98) |
| Crop damage by insects /diseases | -201.74 | -159.61* | -158.99* |
| | (127.62) | (89.48) | (89.5) |
| Total no. of constraints reported | 59.62 | 85.44 | 85.03 |
| | (92.14) | (76.23) | (76.12) |
| Total land owned (acres) | 22.74** | 7.62 | 7.57 |
| | (10.03) | (8.11) | (8.12) |
| Used chemical fertilizer | -198.61* | -20.82 | -20.64 |
| | (101.34) | (57.4) | (57.32) |
| Used manure | 82.58 | -25.97 | -26.33 |
| | (80.13) | (44) | (43.74) |
| Proportion of land left fallow | -64.25 | -66.77 | -67.71 |
| | (139.65) | (118.73) | (118.59) |
| Used water pump | 2328.77* | 904.56 | 908.65 |
| | (1189.2) | (551.14) | (554.77) |
| Elevation (meters) | - | -.01 | -.01 |
| | | (.08) | (.08) |
| Distance to river (meters) | - | -.02* | -.02* |
| | | (.01) | (.01) |
| Constant | -12,146.59 | 3.41 | -8.43 |
| | (37,917.72) | (12.17) | (11.81) |

| Outcome: Yield | OLS<br>(1) | SFD<br>(2) | SFD<br>(3) |
|---|---|---|---|
| Observations | 1,334 | 1,400 | 1,400 |
| Year fixed effects | Yes | No | Yes |
| Chiwog fixed effects | Yes | No | No |

Robust standard errors clustered at the chiwog level are given in the parenthesis.
*** p<0.01, ** p<0.05, * p<0.1
Additional controls include monthly precipitation, and monthly minimum and maximum temperature

Finally, other constraints other than irrigation problems and drought do matter for paddy and maize yields.[7] For paddy (Table 5, Column 3), we find that unproductive land, labor shortages, landslides, and insects/diseases lead to yield reductions. The estimated reductions in yields from landslide, unproductive land, and insects/diseases are much larger than the irrigation impacts, while the impacts of labor shortages are close in magnitude to the impacts of irrigation constraints. For maize (Table 6), hailstorms/wind, landslides, wild animals, and insects/diseases lead to yield reductions. Similar to paddy, the impacts of landslides on yields for maize are much larger than the impact of irrigation, indicating that landslides are disastrous events. However, the impact of droughts holds by far the largest negative impact on maize yields relative to the other constraints. Hailstorms, wild animals, and insects/diseases have roughly the same magnitude impact on maize yield reductions as irrigation constraints do.

Next, we explore heterogeneous effects of the various constraints by region. In Table 6, we find that the impact of irrigation problems (and drought) on paddy yield reductions is largest in the east, while the impacts are fairly similar in the central, southeast, and southwest. This indicates a huge opportunity to invest in irrigation and drought tolerance in the east. Notably, the impacts of

[7] A back-of-the-envelope estimation indicates that the elimination of all constraints for a chiwog with all holdings facing all constraints would increase the yields by more than double (for irrigated paddy, the predicted effect is 1,866.25 with the standard error of 1,023.49 and for maize, the predicted effect is 1,440.64 with the standard error of 839.63). The estimations are based on column (3) of tables 3 and 4.

all the other constraints on paddy yields are also most negative in the east, indicating that investments to address a broad set of constraints would help improve yields in the east. We find an a priori counterintuitive positive impact of irrigation problems on paddy yields in the west. This region has a relatively smaller sample size and includes areas which are generally more diversified out of farming activities (i.e. Thimphu). In Annex Table A11, we present holding-level SFD estimates by region on the impact of various constraints on paddy yields. The estimates are quite noisy and do not yield clear results.

In Table 7, we note that likely due to sample size constraints when separating the estimation by regions, we lose precision of the estimates of irrigation and drought problems on maize yields. The impact of droughts on maize yields are most negative in the east. In Annex Table A12, we present holding-level SFD estimates by region on the impact of various constraints on maize yields. Similar to the main results in Table 7, the impact of doughts on maize yields is greatest in the esast, but also in the southwest.

Finally, in Annex Table A13, we present heteroegenous impacts of irrigation problems and drought by farm size. We do not find any evidence that the negative impacts of irrigation and droughts vary by land size, indicating that all farm sizes are impacted equally by irrigation/drought problems.

*Table 7: Estimated Effects of Various Constraint on Yield of Irrigated Paddy, by region (SFD)*

| Outcome: Yield | (1)<br>Central | (2)<br>East | (3)<br>South-East | (4)<br>South-West | (5)<br>West |
|---|---|---|---|---|---|
| Irrigation problem | -181.2 | -1021.81** | -281.6 | -119.15 | 1435.58** |
| | (117.53) | (405.82) | (208.62) | (153.07) | (584.2) |
| Drought | -361.36 | -744.56** | 18.03 | -379.11* | 317.78 |
| | (333.82) | (308.23) | (287.42) | (224.63) | (532.73) |
| Unproductive land | 84.95 | -448.91 | -522.27* | -597.96*** | 826.93 |
| | (287.13) | (408.71) | (291.5) | (165.17) | (970.83) |
| Shortage of land | -202.14 | -916.99** | 120.99 | 158.4 | 866.26 |
| | (182.49) | (444.31) | (305.98) | (208.94) | (569.91) |

| Outcome: Yield | (1)<br>Central | (2)<br>East | (3)<br>South-East | (4)<br>South-West | (5)<br>West |
|---|---|---|---|---|---|
| Labour shortage | 96.43 | -891.26*** | -248.54 | -191.29 | 2009.33 |
| | (154.35) | (331.72) | (243.69) | (172.13) | (1348.26) |
| Limited access to market | -181.09 | -961.17** | -306.81 | -392.7** | 2188.09** |
| | (131.65) | (425.95) | (218.42) | (163.33) | (944.71) |
| Excessive rain | -717.73 | -1698.25*** | -460.95 | -264.6 | 1807.94 |
| | (632.91) | (590.43) | (629.15) | (366.03) | (1138.79) |
| Hailstorm / wind | 759.01 | -458.42* | -286.17 | -306.48 | 6326.32 |
| | (461.28) | (275.82) | (190) | (258.56) | (4866.07) |
| Landslides / soil erosion | 328.02 | -853.28 | -535.97 | -953.2* | -2987.49 |
| | (526.43) | (523.87) | (334.22) | (493.41) | (6720.83) |
| Crop damage by wild animals | -295.02** | -1103.25*** | -130.52 | 13.11 | 938.08 |
| | (118.29) | (383.76) | (210.24) | (153.8) | (629.26) |
| Crop damage by insects /diseases | -244.56** | -1384.31** | -78.17 | -357.74** | 1792.96** |
| | (123.45) | (572.16) | (245.66) | (170.36) | (809.71) |
| Total no. of constraints reported | 178.71* | 980.91** | 53.01 | 156.25 | -1253.57** |
| | (103.25) | (421.49) | (140.51) | (119.76) | (607.1) |
| Constant | -6.38 | -17.48 | -38.15 | -10.73 | -88.06 |
| | (31.3) | (35.85) | (59.46) | (50.1) | (75.22) |
| Observations | 247 | 319 | 154 | 306 | 97 |
| R-squared | 0.10 | 0.15 | 0.11 | 0.13 | 0.28 |
| Year Fixed Effects | Yes | Yes | Yes | Yes | Yes |

Robust standard errors clustered at the chiwog level are given in the parenthesis.
*** p<0.01, ** p<0.05, * p<0.1

*Table 8:Estimated Effects of Various Constraint on Yield of Maize, by region (SFD)*

| Outcome: Yield | (1)<br>Central | (2)<br>East | (3)<br>South-East | (4)<br>South-West | (5)<br>West |
|---|---|---|---|---|---|
| Irrigation problem | -466.78 | -140.94 | -139.11 | 72.04 | 390.61 |
| | (326.43) | (175.16) | (246.84) | (74.55) | (518.28) |
| Drought | 443.83 | -531.52** | -266.3 | -102.5 | -635.63 |
| | (695.32) | (205.26) | (270.32) | (123.88) | (592.3) |
| Unproductive land | -460.3 | -85.12 | -206.38 | 98.08 | -760.6 |
| | (497.07) | (171.34) | (264.2) | (99.23) | (695.08) |
| Shortage of land | -170.35 | -40.26 | -427.56 | 174.62 | 1314.69 |
| | (428.1) | (174.41) | (262.03) | (111.64) | (827.99) |
| Labour shortage | -287.75 | -4.68 | -53.15 | 62.34 | 559.56 |

| Outcome: Yield | (1)<br>Central | (2)<br>East | (3)<br>South-East | (4)<br>South-West | (5)<br>West |
|---|---|---|---|---|---|
| | (386.05) | (145.16) | (210) | (70.59) | (532.92) |
| Limited access to market | -91.59 | -64.04 | -304.71 | 152.56* | 943.37 |
| | (331.03) | (145.38) | (212.87) | (83.07) | (659.08) |
| Excessive rain | 1021.02 | -416.71 | 562.02* | 359.73** | 1062.66 |
| | (919.11) | (259.98) | (319.81) | (170.66) | (1045.36) |
| Hailstorm / wind | -2156.19** | -190.66 | -440.58* | -149.87 | -75 |
| | (1035.57) | (140.63) | (245.43) | (116.54) | (1618.84) |
| Landslides / soil erosion | -432.57 | -138.76 | -160.91 | -350.09** | -132.16 |
| | (782.82) | (232.51) | (241.25) | (144.61) | (1514.27) |
| Crop damage by wild animals | -405.78 | -367.61** | -342.38 | -104.58* | 992.02 |
| | (319.97) | (152.63) | (213.42) | (61.86) | (789.1) |
| Crop damage by insects /diseases | -173.82 | -160.02 | -371.59 | -47.35 | 371.87 |
| | (358.64) | (152.71) | (254.39) | (80.42) | (365.02) |
| Total no. of constraints reported | 146.23 | 120.81 | 326.65 | -23.79 | -489.6 |
| | (269.6) | (139.81) | (206.38) | (58.01) | (456.68) |
| Constant | 17.1 | -2.29 | 8.89 | -8.56 | -.47 |
| | (46.03) | (10.74) | (23.72) | (21.22) | (119.4) |
| Observations | 173 | 552 | 235 | 345 | 61 |
| R-squared | 0.07 | 0.06 | 0.09 | 0.11 | 0.18 |
| Year fixed effects | Yes | Yes | Yes | Yes | Yes |

