Abstract

Extreme weather events have occurred more frequently because of global climate change. For farmers, diversification, including crop and income diversification, is one of the most effective strategies to improve rural livelihoods by managing risk and coping with weather shocks. We investigate the empirical linkages among weather shocks, livelihood diversification, and household food security, exploiting three waves of nationally representative rural household panel data merged with granular weather data in Bangladesh. Using instrumental variable methods to control for the possible endogeneity of livelihood diversification decisions, we find that weather shocks are significant drivers of crop and income diversification. Moreover, both crop and income diversification are found to impact per capita food expenditure, while their effects on household dietary diversity are not robust. In particular, the distributional effects of income diversification are uniformly positive and significant for all quantiles of a per capita food expenditure distribution but are more sizable for the richest households. The findings, therefore, highlight the unequal effect of livelihood diversification within the context of rural South Asia, suggesting the need for diversification interventions targeting rural low-income groups with the goal of improving socioeconomic status, institutional conditions, and infrastructure.

1. Introduction

Extreme climate events have occurred much more frequently as a result of global climate change. From the long-term perspective, the potential impact of climate change on agricultural production, yield, and productivity presents an additional strain on the global food system (Hossain et al., 2018; Miller et al., 2021). Smallholder farmers are particularly vulnerable to weather shocks owing to their high dependence on agriculture for their livelihood, chronic food insecurity, physical isolation, and lack of access to formal safety nets (Chuang, 2019), which as a result leads to unstable welfare (Carpena, 2019). From the short-term perspective, weather shocks are typical examples of production risk factors that produce adverse effects on agricultural yield and food security (Chavas et al., 2022). For developing countries, in addition to the negative consequence of weather shocks on food security due to shortages in food production (Lascano Galarza, 2020), weather shocks can also impact food security negatively by inducing food price variability in local food markets (Kubik and May, 2019; Dietrich and Schmerzeck, 2019). Adapting to intense weather shocks is deemed imperative to sustain farmers' livelihoods and food security in these countries.

Livelihood diversification, which is defined as the process by which rural families construct a diverse portfolio of activities and social support capabilities in their struggle to survive and improve their standards of living (Ellis, 1998), is one of the most remarkable characteristics of rural livelihoods (Gautam and Andersen, 2016). Diversification is a viable strategy to manage production risks from weather shocks (Chavas et al., 2022; Lascano Galarza, 2020). Diversification of on-farm production systems and livelihood-supporting sources can help to mitigate the risk of climate-induced production and market uncertainty (Asfaw et al., 2019). Furthermore, through both subsistence- and income-generating pathways, diversification of agricultural production systems may improve dietary quality and generate environmental benefits. Therefore, diversification in its various forms is an important strategy for improving diet and nutritional outcomes in low- and middle-income countries (Jones, 2017), incentivizing households to diversify (Chavas and Di Falco, 2012).

In this article, we study how farmers respond to weather shocks through livelihood diversification and to what extent this diversification strategy improves household food security in Bangladesh. To this end, we make use of three waves of a nationally representative rural household survey in Bangladesh, to which is matched with geo-referenced historical weather data. In addition to the identification of its effect on food security, we also investigate whether there are any heterogeneous impacts of livelihood diversification across the distribution of per capita food expenditure.

The contributions of the present study are threefold. First, in Bangladesh, households with small farm sizes dominate the agricultural sector (Moniruzzaman, 2015), which suggests that the livelihood of many people in the country is vulnerable to weather shocks. Significant progress in reducing poverty and improving malnutrition in the country has been made over the past two decades, yet many indicators of food security and malnutrition remain high (Islam et al., 2018). Bangladesh is also one of the most vulnerable countries to climate-related risks, and it is disaster prone because of its geophysical setting and projected future changes in climate (Sarker et al., 2020). Farm and income diversification are crucial under the threat of climate change for poverty reduction and food security improvement in Bangladesh. However, attempts to investigate the impact of livelihood diversification on household food security while controlling for weather shocks have been sparse. Our study adds to the slim body of literature on the effects of weather shocks on livelihood diversification and food security by providing empirical evidence for a disaster-prone country such as Bangladesh. Our second contribution lies in the methodological ground and the use of a research population from a South Asian country. This study uses three waves of nationally rural representative panel data that are combined with historical weather data in Bangladesh. Most of the earlier studies used cross-sectional data in which controlling for endogeneity is tricky. Here, we use three rounds of panel data and panel econometrics to control the drawbacks of cross-sectional data. Moreover, to the best of our knowledge, a number of studies have assessed the linkages between climate shock, livelihood diversification, and food security in African settings (e.g., Asfaw et al., 2018, 2019; Olale and Henson, 2013; Bozzola and Smale, 2020; Islam et al., 2018; Dedehouanou and McPeak, 2020; Amfo et al., 2021). However, the knowledge gap remains in understanding the impacts of weather shocks on smallholder systems in South Asia. Finally, we explicitly test for the presence of a heterogeneous impact of livelihood diversification across rural households' distribution of per capita food expenditure. By doing so, important policy implications regarding the distributional effects of diversification can be inferred from the present study.

The remainder of this article is organized as follows. In Section 2, we explain our conceptual framework, followed by a description of the data source and key variables that are of interest in Section 3. In the next section, we present the identification strategy and empirical specification used in the analysis. Section 5 discusses the results and presents robustness checks. Finally, Section 6 provides concluding remarks and policy implications.

2. Conceptual framework

The conceptual framework in this study is based on the sustainable livelihood framework used in Ellis (2000), which was developed and adopted in the relevant literature by Ellis (1998), Asfaw et al. (2019), and Gao and Mills (2018). By considering livelihood diversification as one of the primary strategy for smallholder households to manage adverse impacts on food security due to extreme weather events and unexpected market shocks (Barrett et al., 2001b; Asfaw et al., 2019), this study investigates the impact of diversification on rural household food security, which is measured by the household dietary diversity score (HDDS) and per capita food expenditure.

We assume that lagged weather shocks affect livelihood diversification decisions, while livelihood diversification improves household security. It is worth noting that multiple motives prompt households and individuals to diversify their assets, incomes, and activities (Barrett et al., 2001b). The conceptual model is specified as

$$H = f(D(\mathbf{W}, \mathbf{X}), \mathbf{X}; \mathbf{Z}) \tag{1}$$

where H is household food security, D is livelihood diversification, $\mathbf{W}$ is the vector of lagged weather shocks, $\mathbf{X}$ is the vector of covariates, and $\mathbf{Z}$ is the vector of unobserved factors. The impacts of weather shocks and livelihood diversification are described as follows:

$$\frac{\partial f(D(\mathbf{W},\mathbf{X}),\mathbf{X};\mathbf{Z})}{\partial D} > 0 \tag{2}$$

Weather shocks are hypothesized to affect livelihood diversification decisions, denoted by $D(\mathbf{W},\mathbf{X})$, as presented by Mulwa and Visser (2020). In our conceptual model, livelihood diversification works as a climate change adaptation strategy mitigating the negative effect of extreme weather events (Gao and Mills, 2018; Barrett et al., 2001b). We thus hypothesize $\partial H/\partial D > 0$ in (2). The conceptual framework is also depicted in Figure 1.

3. Data

3.1. Data source

The weather data are taken from the Bangladesh Meteorology Department, which includes monthly precipitation and temperature from March 1992 to February 2019 on a global grid using units of 0.5-degree latitude by 0.5-degree longitude. Following Hossain et al. (2018), weather data are compiled into two seasons: (1) Rabi, from March to November; and (2) Kharif, from December to February, as shown in Table 1. We construct drought, flood, and temperature shock variables for the two seasons using historical data.

The household data for this study are drawn from a recently collected three-round panel survey, the Bangladesh Integrated Household Survey (BIHS), which was designed and supervised by researchers at the International Food Policy Research Institute (IFPRI) in 2011/2012, 2015, and 2019. The sample is representative of rural areas of the seven administrative divisions of the county (Islam et al., 2018; Ahmed and Tauseef, 2021). BIHS used a stratified sampling procedure in two stages. The sample design of the BIHS used stratified sampling in two stages—the selection of primary sampling units (PSUs) and the selection of households within each PSU—following the sampling framework of the 2001 Population and Housing Census of Bangladesh (Ahmed and Tauseef, 2021). The total sample size in the first wave is 6503 households in 318 PSUs allocated among seven divisions, and the total sample sizes in the second and third waves are 5430 and 4891 households, respectively[1]. Since our data are panel in nature, we are concerned about whether the attrition is related to any household characteristics. According to Ahmed & Tauseef (2022), attrition between 2011/12 and 2019 is random. Therefore, the estimates presented in this work are not adjusted for attrition. Descriptive statistics, including household socioeconomic characteristics and institutional and agronomic information, are presented in Table 2.

3.2. Description of outcome and explanatory variables

We introduce an income (crop) diversification index that is transformed from the Simpson index usually used to indicate the degree of diversity (Asfaw et al., 2019). The index is written as follows:

$$Simpson = 1 - \sum_{k=1}^{n} \left[\frac{s_k}{S}\right]^2 \tag{3}$$

where s_k is income (farmland area) for income (crop) k, and S is total income (farmland area). A highly diversified household has an index close to 1, while a fully specialized household has an index of 0. Moreover, we divide income sources into farm income, farm wage, nonfarm wage, nonfarm self-employment, and nonearned income, including remittances and social network program transfers, following the method used by Khandker (2012). To describe which crops Bangladesh farmers usually use for diversification, we present the farmland allocation for each crop in the three rounds in Figure 2. Almost all farmland is distributed to cereal production (77%-80%), followed by fiber crops and pulses (approximately 5%). Moreover, Figure 3 shows that the share of nonfarm income is approximately 50% of the total income of households. Figure 4 shows the density distributions of crop and income diversification index by waves.