Robust standard errors clustered at the chiwog level are given in the parenthesis.
*** p<0.01, ** p<0.05, * p<0.1

## 5. Discussion

With a total population of 700,000 in the Himalayan country of Bhutan, almost 60 percent of the population resides in rural areas (WDI, 2020). More than half of the population depends primarily on agriculture, livestock, and forestry (RNR sector). Although GDP from this sector has increased in absolute terms in the recent years, its percentage contribution has declined by as much as 33 percent since 2004, standing at less than 20 percent in 2018 (National Accounts Statistics, 2019). A broad-based consultation commissioned for the development of Bhutan's RNR strategy 2040 revealed that this decline in sectoral GDP is linked to declining public sector investment in production inputs, frequent institutional restructuring, local issues of human-wildlife conflicts, and increasing vulnerability to climate change impacts.[8]

Public sector investment within the agriculture sector has also been on the decline over the last two decades, which matches the decline in agricultural productivity. Overall, spending for agricultural development has also shown a decrease, from 9 percent of total expenditures in 1981–1986 to 5.5 percent in 2008–2013. Additionally, Bhutan only attracts a limited level of Foreign Direct Investment (FDI), evidenced by the fact that the average FDI across all sectors stands at 2 percent foreign ownership of businesses, which is lower in the agribusiness sector at 0.01 percent foreign ownership of agribusinesses (World Bank, 2017).

Since the beginning of the government's involvement in providing support to the agriculture sector in the late 1960s, public sector investments in agricultural inputs took a hit by the 9th Five Year Plan (FYP) (2002-2008),[9] when certain development activities were devolved from the central to Dzongkhag level, including irrigation. This devolution also resulted in a loss in agricultural development, as Bhutan now faces two major challenges: (i) weakening public sector irrigation development capacity and a lack of irrigation facilities and (ii) a decrease in the cultivated crop area (World Bank, 2018).

Owing to a general scarcity in public sector investment in irrigation water, irrigation coverage is still at suboptimal level, as farmers have relied on small-scale and traditional practices

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[8] Bhutan ranked 99 out of 182 countries in the 2022 The Notre Dame Global Adaptation Initiative (ND-GAIN) Index.
[9] The development policy objectives of Bhutan are emobidied in national Five Year Plans (FYPs). The most recent being the 12th FYP.

such as community-managed irrigation systems (CMIS).[10] Bhutan has a total of 1,200 CMIS, of which 1,000 are functional, irrigating about 64,428 acres— which is well below the 200,000-acre mark, or 50 percent of Bhutan's cultivable land that is considered irrigable. The government had set a target to increase irrigated acres to 91,000 by 2032 (AED, 2018).

In addition to the lack of irrigation facilities, the efficiency and functionality of already-existing irrigation facilities is also a challenge, with 20 percent of them being inoperable due to technical problems, 18 percent being inoperable due to social issues, 8 percent being inoperable due to problems with the water source, and a significant portion being inoperable for reasons that could not even be identified. Engineers' inadequate knowledge of irrigation planning, design, building, and maintenance and their lack of experience are major contributors to their inability to pinpoint the root of dysfunction (Dizon et al., 2019).

An assessment of water availability through surface runoff showed it not to be a constraint for irrigation development. According to this analysis, 71 percent of the present systems can be upgraded for increasing irrigated areas and/or cropping intensities, and the remaining systems (29 percent) can only be updated through the diversification of water sources. Using observed meteorological data from Class A weather stations - assessments also suggest that the availability of 80 percent dependable water at the level of a district will not be a constraint for developing new irrigation systems (AED, 2018).

Despite cultivated land being a rarity in Bhutan, about one-third was reported to have been left fallow in 2016 (out of 182,091 acres). These numbers vary across the country, and are as high

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10 Annex Table A14 shows that in 2019 almost 90% of irrigated holdings used surface irrigation system.

as 83 perecent in the eastern part of Bumthang. This decline in agricultural area can reduce agricultural productivity in the long-term (Dizon et al., 2019).

It is important to note that the low level of earmarked public funding for irrigation does not reflect a lack of acknowledgment of its importance in Bhutan's policy objectives - the 12$^{th}$ and the most recent FYP identified water scarcity as one of the flagship priority areas to improve agricultural productivity. The 12$^{th}$ FYP also seeks to achieve its plans through increased focus on decentralization by empowering local governance in areas of fiscal planning and administrative responsibilities. However, with irrigation as a devolved subject, the Department of Agriculture is constrained as it no longer has a focused irrigation division and previously specialized irrigation engineers, and professionals were reassigned to other infrastructure development departments such as roads and building construction. Under the decentralized structure, local irrigation management capacity is limited to repairs as opposed to planning any major irrigation works (AED, 2018).

In addition, the national budget includes many initiatives that prioritize upstream production assistance over value addition downstream in value chains. Along with being crop-specific, public subsidies frequently consist of a prepackaged set of inputs from the government (Dizon et al., 2019).

In conclusion, given the need for developing a climate smart approach to agriculture and mainstreaming resilience across the economy (climate impacts on irrigation systems are expected to reduce yields by 4%-10% in the future), catalyzing private sector investments in the RNR sector are critical for Bhutan (AED, 2018). Conversely, to fulfill the expanding and changing domestic food demand in urban areas and to take advantage of the opportunities in high-value export markets, private sector financing and solutions are required in the increasingly commercializing agriculture and agribusiness domains. Production, processing, retailing, and marketing can benefit from innovation and efficiency brought about by a competitive private sector (Dizon et al., 2019).

Presently, public investment for irrigation development has remained almost absent. As of May 2018, the RGoB had planned at least 14 schemes for irrigation development that are on hold due to shortfalls in the availability of funds. Whatever current irrigation systems exist in the country are largely the result of farmers' own initiatives and investments. With populations located in rural terrains and away from the reach of markets, public sector financing will be essential for guaranteeing food security in underdeveloped regions through initiatives to increase production and productivity as well as potential social safety net programs (AED, 2018).

In addition to the points above, there are several management practices that could affect the responsiveness of crops to the application of irrigation water, but that are not measured in the census data and not assessed in this paper. These include seed rate and seed replacement rate, equitable sharing of water at the head and tail of the scheme to ensure optimal water utilization over a large irrigation command area, increased cropping intensity due to more consistent and higher availability of water, increased irrigation command area, access to markets for sale of agricultural commodities, and depreciation in water conveyance efficiency tied to poor system maintenance issues. The latter may have implications for the sustainability of the impacts measured in this paper. Other important aspects to consider are the elevation and ruggedness of land in Bhutan. Precision or laser land leveling can be helpful in bringing additional land area into effective irrigation by ensuring that irrigation water runoff and leaching of inputs are reduced.

## 6. Conclusions

We study the impacts of irrigation and drought problems in Bhutan on the yields of cereals and other crops, using a novel panel of agricultural census data. We find that irrigation problems cause a substantial reduction in yield for paddy rice, but only minimally so for maize. On the other hand, drought leads to lower yields for maize, but has insignificant impacts on rice yield. We also find that irrigation and drought problems lead to negative impacts on the yields of other crops, for example, vegetables such as spinach, radish and cabbage.

Our paper contributes to the literature on the impacts of small-scale irrigation on productivity, building on the work of IFPRI (2010) in Bhutan and similar to the work by Jones et al. (2021) in Rwanda and by Dillon (2011) in northern Mali. Other constraints also matter. For example, unproductive land, labor shortages, landslides, wild animals, and insects/diseases lead to yield reductions for paddy. However, there is little correlation across the different constraints in the data we use.

While this paper provides answers to critical questions, it is not without limitations. First, we lack depth in our data on crop production and revenues. We do not have an adequate measure of prices, so that our analysis focuses on improvements in physical yields for individual crops as opposed to aggregate value or revenue. This means that we are also not able to say much about whether physical productivity gains lead to increased marketable surplus and increased profits. We also do not have a measure of production in different seasons of the year, so we are not able to distinguish whether the impacts are improvements under the main season (although this should be true for rice, as the weather does not typically allow for a second crop of rice in Bhutan) or via an additional season, such as the case in Rwanda (Jones et al., 2021).

Second, the dataset we use does not allow us to test for dynamics in yields or heterogeneous effects between 2009 and 2019. The estimated effects from the pooled data are the reflection of the average effects of constraints across two rounds and farms with different input usages and production technologies. That is, the negative effects of the constraints may be larger (or smaller) depending on the set of inputs and technologies that farms have or the overall technological progress in the sector between two time periods. Moreover, we abstract away from important longer-term considerations and spillover impacts. An important area of work has been to document the impacts of agricultural productivity gains on the extent and the nature of structural transformation.