[1] Although the sample size of the original 3rd wave is greater than 4891, it includes households that split into several due to changes in marriage status, etc.

From Figure 4, approximately one-third of the farmers specialize in their farm income, while the rest of the farm households have multiple farm income sources.[2]

To measure household food security, we use HDDS (Kennedy et al., 2011) and per capita food expenditure (one month). HDDS is calculated by summing the number of food groups per household over a 7-day recall period (Keding et al., 2012). The 12 food groups include 'cereals', 'white tubers and roots', 'vegetables', 'fruits', 'meat', 'eggs', 'fish and other seafood', 'legumes, nuts, and seeds', 'milk and milk products', 'oils and fats', 'sweets', and 'spices, condiments and beverages' (Kennedy et al., 2007). In addition, food expenditure per capita is deflated to BIHS 2011/2012. The two indicators measure different dimensions of food security. HDDS measures the food utilization dimension and intake of micronutrients (Mulwa and Visser, 2020; Kennedy et al., 2007), while per capita food expenditure measures the food access dimension of food security since it captures other sources of food in addition to the farmer's own production (Mulwa and Visser, 2020).

Weather indicators include 64 district-level records of rainfall (mm) and temperature (°C). District-level rainfall and temperature are divided into two seasons, Rabi and Kharif, which are defined by the Bangladesh Meteorology Department (2013). We use historical weather information to establish the normal climate of the division, measured by the 20 years of collected information before the survey period. For example, we take averages for the seasonal temperature and rainfall variables over 1992–2010/11 for 2011/12, 1995–2014 for 2015, and 1998–2017/18 for 2019. Using deviations from 20-year averages for rainfall and temperature, we identify floods, droughts, and temperature shocks since South Asian countries are drought-

[2] Table 2 and Figures 2-3 indicate that the lowest value in the income diversification index occurred in 2015 since the Simpson index measures the evenness of each income source, and the share of nonfarm income increased in 2015. This may be associated with the heavy floods in August and September 2014 (International Federation of Red Cross and Red Crescent Societies Bangladesh Delegation, 2014). Indeed, the asset index in 2015 was the lowest in all three periods of the survey. The floods may have forced the households to sell assets to smooth over income.

and flood-prone (Auffhammer and Carleton, 2018). Specifically, 1-year lagged flood and drought shocks are defined as those measurements exceeding the 20-year average ± 1 standard deviation (Carrillo, 2020). Moreover, temperature shocks capturing contemporaneous shocks are calculated as the differences between logarithmic seasonal temperature and the logarithmic 20-year average of the seasonal temperature.

4. Empirical framework

4.1. Identification strategy

Livelihood diversification decisions may be related to households' unobserved characteristics, which affect HDDS or per capita food expenditure. Therefore, there is a possible endogeneity problem.

In estimating panel data models, an important issue is how to handle the time-invariant unobserved individual effect a_i, which would affect individual livelihood diversification decisions. An advantage of a fixed-effect model is that unobserved characteristics of a household that do not change over time and might affect dietary behavior do not bias the results (Mehraban and Ickowitz, 2021). Thus, we estimate the fixed-effect model to address time-invariant unobserved heterogeneity, which may have been a source of endogeneity in livelihood diversification.

Although we employ the fixed-effect model, the model might produce biased estimates for the coefficients of diversification strategies due to unsolved endogeneity issues (Maggio et al., 2021). The main variable of interest, livelihood diversification, is itself a decision variable; hence, it may be correlated with the error term in the outcome equations. There are three possible endogeneity issues. First, reverse causality may be present. Our hypothesis is that diversification strategies improve HDDS and per capita food expenditure. However, a household may adopt livelihood diversification because its consumption level drops. This concern is addressed through the timing of the outcome variables and the diversification variables. As stated by Gao and Mills (2018), households decide to diversify their crop and income within 12 months prior to the survey, whereas food consumption occurs a month before the survey. In this case, it is reasonable to assume that livelihood diversification affects food consumption rather than prior consumption changes driving later livelihood diversification. Second, self-selection bias may be present since farmers' decisions on diversification strategies are affected by unobserved socioeconomic and demographic factors (Islam et al., 2018). In Loison's (2015) review of previous studies, the adoption of livelihood diversification in rural areas has been an important determinant of household income in sub-Saharan Africa. Empirical evidence for Asian countries also supports the positive effects of income diversification on household welfare indicators, including household income and thus food security/consumption (e.g., Hoang et al., 2014; Gautam and Anderson, 2016; Adem, 2018; Salam et al., 2019). Therefore, there is possible endogeneity between livelihood diversification and per capita food expenditure since the unobserved socioeconomic characteristics that determine whether the household is inclined to or capable of diversifying also influence their ability to purchase more and better food (Reardon et al., 1992). Salam (2019) also indicated that a livelihood diversification strategy might be endogenous in predicting household welfare (both food and nonfood expenditure) since the eventual goal of adoption is to improve household welfare. Third, there may be omitted-variable bias caused by time-varying and unobservable variables, as indicated by Maggio et al. (2021).

Fixed-effect Poisson and OLS regression with instrumental variables are employed to address endogeneity. Because one of the dependent variables, HDDS, is a count variable, the two-stage residual inclusion (2SRI) developed by Terza et al. (2008) is used to control for the endogeneity of livelihood diversification, as suggested in Wooldridge (2010). The 2SRI approach can address endogeneity problems, whether the model specification is a linear or nonlinear function (Terza et al., 2008). In the 2SRI approach, controlling endogeneity involves using the residuals from the first-stage regression of the endogenous explanatory variable to control for and test for endogeneity in the second stage. For another dependent variable—per capita food expenditure—we apply a two-stage least square (2SLS) approach to address endogeneity.

To perform 2SRI and 2SLS, we need valid instruments that affect crop and income diversification but do not directly affect household food security (exclusive restriction in Angrist et al., (1996)). Based on the economic literature on the important role of peer effects in the decision to adopt an agricultural practice (Conley and Udry, 2001; Munshi, 2004; Di Falco, Doku, and Mahajan, 2020), one of the instrumental variables used in this study is the share of households diversifying their livelihoods within a union. The instrumental variable is calculated by the percentage of households in the union adopting the proposed diversification strategy, excluding the household considered, following Asfaw et al. (2019) and Maggio et al. (2021). In past studies such as Birthal et al. (2015), Arslan et al. (2017), Asfaw et al. (2019), and Maggio et al. (2021), similar peer effect variables were employed as instruments in studying climate change adaptation and household livelihood outcomes. The logic behind using peer effect as an instrument is that peer effect is measured as a leave-out mean at the household level that is expected to be correlated with the household's outcome variable but not correlated with household unobserved heterogeneity (Asfaw et al., 2019). In this sense, neighboring households' livelihood diversification decisions may affect the choice of adaptation strategies but not household food security. Furthermore, we use 1-year lagged weather shocks as the additional instrumental variables. Exposure to 1-year lagged weather shocks affects households' livelihood diversification decisions, indicating short-run adaptation, whereas they are unlikely to affect current household food security since 1-year lagged weather shocks are only influential on food production and consumption one year prior to the survey year (Asfaw et al., 2019; Mulwa and Visser, 2020). As a statistical test for the validity of the instrumental variables, we report the diagnostic test for weak instruments based on the Cragg–Donald Wald F test proposed by Staiger and Stock (1997).

4.2. Model specification

Based on our conceptual framework, the two-stage approach starts with estimating the livelihood diversification equation in the first-stage regression as follows:

$$D_{it} = \beta_0 + \boldsymbol{\beta_1}\mathbf{W}_{dt} + \beta_2 z_{it} + \boldsymbol{\beta_3}\mathbf{X}_{it} + a_i + \rho_t + \epsilon_{it1} \tag{4}$$

where D_{it} is the degree of diversification taken by household *i* at time *t* and $\boldsymbol{\beta_1}$ and $\mathbf{W}_{dt}$ are the vectors of parameters and weather shocks that are adjusted to district level *d*. In (4), z_{it} denotes an instrumental variable measured by the share of households adopting the diversification strategy in a union, which is the smallest administrative level in Bangladesh, and $\boldsymbol{\beta_3}$ and $\mathbf{X}_{it}$ are, respectively, the vectors of parameters and control variables including household socioeconomic characteristics, access to irrigation, markets, roads and extension services. In (4), a_i is the individual fixed effect to control for unobservable, time-invariant heterogeneity among farmers due to differences in skills, access to information, and risk aversion (Maggio et al., 2021; Islam et al., 2018), ρ_t denotes the year dummy accounting for the time effect, and ϵ_{it1} is the idiosyncratic error term. The first-stage regression in (4) is estimated by fixed effect OLS.

The two-stage approach involves estimation of the outcome equation in the second stage, which is specified as:

$$y_{it} = \alpha_0 + \alpha_1 D_{it} + \boldsymbol{\alpha_2}\mathbf{X_{it}} + \alpha_3 r_{it} + a_i + \rho_t + \epsilon_{it2} \tag{5}$$

where y_{it} is the outcome variable, either HDDS or the logarithm of per capita food expenditure, r_{it} is the residual from the first-stage regression as specified in (4), and ϵ_{it2} is an error term. To identify the relationship between livelihood diversification and HDDS, the use of Poisson regression is a natural starting point because our dependent variable HDDS is a count variable (Islam et al., 2018). For the identification of the effect of livelihood diversification on per capita food expenditure, we use a standard individual fixed-effect model. The significant coefficient of the residual term in (5) indicates the presence of endogeneity and possible reduced bias when (5) was estimated without IV.