Third, our measure for irrigation is quite limited. We are unable to identify the exact nature of the irrigation constraint, whether it is lack of access, lack of or infrequent water availability, or poor management. It is also important to note that while improving access to irrigation may improve productivity for the crops assessed here, this does not guarantee efficient use of limited water resources—something that we are unable to investigate here due to data constraints, but that may have important implications not just for productivity but also for crop diversification. Relatedly, while this paper shows that irrigation improvements may increase productivity for cereal crops, another potential avenue for improved overall productivity would be to diversify away from water-thirsty crops into higher value crops that demand less water, such as certain fruits and vegetables. Improving access to innovative high-efficiency microirrigation systems, such as drip and sprinkler irrigation systems, could be promising.

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## Annex

*Table A 1: Means and Standard Deviations of Chiwog-level Production, Planted Area, and Yields for selected crops*

| | *Chiwog level (pooled)* | | *Chiwog level (2009)* | | *Chiwog level (2019)* | |
|---|---|---|---|---|---|---|
| | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** |
| **Panel A: Paddy (Irrigated)** | | | | | | |
| Proportion that grew | 0.76 | 0.42 | 0.81 | 0.39 | 0.73 | 0.45 |
| Area (acres) | 29.3 | 38.9 | 28.3 | 36.9 | 30.2 | 40.5 |
| Production (kg) | 38,992.6 | 57,759.7 | 47,063.8 | 66,159.5 | 32,503.1 | 49,072.3 |
| Yield (kg/acre) | 1,308.7 | 616.9 | 1,585.7 | 411.1 | 1,060.3 | 663.4 |
| Total holdings | 39,415 | | 15,398 | | 24,017 | |
| N | 1,433 | | 678 | | 755 | |
| **Panel B: Maize** | | | | | | |
| Proportion that grew | 0.86 | 0.34 | 0.87 | 0.34 | 0.86 | 0.35 |
| Area (acres) | 38.2 | 45.7 | 41.6 | 50.2 | 35.4 | 41.6 |
| Production (kg) | 34,897.3 | 47,066.0 | 40,753.1 | 51,637.1 | 30,189.0 | 42,483.8 |
| Yield (kg/acre) | 909.0 | 460.1 | 935.8 | 226.8 | 887.2 | 583.9 |
| Total holdings | 64,367 | | 21,984 | | 42,383 | |
| N | 1,619 | | 726 | | 893 | |
| **Panel C: Spinaches and sags** | | | | | | |
| Proportion that grew | 0.96 | 0.19 | 0.97 | 0.18 | 0.96 | 0.19 |
| Area (acres) | 3.2 | 4.6 | 5.0 | 5.4 | 1.7 | 3.2 |
| Production (kg) | 2,452.8 | 3,146.9 | 3,055.9 | 2,956.1 | 1,967.9 | 3,212.6 |
| Yield (kg/acre) | 1,234.7 | 1,592.7 | 690.5 | 317.3 | 1,673.1 | 2,017.4 |
| Total holdings | 53,628 | | 16,400 | | 37,228 | |
| N | 1,809 | | 807 | | 1,002 | |
| **Panel D: Radish** | | | | | | |
| Proportion that grew | 0.96 | 0.19 | 0.96 | 0.19 | 0.96 | 0.19 |
| Area (acres) | 3.3 | 4.8 | 5.4 | 5.8 | 1.6 | 2.8 |
| Production (kg) | 3,819.6 | 7,727.1 | 4,211.1 | 6,027.1 | 3,504.8 | 8,850.9 |
| Yield (kg/acre) | 1,863.2 | 2,869.8 | 830.8 | 583.4 | 2,692.8 | 3,611.2 |

| | *Chiwog level (pooled)* | | *Chiwog level (2009)* | | *Chiwog level (2019)* | |
|---|---|---|---|---|---|---|
| | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** |
| Total holdings | 47,538 | | 16,675 | | 30,863 | |
| N | 1,800 | | 802 | | 998 | |
| **Panel E: Chili** | | | | | | |
| Proportion that grew | 0.94 | 0.23 | 0.92 | 0.27 | 0.96 | 0.19 |
| Area (acres) | 5.1 | 7.8 | 6.7 | 9.4 | 3.9 | 5.9 |
| Production (kg) | 6,234.2 | 13,053.7 | 5,465.6 | 8,293.9 | 6,852.1 | 15,855.1 |
| Yield (kg/acre) | 1,400.7 | 5,016.5 | 1,044.3 | 6,488.5 | 1,673.7 | 3,471.3 |
| Total holdings | 52,043 | | 17,519 | | 34,524 | |
| N | 1,766 | | 766 | | 1,000 | |
| **Panel F: Beans** | | | | | | |
| Proportion that grew | 0.92 | 0.28 | 0.93 | 0.26 | 0.91 | 0.29 |
| Area (acres) | 3.8 | 6.4 | 4.4 | 5.1 | 3.3 | 7.3 |
| Production (kg) | 2,355.7 | 3,874.4 | 2,568.6 | 3,212.4 | 2,184.6 | 4,328.0 |
| Yield (kg/acre) | 960.1 | 1,531.8 | 672.6 | 404.4 | 1,194.9 | 2,002.3 |
| Total holdings | 40,707 | | 12,435 | | 28,272 | |
| N | 1,715 | | 772 | | 943 | |
| **Panel G: Cabbages** | | | | | | |
| Proportion that grew | 0.83 | 0.37 | 0.67 | 0.47 | 0.96 | 0.20 |
| Area (acres) | 1.5 | 4.3 | 1.1 | 2.1 | 1.7 | 5.4 |
| Production (kg) | 2,694.6 | 18,237.5 | 1,225.0 | 5,372.1 | 3,876.2 | 23,957.4 |
| Yield (kg/acre) | 1,637.1 | 1,820.4 | 858.5 | 685.3 | 2,076.5 | 2,094.1 |
| Total holdings | 27,542 | | 3,555 | | 23,987 | |
| N | 1,555 | | 561 | | 994 | |
| **Panel H: Cauliflower** | | | | | | |
| Proportion that grew | 0.69 | 0.46 | 0.45 | 0.50 | 0.89 | 0.32 |
| Area (acres) | 0.7 | 2.1 | 0.4 | 0.9 | 1.0 | 2.6 |
| Production (kg) | 741.2 | 2,969.1 | 241.8 | 564.3 | 1,142.8 | 3,910.5 |
| Yield (kg/acre) | 1,248.4 | 1,205.1 | 722.7 | 433.0 | 1,462.3 | 1,345.1 |
| Total holdings | 15,845 | | 1,329 | | 14,516 | |
| N | 1,293 | | 374 | | 919 | |
| **Panel I: Potato** | | | | | | |
| Proportion that grew | 0.95 | 0.23 | 0.92 | 0.28 | 0.97 | 0.18 |

| | *Chiwog level (pooled)* | | *Chiwog level (2009)* | | *Chiwog level (2019)* | |
|---|---|---|---|---|---|---|
| | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** | **Mean** | **Std. dev.** |
| Area (acres) | 10.3 | 18.7 | 9.7 | 15.9 | 10.7 | 20.7 |
| Production (kg) | 40,594.3 | 122,725.1 | 38,181.8 | 76,035.3 | 42,534.1 | 150,090.8 |
| Yield (kg/acre) | 2,778.9 | 1,853.1 | 3,345.0 | 1,032.4 | 2,347.6 | 2,193.2 |
| Total holdings | 49,915 | | 15,597 | | 34,318 | |
| N | 1,774 | | 767 | | 1,007 | |
| **Panel J: Ginger** | | | | | | |
| Proportion that grew | 0.60 | 0.49 | 0.58 | 0.49 | 0.62 | 0.48 |
| Area (acres) | 1.9 | 6.1 | 1.6 | 3.7 | 2.1 | 7.5 |
| Production (kg) | 2,811.2 | 15,045.3 | 1,218.4 | 3,242.6 | 4,091.8 | 19,909.8 |
| Yield (kg/acre) | 1,156.4 | 1,038.3 | 798.8 | 687.3 | 1,423.7 | 1,168.3 |
| Total holdings | 16,023 | | 4,536 | | 11,487 | |
| N | 1,121 | | 480 | | 641 | |
| **Panel K: Cardamom** | | | | | | |
| Proportion that grew | 0.50 | 0.50 | 0.21 | 0.41 | 0.74 | 0.44 |
| Area (acres) | 12.2 | 38.3 | 1.9 | 11.7 | 20.6 | 48.8 |
| Production (kg) | 1,011.9 | 3,175.9 | 428.3 | 1,989.6 | 1,481.2 | 3,811.5 |
| Yield (kg/acre) | 162.1 | 296.7 | 541.8 | 482.6 | 76.3 | 125.0 |
| Total holdings | 24,291 | | 1,134 | | 23,157 | |
| N | 866 | | 173 | | 693 | |
| **Panel L: Mandarin** | | | | | | |
| Proportion that grew | 0.74 | 0.44 | 0.73 | 0.45 | 0.75 | 0.44 |
| Area (acres) | 788.0 | 2,310.7 | 729.6 | 2,066.7 | 834.9 | 2,489.6 |
| Production (kg) | 24,076.3 | 72,529.0 | 22,327.1 | 64,360.2 | 25,482.7 | 78,485.4 |
| Yield (kg/acre) | 33.0 | 46.0 | 33.1 | 29.0 | 33.0 | 55.8 |
| Total holdings | 35,494 | | 13,336 | | 22,158 | |
| N | 1,328 | | 580 | | 748 | |

*Table A 2: Mean no. of times each crop was planted (holding level, 2019)*

| Crop | Mean no. of times crop was planted |
|---|---|
| Paddy (Irrigated) | 1.00 |
| Maize | 1.14 |
| Spinaches and sags | 1.17 |
| Radish | 1.03 |
| Chili | 1.12 |
| Beans | 1.13 |
| Cabbages | 1.07 |
| Cauliflower | 1.07 |
| Potato | 1.02 |
| Ginger | 1.05 |

Note: The indicator was only available for 2019. No data was available for mandarin and cardamon.