5. Results and discussion

5.1. Determinants of diversification strategies

Table 3 reports the results of the stage 1 regression of the livelihood diversification determination equation. The coefficient of the peer effect, which is the instrumental variable, indicates that households located in a union characterized by a higher percentage of diversification exhibit higher levels of diversification. This result is consistent with previous findings by Birthal et al. (2015), Arslan et al. (2017), Asfaw et al. (2019), and Maggio et al. (2021). Moreover, the null hypothesis of the weak instrument is rejected since the F-statistic is significant in both the crop and income diversification equations.

Weather shocks have been confirmed to act as a push factor for crop diversification in developing countries such as Malawi and Niger (Asfaw et al., 2019). The results in Table 3 indicate that past drought shocks in Rabi significantly affect crop diversification, while the negative temperature shock in Kharif has a positive effect on crop and income diversification. The results in Table 3 indicate that while exposure to a 1-year lagged flood shock in Kharif is not a driver of crop and income diversification, a 1-year lagged drought shock in Rabi increases crop diversification. As such, exposure to weather shocks in the past could drive households to hedge against future extreme weather events through livelihood diversification, which is in line with previous studies for sub-Saharan and Eastern African countries (Asfaw et al., 2018, 2019; Salazar-Espinoza et al., 2015; Arslan et al., 2017).

In terms of socioeconomic variables, our results show that the gender and age of the household head are significant determinants for the adoption of both crop diversification and income diversification. A larger operation scale in terms of farmland size is also found to be a driver for the two diversification strategies. These findings are consistent with the results reported in Asfaw et al. (2018, 2019). The relationship between the household head's educational level and livelihood diversification, however, is found to be insignificant in our study. A plausible explanation offered by Asfaw et al. (2019) is that more educated households have more opportunities for off-farm labor and crop diversification, but they could be less risk-averse. Thus, the empirical relationships between educational level and diversification are usually mixed and unclear. Furthermore, farm households that have fewer assets are more likely to diversify their crop choices. As indicated in Asfaw et al. (2019), wealthier households may have a greater capacity to explore off-farm labor and new income opportunities as well as to adopt more diversified crop production systems.

For agronomic, institutional, and infrastructure variables, owning more land is found to enhance the opportunity to diversify the crop and income portfolio, which is consistent with Asfaw et al. (2018) and Musumba et al. (2022). Moreover, it is found in this study that the usage of irrigation and access to agricultural extension services are significant determinants of livelihood diversification. According to Martin and Lorenzen (2016), income from nonfarm sources in the form of liquid cash may be important both for the ability to hire wage labor and for the timely purchase of farm inputs such as irrigation pumps, leading to improved cultivation practices and higher farm productivity. Additionally, our results suggest that farm households obtaining information concerning new agricultural products and adaptive strategies through agricultural extension services will diversify more, either in terms of the land area allocated to different crops or in terms of sources of income. This result is consistent with what was found in Asfaw et al. (2019).

5.2. Impact of livelihood diversification on household food security

In this section, we present the examination of the impact of the two diversification strategies on household food security. Table 4 reports the exponential mean models by Poisson fixed effect (Columns (1) and (3)) and the linear models by OLS fixed effect (Columns (2) and (4)). The results in Columns (1) and (2) indicate that crop diversification significantly affects per capita food expenditure, while it does not improve HDDS. A 1% increase in the crop diversification index is found to lead to a 0.562% increase in per capita food expenditure. For income diversification, the estimates reported in Columns (3) and (4) indicate that income diversification significantly increases the two food security measures. The result indicates that a 1% increase in the income diversification index leads to a 0.612% increase in per capita food expenditure. The results are as expected since income diversification not only improves food availability but also reduces poverty through off-farm employment (Davis et al., 2010: Khandker, 2012). Columns (5) and (6), on the other hand, list estimates of the effect of both crop and income diversifications, among other control variables. When we consider the specification with the adoption of both crop and income diversifications, only income diversification is found to significantly improve HDDS and per capita food expenditure. Our findings thus suggest the robustness of the positive effect of income diversification even when crop diversification is simultaneously adopted.

For household characteristics, we find that household size is a significant determinant of HDDS and per capita food expenditure. A significant relationship between household size and food security measures is expected because larger families consume more food within a household, resulting in more diversified food groups and less per capita food expenditure due to budget constraints. This result is consistent with past studies by Islam et al. (2018). In line with Jones (2017), Islam et al. (2018), and Asfaw et al. (2019), we find that larger farm sizes and better market access are associated with per capita food expenditure. Moreover, access to agricultural extension services is significantly correlated with HDDS. Our results indicate that richer natural capital, developed infrastructure and better institutional access play an important role in improving household food security.