*Table A 3:Area, production and yields by old and new Chiwogs*

| | Mean: Common Chiwogs (2009) | Mean: Common Chiwogs (2009) | Change (%) | Mean: New Chiwogs (in 2019 but not in 2009) | Mean: Dropped Chiwogs (in 2009 but not in 2019) |
|---|---|---|---|---|---|
| **Panel A: Paddy (Irrigated)** | | | | | |
| Area | 41.19 | 41.96 | 1.9% | 40.60 | 8.16 |
| Prod | 68,884.14 | 49,189.61 | -28.6% | 33,236.01 | 12,645.01 |
| Yield | 1,590.75 | 1,139.35 | -28.4% | 856.25 | 1,564.58 |
| **Panel B: Maize** | | | | | |
| Area | 51.61 | 42.36 | -17.9% | 37.67 | 2.35 |
| Prod | 50,617.82 | 40,025.33 | -20.9% | 20,496.68 | 1,763.02 |
| Yield | 941.34 | 978.51 | 3.9% | 613.69 | 867.42 |

*Table A 4: District wise means for area, production and yields*

| Region | District | Mean area (2009) | Mean area (2019) | Change (%) | Mean production (2009) | Mean production (2019) | Change (%) | Mean yield (2009) | Mean yield (2019) | Change (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Panel A: Paddy (Irrigated)** | | | | | | | | | | |
| Central | Bumthang | 3.5 | 8.1 | 134% | 4,320.9 | 9,167.3 | 112% | 1,270.3 | 1,141.2 | -10% |
| Central | Gasa | 20.7 | 16.8 | -19% | 33,776.0 | 20,452.9 | -39% | 1,505.4 | 1,072.9 | -29% |
| Central | Punakha | 77.5 | 79.3 | 2% | 148,668.9 | 126,933.3 | -15% | 1,907.8 | 1,608.0 | -16% |
| Central | Trongsa | 42.3 | 52.4 | 24% | 67,501.1 | 45,844.7 | -32% | 1,578.9 | 843.9 | -47% |
| Central | Wangdue Phodrang | 55.9 | 57.4 | 3% | 99,712.5 | 70,808.5 | -29% | 1,734.0 | 1,252.1 | -28% |
| East | Lhuentse | 31.1 | 33.5 | 8% | 49,606.3 | 47,767.0 | -4% | 1,628.6 | 1,479.9 | -9% |
| East | Mongar | 24.1 | 14.9 | -38% | 35,264.5 | 13,111.3 | -63% | 1,484.3 | 876.3 | -41% |
| East | Pema Gatshel | 6.8 | 6.9 | 2% | 10,174.7 | 4,699.7 | -54% | 1,420.2 | 701.8 | -51% |
| East | Trashigang | 31.9 | 26.3 | -17% | 48,616.5 | 39,946.4 | -18% | 1,498.2 | 1,622.1 | 8% |
| East | Trashi Yangtse | 31.3 | 19.2 | -39% | 43,597.5 | 25,050.6 | -43% | 1,363.9 | 1,284.8 | -6% |
| South-East | Samdrup Jongkhar | 47.7 | 54.3 | 14% | 77,445.3 | 55,528.4 | -28% | 1,553.2 | 958.2 | -38% |
| South-East | Sarpang | 38.7 | 53.2 | 38% | 63,595.7 | 41,375.7 | -35% | 1,728.5 | 803.3 | -54% |
| South-East | Zhemgang | 26.9 | 26.1 | -3% | 40,191.6 | 17,783.0 | -56% | 1,529.1 | 708.9 | -54% |
| South-West | Chukha | 27.5 | 25.2 | -9% | 38,514.8 | 20,858.3 | -46% | 1,387.5 | 805.7 | -42% |
| South-West | Dagana | 42.3 | 43.5 | 3% | 67,397.1 | 27,779.2 | -59% | 1,635.9 | 654.7 | -60% |
| South-West | Samtse | 30.3 | 59.3 | 96% | 48,165.9 | 39,093.7 | -19% | 1,442.2 | 618.3 | -57% |
| South-West | Tsirang | 50.0 | 25.6 | -49% | 81,284.1 | 15,729.2 | -81% | 1,507.8 | 649.9 | -57% |
| West | Haa | 12.8 | 17.2 | 34% | 19,270.3 | 17,130.8 | -11% | 1,442.0 | 961.5 | -33% |
| West | Paro | 64.6 | 61.7 | -4% | 116,994.7 | 105,307.8 | -10% | 1,733.9 | 1,850.5 | 7% |
| West | Thimphu | 14.6 | 28.9 | 98% | 21,917.7 | 53,725.9 | 145% | 1,539.3 | 1,970.0 | 28% |
| **Panel B: Maize** | | | | | | | | | | |
| Central | Gasa | 0.6 | 1.1 | 99% | 455.5 | 1,231.3 | 170% | 1,084.5 | 708.2 | -35% |
| Central | Punakha | 8.4 | 4.3 | -48% | 7,414.6 | 6,041.4 | -19% | 912.1 | 1,139.4 | 25% |
| Central | Trongsa | 28.9 | 17.6 | -39% | 26,815.9 | 14,247.5 | -47% | 863.4 | 916.0 | 6% |
| Central | Wangdue Phodrang | 6.8 | 4.0 | -41% | 5,998.2 | 3,131.8 | -48% | 919.7 | 909.4 | -1% |
| East | Lhuentse | 40.9 | 35.8 | -12% | 38,499.2 | 43,336.7 | 13% | 934.8 | 1,386.3 | 48% |
| East | Mongar | 68.9 | 81.9 | 19% | 67,895.0 | 93,344.2 | 37% | 967.8 | 1,198.6 | 24% |
| East | Pema Gatshel | 80.0 | 48.7 | -39% | 74,170.8 | 42,959.8 | -42% | 888.2 | 950.0 | 7% |
| East | Trashigang | 58.6 | 47.1 | -20% | 52,037.4 | 69,448.3 | 33% | 865.1 | 1,485.5 | 72% |
| East | Trashi Yangtse | 32.8 | 27.5 | -16% | 25,892.7 | 37,859.0 | 46% | 785.7 | 1,375.7 | 75% |
| South-East | Samdrup Jongkhar | 70.1 | 51.0 | -27% | 68,453.1 | 51,072.0 | -25% | 999.1 | 1,025.0 | 3% |
| South-East | Sarpang | 69.2 | 33.1 | -52% | 74,563.2 | 12,332.2 | -83% | 1,049.7 | 367.2 | -65% |
| South-East | Zhemgang | 73.3 | 56.6 | -23% | 77,185.3 | 46,127.7 | -40% | 1,061.2 | 841.5 | -21% |
| South-West | Chukha | 50.9 | 38.3 | -25% | 52,687.7 | 26,801.9 | -49% | 953.3 | 700.2 | -27% |
| South-West | Dagana | 78.2 | 57.6 | -26% | 83,277.9 | 26,035.4 | -69% | 1,021.9 | 405.9 | -60% |
| South-West | Samtse | 31.6 | 43.6 | 38% | 32,915.4 | 16,979.0 | -48% | 1,056.5 | 405.6 | -62% |
| South-West | Tsirang | 73.3 | 58.0 | -21% | 76,783.3 | 32,249.1 | -58% | 1,007.9 | 564.1 | -44% |
| West | Haa | 14.7 | 20.0 | 36% | 14,969.6 | 12,367.8 | -17% | 963.3 | 1,111.9 | 15% |
| West | Paro | 4.0 | 1.6 | -61% | 2,872.7 | 609.6 | -79% | 735.8 | 804.8 | 9% |
| West | Thimphu | 1.7 | 1.2 | -33% | 1,268.6 | 1,470.9 | 16% | 676.5 | 1,659.5 | 145% |

*Table A 5: Paddy and maize growers by region*

| | | ***Count of holdings*** | | | | | ***Proportion of holdings*** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Region** | **Grew paddy but not maize** | **Grew maize but not paddy** | **Grew both** | **Grew neither** | **Total** | **Grew paddy but not maize** | **Grew maize but not paddy** | **Grew both** | **Grew neither** | **Total** |
| 2009 | Bhutan | 7,691 | 18,979 | 19,552 | 11,384 | 57,606 | 13% | 33% | 34% | 20% | 100% |
| 2009 | Central | 3,373 | 325 | 1,590 | 3,067 | 8,355 | 40% | 4% | 19% | 37% | 100% |
| 2009 | East | 626 | 9,229 | 6,812 | 1,791 | 18,458 | 3% | 50% | 37% | 10% | 100% |
| 2009 | South-East | 599 | 4,290 | 3,333 | 970 | 9,192 | 7% | 47% | 36% | 11% | 100% |
| 2009 | South-West | 1,101 | 4,714 | 7,571 | 2,959 | 16,345 | 7% | 29% | 46% | 18% | 100% |
| 2009 | West | 1,992 | 421 | 246 | 2,597 | 5,256 | 38% | 8% | 5% | 49% | 100% |
| 2019 | Bhutan | 9,112 | 27,478 | 14,905 | 15,129 | 66,624 | 14% | 41% | 22% | 23% | 100% |
| 2019 | Central | 4,172 | 440 | 1,168 | 3,717 | 9,497 | 44% | 5% | 12% | 39% | 100% |
| 2019 | East | 425 | 11,701 | 5,114 | 1,857 | 19,097 | 2% | 61% | 27% | 10% | 100% |
| 2019 | South-East | 1,012 | 5,306 | 2,592 | 1,975 | 10,885 | 9% | 49% | 24% | 18% | 100% |
| 2019 | South-West | 1,482 | 9,571 | 5,944 | 4,051 | 21,048 | 7% | 45% | 28% | 19% | 100% |
| 2019 | West | 2,021 | 460 | 87 | 3,529 | 6,097 | 33% | 8% | 1% | 58% | 100% |

*Table A 6: Correlation among perceived constraints (Chiwog level, pooled)*

**Panel A: Chiwogs that produce Irrigated Paddy**

| | Irrigation problem | Drought | Unproductive land | Shortage of land | Labour shortage | Limited access to market | Excessive rain | Hailstorm / wind | Landslides / soil erosion | Crop damage by wild animals | Crop damage by insects /diseases | Total no. of constraints reported |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation problem | 1.00 | | | | | | | | | | | |
| Drought | 0.05 | 1.00 | | | | | | | | | | |
| Unproductive land | 0.03 | -0.01 | 1.00 | | | | | | | | | |
| Shortage of land | 0.11 | -0.05 | 0.20 | 1.00 | | | | | | | | |
| Labour shortage | -0.05 | -0.09 | 0.03 | 0.01 | 1.00 | | | | | | | |
| Limited access to market | -0.14 | -0.08 | 0.12 | 0.12 | -0.09 | 1.00 | | | | | | |
| Excessive rain | -0.14 | 0.01 | 0.09 | 0.02 | -0.02 | 0.08 | 1.00 | | | | | |
| Hailstorm / wind | -0.23 | -0.02 | -0.03 | -0.13 | -0.06 | 0.02 | 0.23 | 1.00 | | | | |
| Landslides / soil erosion | -0.09 | -0.04 | 0.18 | 0.07 | -0.07 | 0.09 | 0.11 | 0.12 | 1.00 | | | |
| Crop damage by wild animals | -0.15 | -0.08 | -0.03 | -0.23 | -0.08 | 0.04 | 0.02 | 0.11 | 0.06 | 1.00 | | |
| Crop damage by insects /diseases | -0.14 | 0.07 | 0.09 | -0.04 | -0.03 | 0.24 | 0.10 | 0.12 | 0.14 | 0.21 | 1.00 | |
| Total no. of constraints reported | 0.21 | 0.11 | 0.37 | 0.29 | 0.25 | 0.44 | 0.19 | 0.15 | 0.20 | 0.31 | 0.58 | 1.00 |

**Panel B: Chiwogs that produce Maize**

| | Irrigation problem | Drought | Unproductive land | Shortage of land | Labour shortage | Limited access to market | Excessive rain | Hailstorm / wind | Landslides / soil erosion | Crop damage by wild animals | Crop damage by insects /diseases | Total no. of constraints reported |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation problem | 1.00 | | | | | | | | | | | |
| Drought | 0.05 | 1.00 | | | | | | | | | | |
| Unproductive land | 0.06 | 0.01 | 1.00 | | | | | | | | | |
| Shortage of land | 0.13 | -0.01 | 0.24 | 1.00 | | | | | | | | |
| Labour shortage | -0.06 | -0.07 | 0.01 | 0.01 | 1.00 | | | | | | | |

**Panel B: Chiwogs that produce Maize**

| | Irrigation problem | Drought | Unproductive land | Shortage of land | Labour shortage | Limited access to market | Excessive rain | Hailstorm / wind | Landslides / soil erosion | Crop damage by wild animals | Crop damage by insects /diseases | Total no. of constraints reported |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Limited access to market | -0.15 | -0.08 | 0.10 | 0.10 | -0.07 | 1.00 | | | | | | |
| Excessive rain | -0.11 | 0.05 | 0.08 | -0.01 | -0.01 | 0.08 | 1.00 | | | | | |
| Hailstorm / wind | -0.25 | -0.03 | -0.05 | -0.12 | -0.04 | 0.02 | 0.19 | 1.00 | | | | |
| Landslides / soil erosion | -0.08 | -0.03 | 0.19 | 0.14 | -0.07 | 0.08 | 0.09 | 0.06 | 1.00 | | | |
| Crop damage by wild animals | -0.10 | -0.06 | -0.06 | -0.23 | -0.08 | 0.04 | -0.01 | 0.09 | -0.03 | 1.00 | | |
| Crop damage by insects /diseases | -0.10 | 0.07 | 0.10 | -0.01 | -0.02 | 0.21 | 0.11 | 0.12 | 0.12 | 0.15 | 1.00 | |
| Total no. of constraints reported | 0.23 | 0.13 | 0.37 | 0.32 | 0.24 | 0.42 | 0.19 | 0.16 | 0.19 | 0.29 | 0.59 | 1.00 |

*Table A 7: Chiwog-level Panel FE estimation results for all crops (Chiwog and Year FE)*

| Outcome: Yield | (1) Paddy (Irrigated) | (2) Maize | (3) Spinaches and sags | (4) Radish | (5) Chili | (6) Beans | (7) Cabbages | (8) Cauliflower | (9) Potato | (10) Ginger | (11) Cardamom | (12) Mandarin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation problem | -400.1*** | -140.8 | -10.94 | -1,785** | -2,140 | -1,417* | -1,856*** | -339.3 | -713.8** | -426.5 | -7.609 | -9.586 |
| | (133.9) | (131.8) | (305.2) | (694.3) | (1,371) | (757.0) | (713.3) | (376.3) | (313.7) | (315.1) | (150.3) | (9.171) |
| Drought | -252.4 | -606.0*** | -209.1 | -2,645** | -2,861 | -2,004* | -2,811*** | -294.2 | -1,919*** | -440.7 | 208.3 | 18.92 |
| | (202.5) | (186.3) | (346.3) | (1,160) | (2,102) | (1,105) | (1,070) | (481.3) | (458.9) | (346.0) | (184.7) | (16.54) |
| Shortage of land | -561.8*** | -558.1*** | -11.39 | -1,285* | -2,296** | -1,782*** | -1,584** | -1,309*** | -1,395*** | -897.2* | 98.64 | -5.526 |
| | (170.9) | (202.2) | (456.4) | (773.4) | (1,082) | (569.9) | (675.2) | (497.4) | (396.1) | (532.3) | (190.2) | (12.65) |
| Labour shortage | -408.9*** | -83.23 | -212.4 | -1,764* | -1,551 | -1,149 | -1,797** | -584.6 | -541.7* | -422.5 | 61.67 | -7.373 |
| | (144.8) | (149.6) | (317.3) | (927.0) | (1,413) | (766.1) | (783.9) | (422.5) | (327.0) | (305.4) | (184.6) | (9.264) |
| Limited access to market | -131.1 | 56.14 | -175.1 | -700.8 | -2,238* | -856.1 | -725.1 | -670.8 | 200.1 | -507.2 | -182.1 | -7.988 |
| | (163.2) | (145.8) | (323.1) | (726.7) | (1,345) | (524.5) | (646.4) | (528.5) | (320.7) | (320.6) | (155.8) | (9.596) |
| Unproductive land | -41.45 | 317.3* | 250.9 | -1,249 | -1,142 | -785.0 | -1,076 | 42.78 | 129.4 | -295.0 | -512.7** | -0.365 |
| | (203.3) | (180.0) | (491.1) | (1,120) | (1,611) | (856.3) | (928.0) | (605.8) | (470.2) | (513.7) | (250.8) | (13.47) |
| Excessive rain | 49.01 | -254.7 | -844.6 | -3,078* | -2,234** | -1,938*** | -4,375** | -1,500** | -421.7 | -592.8 | 720.8* | -28.98 |
| | (365.6) | (367.8) | (672.8) | (1,838) | (895.9) | (749.5) | (2,217) | (689.1) | (1,080) | (880.4) | (417.3) | (24.35) |
| Hailstorm / wind | 272.2 | -270.2* | 225.2 | -156.1 | -1,334 | -666.5** | -914.4 | -368.4 | -316.6 | -1,171*** | 341.5 | 3.213 |
| | (343.9) | (148.0) | (324.6) | (1,133) | (1,320) | (274.6) | (572.5) | (453.6) | (303.8) | (329.3) | (222.2) | (10.60) |
| Landslides / soil erosion | 446.7 | 276.1 | -235.4 | 408.8 | -3,808 | -88.97 | -459.7 | -1,179 | 1,253 | 398.1 | -403.8 | 20.78 |
| | (338.0) | (244.6) | (596.2) | (1,341) | (3,348) | (732.2) | (1,067) | (1,044) | (843.9) | (750.1) | (307.2) | (35.62) |
| Crop damage by wild animals | -528.4*** | -357.6** | -633.5* | -1,430** | -257.3 | -1,290** | -2,076*** | -1,270*** | -1,440*** | -740.4** | -138.7 | 3.441 |
| | (190.3) | (147.1) | (339.3) | (686.5) | (1,526) | (586.4) | (585.3) | (453.0) | (434.2) | (323.6) | (156.5) | (9.672) |
| Crop damage by insects /diseases | -483.2*** | -404.4*** | -271.4 | -1,967* | -1,053 | -793.9 | -1,925** | -534.5 | -648.3** | -454.6* | -56.55 | 3.753 |
| | (149.8) | (143.8) | (281.6) | (1,022) | (1,969) | (877.1) | (789.7) | (408.1) | (280.2) | (264.4) | (175.9) | (8.775) |
| Total no. of constraints reported | 335.5*** | 153.2 | 91.53 | 1,249* | 1,451 | 985.0 | 1,361** | 574.3* | 645.9*** | 550.2** | -51.90 | 4.708 |
| | (110.3) | (111.8) | (254.7) | (700.5) | (1,149) | (635.2) | (611.1) | (320.9) | (201.4) | (237.3) | (115.0) | (7.605) |
| Constant | 1,686*** | 1,140*** | 1,122*** | 1,452*** | 708.8* | 976.0*** | 1,824*** | 1,130*** | 3,539*** | 716.2*** | 885.9*** | 23.30*** |
| | (145.9) | (102.8) | (346.1) | (377.5) | (387.6) | (197.8) | (393.7) | (339.1) | (272.4) | (237.5) | (195.9) | (7.369) |