5.3. Heterogeneous impact of livelihood diversification on household food security

In this section, we investigate the heterogeneous effect of livelihood diversification on the distribution of per capita food expenditure. Previous studies have found a heterogeneous effect of livelihood diversification strategies on welfare (Asfaw et al., 2018, 2019) and on multidimensional poverty reduction (Dagunga et al., 2020). To the best of our knowledge, few studies have investigated the heterogeneous impact of livelihood diversification on household food security in the context of South Asia. It was found by Barrett et al. (2001b) that diversification can raise household income, though the increased off-farm employment of unskilled labor did little to reduce household risk exposure or raise expected income. Therefore, we hypothesize that the effect of livelihood diversification on per capita food expenditure is larger for households that spend more on food consumption than for those that are relatively poor.

Using quantile IV fixed-effect regression, we examine the distributional effect of livelihood diversification on per capita food expenditure conditioned on the 10%, 50%, and 90% quantiles. Table 5 reports the estimated coefficients associated with the two diversification indices. In terms of crop diversification, all the coefficients are insignificant. However, in Columns (4), (5), and (6), the impacts of income diversification are uniformly and significantly positive. Moreover, the results indicate that the impact of a marginal increase in income diversification is greater at the higher and middle segments of the distribution, suggesting that the impact of income diversification is generally higher for the richest households. Our finding that wealthier households benefit more from income diversification than poorer households is consistent with Barret et al. (2001b). According to Barret et al. (2001b), there are barriers resulting in fewer benefits of remunerative income diversification received by poorer households. First, the poor, unskilled and uneducated from more remote areas are likely to participate in nonfarm employment. Second, poor rural households do not have enough access to financial systems to provide sufficient working capital. The last barrier is that the rural poor are generally incapable of accessing nonfarm or market opportunities.

5.4. Robustness checks

The causal effect of crop/income diversification on livelihood may vary with different measures of the diversification index. Therefore, in this section, an alternative indicator of livelihood diversification, the Shannon diversification index, is used to test the robustness of our findings on the impact of livelihood diversification on food security.

The Shannon diversification index is derived as follows.

$$Shannon = -\sum p_k \times ln\ (p_k)$$

where p_k is the share of farmland area of crop k (crop diversification index) or the share of income source k (income diversification index). The Shannon diversification index considers the relative land (income) abundance among crops (income sources), whereas the Simpson index reflects the degree to which one or several crops (income sources) dominate per household (Bozzola and Smale, 2020). When the Shannon diversification index is zero, it indicates that none of the households diversify their crops or income sources.

Table 6 reports the determinants of livelihood diversification measured using the Shannon formula. Similar to the results reported in Table 3, the higher the percentage of households in a union adopting livelihood diversification, the higher the probability that the household diversifies either in crops or income sources. Table 6 also confirms the significant effects of weather shocks on livelihood diversification decisions. In addition, similar to those reported in Table 4, the results in Table 7 confirm the effect of the two livelihood diversification strategies on per capita food expenditure. We report in Table 8 the results of the heterogeneous effect of livelihood diversification on per capita food expenditure. The effects of income diversification are positive and significant at the 10%, 50% and 90% quantiles, as shown in Table 5. In sum, the results in Tables 7 and 8 suggest that the findings in this study are robust—the poorest and richest households uniformly derive benefits from income diversification, whereas the poorest households with highly diversified portfolios have low marginal returns.

6. Conclusions and policy implications

This study contributes to a slim body of literature examining determinants of diversification strategies, including both crop and income diversification, in the context of Bangladesh and South Asia. Moreover, the impact of livelihood diversification on household food security is examined using panel data drawn from a three-wave nationally representative rural household survey carried out in 2011/12, 2015, and 2019. The household panel data are combined with geo-referenced historical rainfall and temperature data to perform an empirical analysis considering the endogeneity of livelihood diversification.

In line with previous studies, our results show that the proximity to neighboring households adopting diversification positively impacts the adoption of crop and income diversification. Moreover, we find that weather shocks, farm size, irrigation usage, and access to agricultural extension services are drivers of livelihood diversification. Moreover, this study finds that both crop and income diversification can improve food security by raising per capita food expenditure. Moreover, the results show that the impact of income diversification is greater for the higher and middle quantiles of the per capita food expenditure distribution. This is probably because the lowest income-earners have little choice but to diversify out of farming into unskilled off-farm labor, whether in agriculture or not. (Barret et al., (2001b)).