| Outcome: Yield | (1) Paddy (Irrigated) | (2) Maize | (3) Spinaches and sags | (4) Radish | (5) Chili | (6) Beans | (7) Cabbages | (8) Cauliflower | (9) Potato | (10) Ginger | (11) Cardamom | (12) Mandarin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observations | 1,082 | 1,334 | 1,520 | 1,518 | 1,486 | 1,424 | 1,070 | 672 | 1,474 | 754 | 328 | 1,040 |
| R-squared | 0.660 | 0.495 | 0.552 | 0.582 | 0.508 | 0.545 | 0.636 | 0.601 | 0.647 | 0.610 | 0.691 | 0.562 |

Robust standard errors clustered at the chiwog level are given in the parenthesis. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

## *Table A 8: Chiwog-level pooled SFD estimation results for all crops*

| Outcome: Yield | (1) Paddy (Irrigated) | (2) Maize | (3) Spinaches and sags | (4) Radish | (5) Chili | (6) Beans | (7) Cabbages | (8) Cauliflower | (9) Potato | (10) Ginger | (11) Cardamom | (12) Mandarin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation problem | -169.74* | -149.16* | -46.29 | -1726.72** | -2796.57* | -1265.01 | -1528.81** | -532.22 | -544.4* | -370.07 | -31.2 | 8.5 |
| | (100.58) | (87.39) | (221.65) | (709.2) | (1507.15) | (802.23) | (634.24) | (398.36) | (280.95) | (324.82) | (57.25) | (6.82) |
| Drought | -53.86 | -415.07*** | -421.17 | -1185.38* | -3744.63** | -1326.37** | -706.92 | -670.71 | -1209.88*** | -555.13* | -51.79 | 24.29 |
| | (130.2) | (127.13) | (256.82) | (669.69) | (1861.12) | (564.54) | (609.84) | (527.84) | (370.65) | (311.81) | (66.98) | (14.86) |
| Unproductive land | -275.58** | -21.41 | 354.45 | -963.48 | -1811.92 | -825.24 | 123.43 | 590.29 | 33.84 | -632.29* | 43.37 | 6.33 |
| | (133.25) | (94.32) | (290.37) | (663.72) | (1144.09) | (583.19) | (582.4) | (464.35) | (321.19) | (351.55) | (65.82) | (12.6) |
| Shortage of land | -88.26 | -68.58 | -147.84 | -1296.43 | -4247.22* | -1092.96 | -905.42 | .54 | -105.09 | 278.94 | 28.53 | 9.96 |
| | (124.29) | (102.87) | (280.81) | (820.06) | (2177.7) | (711.35) | (639.89) | (438.62) | (368.63) | (397.39) | (79.45) | (10.38) |
| Labour shortage | -124.25 | -38.43 | -500.49 | -790.49 | -1152.76 | -855.39** | -887.16* | -87.66 | -87.93 | -124.65 | -13.87 | 8.18 |
| | (98.1) | (87.26) | (322.07) | (579.27) | (726.82) | (430.24) | (479.23) | (394.32) | (269.62) | (329.11) | (60.05) | (11.54) |
| Limited access to market | -85.43 | -74.84 | -143.66 | -1359.38** | -2861.98* | -907.44 | -919.36 | -380.37 | -75.55 | -322.18 | 10.22 | 24.73** |
| | (107.13) | (94.1) | (216.24) | (672.93) | (1474.54) | (630.75) | (563.51) | (453.03) | (253.31) | (315.02) | (63.4) | (12.14) |
| Excessive rain | -512.46 | 177.01 | 549.57 | -544.73 | -6274.22 | -802.83 | 748.78 | 698.28 | 1863.07** | -258.6 | 132.79 | 5.71 |
| | (330.25) | (162.37) | (457.75) | (1151.65) | (4699.11) | (1062.02) | (1083.99) | (854.5) | (821.47) | (625.02) | (171.66) | (22.43) |
| Hailstorm / wind | 181.13 | -192.59** | -38.86 | -944.51 | -1458.28 | -603.45** | -312.02 | 383.81 | -360 | -615.63** | -38 | 23.68*** |
| | (200.21) | (87.08) | (204.92) | (631.57) | (1054.89) | (267.95) | (456.45) | (397.62) | (253.55) | (299.1) | (56.16) | (8.59) |
| Landslides / soil erosion | -357.81* | -298.99** | 261.24 | -619.13 | -1336.79 | -1452.47* | -1232.82* | -637.89 | -737.12 | -509.37 | -55.08 | 55.89** |
| | (182.7) | (120.91) | (265.17) | (728.99) | (1341.87) | (784.92) | (729.38) | (615.85) | (458.68) | (639.97) | (95.24) | (22.64) |
| Crop damage by wild animals | -149.22 | -196.2** | -328.71 | -1013.96* | -1811.51* | -819.24 | -434.9 | -248.84 | -256.44 | -481.74 | 32.44 | 17.46* |
| | (96.91) | (85.16) | (210.4) | (584.13) | (1080) | (570.76) | (502.48) | (305.4) | (256.91) | (351.12) | (60.14) | (9.02) |
| Crop damage by insects /diseases | -234.61** | -166.63* | 115.2 | -1114.85 | -1035.85 | -1135* | -1038.06* | -145.61 | 85.9 | 3.14 | 5.5 | 3.87 |
| | (100.79) | (88.19) | (227.61) | (682.21) | (1138.31) | (639.44) | (529.94) | (384.75) | (303.05) | (319.15) | (54.7) | (8.59) |
| Total no. of constraints reported | 107.21 | 78.98 | 38.74 | 1370.7** | 2001.03* | 1038.08 | 1090.17* | 270.75 | -2.14 | 262.96 | -19.63 | -12.12* |
| | (80.75) | (74.24) | (204.26) | (660.92) | (1164.03) | (661.06) | (564.87) | (362.22) | (222.94) | (266.29) | (54.4) | (7.05) |
| Constant | -9.97 | 8.17 | 10.16 | 50.86 | -1.23 | 23.76 | -2.04 | 12.1 | -11.6 | -22.38 | -.98 | -1.36 |
| | (17.14) | (11.71) | (48.26) | (77.29) | (188.89) | (52.6) | (57.82) | (44.19) | (45.74) | (41.18) | (8.14) | (1.71) |

| Outcome: Yield | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Paddy (Irrigated) | Maize | Spinaches and sags | Radish | Chili | Beans | Cabbages | Cauliflower | Potato | Ginger | Cardamom | Mandarin |
| Observations | 1,163 | 1,400 | 1,595 | 1,587 | 1,574 | 1,506 | 1,289 | 984 | 1,571 | 835 | 749 | 1,094 |
| R-squared | 0.02 | 0.03 | 0.01 | 0.02 | 0.01 | 0.02 | 0.04 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 |

Robust standard errors clustered at the chiwog level are given in the parenthesis. *** p<0.01, ** p<0.05, * p<0.1