Some caveats related to the inherent nature of the key variables deserve further note. The dataset includes not only farm households but also nonfarm households in rural Bangladesh, so approximately half of the household data are not used when we consider crop diversification. Moreover, the crop diversification index includes only the land share of each crop. Due to data availability, we are not able to consider either fish and poultry diversity or the crop diversification index based on the revenue shares of crops by taking prices into account. Further data collection is needed to overcome these caveats. Finally, our analysis does not account for the economy-wide effects related to changes in food prices, urban–rural linkages and multiplier effects. These effects need to be investigated using an appropriate economy-wide modeling approach.

Regardless of the caveats, important policy-relevant insights can be drawn from our findings. First, while our results indicate that the income diversification strategy is an effective coping strategy on average for rural households in Bangladesh, the heterogeneous impact of income diversification suggests that poorer households enjoy fewer benefits from diversifying income sources. Therefore, income diversification should be promoted and considered as a possible strategy for reversing the trend of food insecurity. The heterogeneous impact of different livelihood diversification strategies found in this study is helpful in identifying policy options that are better tailored to the needs of the socioeconomically diverse rural population in Bangladesh.

A policy-relevant determinant of rural households' diversification decisions identified in this study is access to irrigation. Access to irrigation provides opportunities to enhance farm resilience and mitigate weather shocks. Additionally, our findings suggest that more extension services should be considered when designing programs to effectively assist farmers in coping with climate change. More access to agricultural extension services also enables farmers to access information on livelihood diversification and farming practices for sustainable production. Moreover, building infrastructure may also be effective for household food security since our findings suggest that better market access increases per capita food expenditure as well as nonfarm work opportunities.

Our findings highlight the importance of developing policies and programs that are designed not only to promote livelihood diversification as adaptive strategies but also to strengthen the support for poorer and vulnerable households to adapt to climate change. There is a consensus that the impacts of climate change will continue to last in the next few decades, despite global efforts to mitigate greenhouse gas emissions that lead to the global warming problem (Mulwa and Visser, 2020). To build resilient livelihoods in the face of these challenges, policy-makers in South Asia need to facilitate fast-track access to remunerative nonfarm opportunities in rural areas since nonfarm income is a dominant source of rural household income.

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Table 1: Climate of Bangladesh

Seasons	Period	Main crops
Kharif	March to November	Aus (rice), Aman (rice)
Rabi	December to February	Boro (rice), Wheat, Maize, Potato/Tomato

Source: Hossain et al. (2018)

Table 2 Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
		2011/12			2015			2018/19	
Household Dietary Diversity	6,503	9.121	1.423	6,225	9.766	1.240	5,111	9.939	1.188
Per capita food expenditure (deflated to baseline value)	6,503	1598.295	864.425	6,224	1709.245	1017.864	5,111	1710.546	904.396
Crop Diversification Index	3,409	0.449	0.256	3,306	0.425	0.264	2,746	0.401	0.261
Income diversification index	6,425	0.403	0.285	6,206	0.286	0.227	5,098	0.385	0.268
share of households adopting crop diversification within the union	3,409	0.485	0.201	3,306	0.432	0.214	2,746	0.224	0.000
share of households adopting income diversification within the union	6,425	0.786	0.133	6,206	0.779	0.120	5,098	0.503	0.000
Flood shock 1-year lag in Kharif	6,503	0.077	0.266	6,225	0.142	0.349	5,111	0.850	0.358
Drought shock 1-year lag in Rabi	6,503	0.264	0.441	6,225	0.557	0.497	5,111	0.090	0.286
Temperature shock 1-year lag in Rabi	6,503	0.028	0.007	6,225	0.005	0.006	5,111	-0.001	0.005
Male(=1)	6,503	44.171	13.980	6,224	0.813	0.390	5,111	0.789	0.408
Age of HH	6,503	4.196	1.628	6,224	46.192	13.703	5,111	47.693	13.288
Household size	6,502	3.330	3.938	6,224	4.862	1.883	5,111	5.501	2.162
Schooling year of HH	6,503	3.665	1.595	6,222	3.474	3.949	5,108	3.595	4.021
Asset index	6,503	3.452	1.684	6,224	-0.292	0.462	5,111	0.041	0.278

Farm Size(decimal)	6,503	91.311	145.424	6,221	3.602	1.631	5,111	3.583	1.591
Market access (minute)	6,411	17.446	10.724	6,134	15.807	9.591	5,089	13.269	8.487
Road access (minute)	6,355	14.655	11.491	6,011	12.210	10.990	5,050	12.133	11.204
Access to agricultural extension service (=1 if yes)	6,503	0.061	0.239	6,224	0.543	0.498	5,111	0.725	0.447
Irrigation(=1)	6,503	0.453	0.498	6,224	0.446	0.497	5,111	0.453	0.498

Source: Bangladesh Integrated Household Survey 2011/12, 2015, 2018/19.

Note: 100 decimals are 0.4 ha; the currency is Bangladesh Taka.