*Table A 9: Chiwog-level pooled SFD estimation results for all crops, with year fixed effects*

| Outcome: Yield | (1) Paddy (Irrigated) | (2) Maize | (3) Spinaches and sags | (4) Radish | (5) Chili | (6) Beans | (7) Cabbages | (8) Cauliflower | (9) Potato | (10) Ginger | (11) Cardamom | (12) Mandarin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation problem | -169.45* | -149.08* | -46.3 | -1725.46** | -2796.56* | -1265.51 | -1528.65** | -531.67 | -543.78* | -369.62 | -31.98 | 8.2 |
| | (101.25) | (87.41) | (221.69) | (709.7) | (1507.7) | (803.62) | (634.43) | (398.01) | (281.35) | (324.99) | (57.31) | (6.81) |
| Drought | -53.8 | -414.34*** | -421.61 | -1178.55* | -3744.3** | -1327.78** | -707.02 | -665.47 | -1211.99*** | -554.38* | -53.98 | 23.95 |
| | (130.26) | (127.34) | (256.98) | (669.73) | (1858.46) | (565.7) | (610.06) | (527.81) | (370.65) | (312.37) | (67.3) | (14.81) |
| Unproductive land | -275.16** | -20.9 | 354.35 | -963.59 | -1811.7 | -825.37 | 124.36 | 591.53 | 34.28 | -631.69* | 41.79 | 6.12 |
| | (133.82) | (94.19) | (290.32) | (664.19) | (1145.51) | (583.74) | (582.36) | (464.42) | (321.32) | (351.06) | (65.53) | (12.58) |
| Shortage of land | -88.08 | -68.65 | -147.71 | -1295.5 | -4247.44* | -1093.47 | -906.08 | 12.13 | -105.03 | 279.6 | 28.25 | 9.85 |
| | (124.54) | (102.95) | (280.77) | (820.58) | (2178.1) | (712.32) | (640.17) | (439.03) | (368.9) | (397.63) | (79.25) | (10.33) |
| Labour shortage | -123.78 | -38.09 | -500.56 | -789.8 | -1152.64 | -856.06** | -887.56* | -84.75 | -88.51 | -123.89 | -14.33 | 7.81 |
| | (98.52) | (87.35) | (322.49) | (579.17) | (727.08) | (430.49) | (479.19) | (394.03) | (269.42) | (329.48) | (60.19) | (11.51) |
| Limited access to market | -85.09 | -74.61 | -143.78 | -1357.9** | -2861.92* | -907.85 | -919.01 | -375.86 | -74.43 | -321.31 | 10.01 | 24.4** |
| | (107.45) | (94.22) | (216.01) | (673.22) | (1474.93) | (631.51) | (563.7) | (452.65) | (253.6) | (315.47) | (63.35) | (12.12) |
| Excessive rain | -511.88 | 177.01 | 550.25 | -546.72 | -6275.28 | -803.29 | 746.88 | 701.32 | 1864.93** | -259.56 | 137.66 | 5.81 |
| | (329.88) | (162.33) | (458.78) | (1153.51) | (4718.94) | (1062.85) | (1085.16) | (853.99) | (821.26) | (625.52) | (171.16) | (22.27) |
| Hailstorm / wind | 181.75 | -192.65** | -38.67 | -946.16 | -1458.57 | -603.82** | -312.06 | 390.33 | -358.37 | -614.7** | -39.45 | 23.37*** |
| | (201.14) | (87.15) | (205.17) | (631.99) | (1055.26) | (269.1) | (456.62) | (397.48) | (253.4) | (299.49) | (55.69) | (8.55) |
| Landslides / soil erosion | -357.31* | -297.17** | 260.54 | -609.64 | -1335.25 | -1453.24* | -1234.58* | -626.02 | -743.29 | -506.29 | -53.35 | 55.24** |
| | (182.98) | (120.85) | (264.62) | (730.94) | (1353.71) | (786.67) | (730.69) | (619.05) | (461.75) | (638.76) | (94.14) | (22.59) |
| Crop damage by wild animals | -149.14 | -195.91** | -328.51 | -1014.57* | -1811.64* | -819.65 | -434.82 | -249.12 | -255.47 | -481.09 | 32.92 | 17.16* |
| | (97.11) | (85.11) | (209.91) | (584.35) | (1080.54) | (571.46) | (502.64) | (305.68) | (256.91) | (350.71) | (60.05) | (9.03) |
| Crop damage by insects /diseases | -234.31** | -166.24* | 115.39 | -1114.82 | -1035.73 | -1135.57* | -1038.17* | -143.01 | 85.31 | 3.38 | 4.97 | 3.67 |
| | (101.31) | (88.27) | (228.01) | (682.76) | (1139.98) | (640.21) | (530.08) | (384.51) | (302.8) | (319.3) | (54.59) | (8.56) |
| Total no. of constraints reported | 106.94 | 78.7 | 38.76 | 1369.6** | 2001.02* | 1038.63 | 1090.14* | 268.95 | -2.4 | 262.06 | -18.86 | -11.85* |
| | (81.12) | (74.23) | (204.24) | (661.43) | (1164.43) | (661.94) | (565.08) | (361.85) | (223.21) | (266.65) | (54.25) | (7.01) |
| Constant | -12.48 | .99 | 14.82 | 3.86 | -9.87 | 29.51 | 4.96 | -58.99 | 15.89 | -29.67 | 15.16 | .61 |
| | (22.41) | (11.09) | (18.48) | (31.88) | (413.74) | (25.05) | (43.95) | (37.65) | (46.5) | (51.95) | (59.55) | (1.82) |

| Outcome: Yield | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Paddy (Irrigated) | Maize | Spinaches and sags | Radish | Chili | Beans | Cabbages | Cauliflower | Potato | Ginger | Cardamom | Mandarin |
| Observations | 1163 | 1400 | 1595 | 1587 | 1574 | 1506 | 1289 | 984 | 1571 | 835 | 749 | 1094 |
| R-squared | 0.02 | 0.03 | 0.01 | 0.02 | 0.01 | 0.02 | 0.04 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 |
| Year fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Robust standard errors clustered at the chiwog level are given in the parenthesis. *** p<0.01, ** p<0.05, * p<0.1

*Table A 10: Holding level SFD estimation results for all crops (2019 only)*

| Outcome: Yield | (1)<br>Paddy (Irrigated) | (2)<br>Maize | (3)<br>Spinaches and sags | (4)<br>Radish | (5)<br>Chili | (6)<br>Beans | (7)<br>Cabbages | (8)<br>Cauliflowe r | (9)<br>Potato | (10)<br>Ginger | (11)<br>Cardamom | (12)<br>Mandarin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation problem | -48.22** | 10.02 | -30.5 | 197.93** | -77.74 | 49.01 | 287** | 119.4 | -131.58 | 48.46 | -9.98 | 2.68 |
| | (24.33) | (24.97) | (66.77) | (88.93) | (58.34) | (51.21) | (133.43) | (112.98) | (137.64) | (159.98) | (8.12) | (2.44) |
| Drought | 104.3** | -185.89*** | -332.83*** | 36.9 | 166.6 | 82.83 | 379.19 | 205.41 | 96.28 | 407.97 | -34.16*** | 15.55*** |
| | (44.65) | (32.7) | (113.81) | (194.23) | (130.1) | (110.12) | (329.36) | (265.2) | (171.2) | (260.88) | (11.04) | (5.5) |
| Unproductive land | -23.7 | 57.02** | -108.39 | 121.87 | -95.61 | -115.58 | 206.44 | -116.69 | -45.26 | -145.96 | -15.98 | -.12 |
| | (41.85) | (28.97) | (93.24) | (127.94) | (86.91) | (72.98) | (160.16) | (122.99) | (122.51) | (180.37) | (11.96) | (3.62) |
| Shortage of land | 15.48 | 31.26 | -257.28*** | -284.8** | -218.56*** | -53.2 | -42.32 | -106.93 | 11.86 | 52.82 | 15.38* | -8.24*** |
| | (29.78) | (22.89) | (74.09) | (111.25) | (66.98) | (61.15) | (149.2) | (137.97) | (94.73) | (177.5) | (8.36) | (3.14) |
| Labour shortage | 17.81 | -15.19 | -212.12*** | 67.6 | -56.95 | -51.52 | -21.81 | 31.24 | 32.57 | 108.05 | -13.61 | .07 |
| | (22.68) | (21.27) | (69.64) | (94.73) | (61.58) | (48.17) | (135.52) | (103.34) | (77.47) | (164.72) | (8.37) | (2.43) |
| Limited access to market | 75.07 | 31.73 | -11.28 | 359.8*** | 173.37** | -95.31 | 336.97* | 293.21** | 220.14 | 3.76 | 1.17 | -5.66* |
| | (47.55) | (27.49) | (86.13) | (118.54) | (74.85) | (65.51) | (199.09) | (146.54) | (141.51) | (219.49) | (9.33) | (3.43) |
| Excessive rain | 53.4 | 128.61* | 114.97 | -.85 | -54.4 | -74.93 | 393.7 | 7.03 | 92.5 | -471.92 | -30.41 | -10.14 |
| | (56.34) | (72.86) | (134.79) | (146.92) | (100.24) | (86.44) | (296.06) | (175.33) | (225) | (291.04) | (22.33) | (8.57) |
| Hailstorm / wind | -59.08 | -48.77 | -47.42 | 150.89 | 69.84 | 114.49 | 160.1 | -52.49 | 466.09*** | -51.56 | -5.03 | 10.57** |
| | (48.64) | (35.76) | (93.35) | (133.85) | (93.15) | (69.78) | (171.66) | (177.05) | (141.6) | (191.57) | (10.56) | (4.54) |
| Landslides / soil erosion | 53.7 | -55.99 | 311.59 | 541.32** | -47.05 | -107.57 | -329.29 | -208.96 | 98.15 | -201.84 | -1.79 | -3.34 |
| | (48.13) | (37.05) | (215.01) | (229.26) | (127.71) | (119.73) | (246.38) | (227.91) | (138.42) | (219.3) | (14.05) | (7.55) |
| Crop damage by wild animals | -29.08 | -75.98*** | -124.99* | -178.76* | -107.17* | -136.61*** | -319.25** | -174.72 | -140.6 | -279.79 | -20.16** | -3.68 |
| | (23.46) | (23.12) | (68.73) | (103.63) | (59.1) | (48.7) | (133.3) | (116.24) | (131.8) | (176.09) | (9.31) | (2.78) |
| Crop damage by insects /diseases | 10.85 | -54.01** | -33.2 | 35.44 | -70.1 | -25.75 | 231.67 | 163.99 | -99.39 | -27.85 | -8.93 | 6.79*** |
| | (23.7) | (25.51) | (77.45) | (100.32) | (69.22) | (47.87) | (149.41) | (119.4) | (84.58) | (185.99) | (7.77) | (2.31) |
| Total no. of constraints reported | -4.49 | 7.21 | 199.59*** | 113.74 | 88.18* | 75.74* | -64.62 | -41.98 | -153.36* | 59.79 | -4.97 | .66 |
| | (20.3) | (19.1) | (57.9) | (79.39) | (51.78) | (41.35) | (113.41) | (98.34) | (81.22) | (151.17) | (6.99) | (2.07) |
| Constant | -.28 | -1.74 | -7.03 | 6.66 | 1.79 | -6.77 | 36.02 | -50.38 | .4 | -5.4 | -.52 | .55 |
| | (9.76) | (9.66) | (23.15) | (36.95) | (20.65) | (17.15) | (47.48) | (40.95) | (43.48) | (69.54) | (2.48) | (1.1) |

| Outcome: Yield | (1)<br>Paddy (Irrigated) | (2)<br>Maize | (3)<br>Spinaches and sags | (4)<br>Radish | (5)<br>Chili | (6)<br>Beans | (7)<br>Cabbages | (8)<br>Cauliflowe r | (9)<br>Potato | (10)<br>Ginger | (11)<br>Cardamom | (12)<br>Mandarin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observations | 12,826 | 29,161 | 20,183 | 14,837 | 18,473 | 14,033 | 9,331 | 4,110 | 19,104 | 4,232 | 13,444 | 7,118 |
| R-squared | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |

Robust standard errors are given in the parentheses. *** p<0.01, ** p<0.05, * p<0.1

*Table A 11:Holding level estimations for irrigated paddy, by region (2019 only)*

| Outcome: Yield | (1)<br>Central | (2)<br>East | (3)<br>South-East | (4)<br>South-West | (5)<br>West |
|---|---|---|---|---|---|
| Irrigation problem | -12.59 | 4.85 | 4.05 | -68.21 | -148.57 |
| | (36.56) | (75.34) | (34.16) | (46.09) | (113.14) |
| Drought | 39.63 | 296.5*** | -13.74 | 28.33 | -142.39 |
| | (75.84) | (109.27) | (64.1) | (49.36) | (146.23) |
| Unproductive land | -21.17 | -64.67 | 16.76 | 21.21 | -108.54 |
| | (80.81) | (102.76) | (85.09) | (62.94) | (126.27) |
| Shortage of land | 66.7 | -166.05** | 99.54* | 36.71 | 81.78 |
| | (53.18) | (72.64) | (56.94) | (58.12) | (105.03) |
| Labour shortage | 68.56* | 55.23 | 17.13 | -9.38 | -7.98 |
| | (40.51) | (63.44) | (38.3) | (36.98) | (91.37) |
| Limited access to market | 41.98 | 144.21 | 28.24 | 82.18 | -143.17 |
| | (84.02) | (99.81) | (65.58) | (92.35) | (143.44) |
| Excessive rain | 379.28*** | 88.34 | -5.2 | -184.06* | 16.63 |
| | (137.13) | (129.01) | (73.7) | (98.73) | (137.18) |
| Hailstorm / wind | -3.19 | 41.21 | -38.24 | -124.05** | 176.05 |
| | (75.62) | (98.44) | (72.84) | (59.82) | (158.64) |
| Landslides / soil erosion | 181.6 | 53.94 | 106.43 | 52.89 | 170.46 |
| | (138.16) | (91.93) | (107.3) | (67.05) | (331.8) |
| Crop damage by wild animals | -7.68 | 12.41 | -31.11 | 1.35 | -122.47 |
| | (42.81) | (65.31) | (44.27) | (45.96) | (87.94) |
| Crop damage by insects /diseases | 50.98 | 82.06 | 1.96 | -71.43 | -97.02 |
| | (42.83) | (60.76) | (37.28) | (43.65) | (99.44) |
| Total no. of constraints reported | -38.54 | -85.72 | 50.2* | 29.16 | 50 |
| | (35.94) | (55.37) | (28.59) | (43.24) | (74.52) |
| Constant | -4.43 | 10.71 | -3.29 | -12.87 | 11.34 |
| | (18.36) | (24.29) | (15.55) | (16) | (44.05) |
| Observations | 3,424 | 2,948 | 1,897 | 3,459 | 1,149 |
| R-squared | 0.003 | 0.008 | 0.012 | 0.006 | 0.007 |

Robust standard errors are given in the parentheses.
*** p<0.01, ** p<0.05, * p<0.1

*Table A 12: Holding level estimations for maize, by region (2019 only)*

| Outcome: Yield | (1)<br>Central | (2)<br>East | (3)<br>South-East | (4)<br>South-West | (5)<br>West |
|---|---|---|---|---|---|
| Irrigation problem | -12.44 | 107.05** | -5.26 | -32.8 | -7.35 |
| | (63.75) | (44.52) | (44.71) | (32.71) | (191.6) |
| Drought | 332.42 | -181.43*** | 33.46 | -119.24*** | -265.17 |
| | (237.28) | (60.9) | (66.9) | (36.52) | (337.24) |
| Unproductive land | 25.35 | 257.31*** | 26.07 | -83.08*** | 344.8 |
| | (141.02) | (70.06) | (62.66) | (27.29) | (576.11) |
| Shortage of land | 33.21 | -13.72 | -20.66 | 13.15 | 417.18 |
| | (97.49) | (54.53) | (55.4) | (22.46) | (255.05) |
| Labour shortage | 66.37 | 27.21 | -75.31* | -19.8 | 182.4 |
| | (82.49) | (39.26) | (44.73) | (27.22) | (230.05) |
| Limited access to market | -541.06 | 86.3 | 41.83 | -15.59 | 103.77 |
| | (363.82) | (53.02) | (65.55) | (30.09) | (245) |
| Excessive rain | 6.46 | 364.43* | 1.72 | -99.6** | -32.86 |
| | (265.32) | (188.04) | (67.89) | (42.76) | (473.14) |
| Hailstorm / wind | -70.37 | -30.07 | -24.91 | -47.64 | 2628.4* |
| | (111.33) | (56.2) | (52.86) | (30.14) | (1344.06) |
| Landslides / soil erosion | 134.18 | 29.09 | -85.96 | -69.66 | 716.7 |
| | (156.26) | (72.47) | (97.42) | (46.28) | (1015.5) |
| Crop damage by wild animals | -91.44 | -35.14 | -175.57*** | -73.26** | -83.3 |
| | (77.15) | (41.61) | (50.6) | (28.67) | (222.01) |
| Crop damage by insects /diseases | -61.89 | 47.82 | 57.17 | -174.39*** | 157.21 |
| | (82.08) | (38.8) | (47.51) | (41.46) | (301.86) |
| Total no. of constraints reported | -62.49 | -68.42* | 78.12* | 46.09** | -90.58 |
| | (58.73) | (35.4) | (42.15) | (22.31) | (203.89) |
| Constant | -2.92 | -2.18 | .65 | -14.17 | -76.04 |
| | (39.69) | (14.7) | (16.14) | (17.44) | (97.27) |
| Observations | 769 | 12,878 | 4,541 | 10,681 | 322 |
| R-squared | 0.03 | 0.01 | 0.01 | 0.00 | 0.07 |

Robust standard errors are given in the parentheses.
*** p<0.01, ** p<0.05, * p<0.1

*Table A 13: Chiwog level estimation for irrigated paddy and maize with farm size (SFD)*

| Outcome: Yield | (1)<br>Paddy (Irrigated) | (2)<br>Maize |
|---|---|---|
| Irrigation problem | -155.71 | -102.69 |
| | (153.34) | (101.06) |
| Drought | -117.1 | -689.1*** |
| | (338.87) | (237.18) |
| Total land owned (acres) | -7.6 | 7.79 |
| | (19.74) | (8.88) |
| Irrigation problem X land owned (acres) | -4.73 | -12.12 |
| | (30.21) | (18.33) |
| Drought X land owned (acres) | 18.41 | 80.65 |
| | (83.31) | (54.3) |
| Unproductive land | -274.39** | -29.45 |
| | (132.79) | (94.06) |
| Shortage of land | -109.19 | -51.5 |
| | (125.15) | (104.38) |
| Labour shortage | -122.93 | -43.01 |
| | (98.67) | (87.62) |
| Limited access to market | -79.19 | -76.01 |
| | (106.92) | (93.61) |
| Excessive rain | -520.18 | 163.98 |
| | (329.71) | (163.6) |
| Hailstorm / wind | 183.91 | -195.38** |
| | (200.78) | (87.83) |
| Landslides / soil erosion | -351.71* | -294.84** |
| | (184.15) | (121.12) |
| Crop damage by wild animals | -151.15 | -201.29** |
| | (97.3) | (85.59) |
| Crop damage by insects /diseases | -234.64** | -169.75* |
| | (101.51) | (88.56) |
| Total no. of constraints reported | 108.85 | 79.49 |
| | (81.49) | (74.53) |
| Constant | -12.8 | .78 |
| | (22.44) | (11.05) |
| Observations | 1,163 | 1,400 |
| R-squared | 0.02 | 0.03 |
| Year fixed effects | Yes | Yes |

Robust standard errors clustered at the chiwog level are given in the parenthesis. *** p<0.01, ** p<0.05, * p<0.1

*Table A 14: Method of irrigation among holdings that use irrigation (2019)*

| Method of irrigation | No. of holdings | % |
|---|---|---|
| Surface | 28,557 | 89.1% |
| Sprinkler | 2,722 | 8.5% |
| Localized (including drip, micro, bubble) | 755 | 2.4% |