Table 3: Determinants of diversification strategies (1st stage)

	(1) Crop diversification	(2) Income diversification
Share of households adopting crop diversification within the union	0.101***	
	(0.020)	
Share of households adopting income diversification within the union		0.233***
		(0.025)
Flood shock 1-year lag in Kharif	-0.006	-0.000
	(0.009)	(0.008)
Drought shock 1-year lag in Rabi	0.018**	0.010*
	(0.007)	(0.006)
Temperature shock 1-year lag in Kharif	-0.954*	-0.160
	(0.492)	(0.395)
Male (=1)	0.037**	0.102***
	(0.018)	(0.010)
Age of HH	0.001**	0.001
	(0.000)	(0.000)
Household size	0.002	0.006**
	(0.004)	(0.003)
Schooling year of HH	-0.002	0.000
	(0.002)	(0.002)
Farm size (log)	0.054***	0.021***
	(0.007)	(0.004)
Irrigation (=1)	0.155***	0.029***
	(0.012)	(0.008)
Market access (minute)	0.000	0.000
	(0.000)	(0.000)
Road access (minute)	-0.000	0.000
	(0.000)	(0.000)
Access to agricultural extension service (=1 if yes)	0.022*	0.039***
	(0.012)	(0.007)
Asset index	-0.005*	0.005**
	(0.003)	(0.002)
Individual FE	Yes	Yes
Year FE	Yes	Yes
Observations	7970	16,735

Note: Robust standard errors clustered by households in parentheses. "*", "**" and "***" denote, respectively, 0.05<=p<0.1, 0.01<=p<0.05 and p<0.01. We reject the null hypothesis of weak instruments based on the Cragg–Donald Wald F statistic (10.236 for crop diversification and 26.741 for income diversification).

Table 4: Impact of livelihood diversification on household food security (2nd stage)

	(1)	(2)	(3)	(4)	(5)	(6)
	HDDS	Per capita food expenditure (log)	HDDS	Per capita food expenditure (log)	HDDS	Per capita food expenditure (log)
Crop Diversification Index	0.129	0.565**			0.157	-0.147
	(0.105)	(0.261)			(0.122)	(0.338)
Income diversification index			0.013**	0.758***	0.017**	0.644**
			(0.005)	(0.163)	(0.008)	(0.307)
Male(=1)	0.016	-0.070**	0.012	-0.067***	0.020	-0.000
	(0.013)	(0.028)	(0.008)	(0.024)	(0.016)	(0.034)
Age of HH	-0.001	-0.000	-0.000	-0.001**	-0.001	-0.000
	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
Household size	0.006***	-0.101***	0.007***	-0.100***	0.006***	-0.085***
	(0.002)	(0.006)	(0.002)	(0.005)	(0.002)	(0.007)
Schooling year of HH	-0.001	0.000	0.001	0.002	-0.001	-0.004
	(0.002)	(0.004)	(0.001)	(0.003)	(0.002)	(0.005)
Asset index	-0.005***	0.003	-0.005**	-0.006	-0.005**	-0.003
	(0.002)	(0.005)	(0.002)	(0.004)	(0.002)	(0.006)
Farm size (log)	0.003	0.031*	0.007***	0.005	0.002	0.030
	(0.008)	(0.018)	(0.002)	(0.007)	(0.007)	(0.023)
Market access (minute)	-0.000	-0.001**	-0.000	-0.001	-0.000	-0.001
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
Road access (minute)	-0.000	-0.000	-0.000	-0.001*	-0.000	-0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Access to agricultural extension service (=1 if yes)	0.018	0.025	-0.002	-0.035***	0.019**	0.041
	(0.011)	(0.022)	(0.004)	(0.013)	(0.009)	(0.027)
Irrigation(=1)	-0.022	-0.090**	0.004	-0.016	-0.025	0.016
	(0.017)	(0.044)	(0.005)	(0.014)	(0.023)	(0.055)
Residual-crop	-0.125				-0.154	
	(0.102)				(0.124)	
Residual-income			0.027		-0.058	
			(0.052)		(0.109)	
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7970	7970	16,734	16,733	7964	7963

Note: Bootstrapped robust standard errors clustered by households in parentheses in columns (1), (3), and (5) while robust standard errors clustered by households in parenthesis in columns (2), (4), and Column (6). Columns (1), (3) and (5) list the results of Poisson FE with IV regression; columns (2), (4), and (6) list the results of OLS FE with IV regression. "*", "**" and "***" denote, respectively, 0.05<=p<0.1, 0.01<=p<0.05 and p<0.01.

Table 5: Quantile effect of livelihood diversification on per capita food consumption expenditure (2SRI)

	(1)	(2)	(3)	(4)	(5)	(6)
	0.10 quantile	0.50 quantile	0.90 quantile	0.10 quantile	0.50 quantile	0.90 quantile
Crop Diversification Index	0.356	0.150	-0.045			
	(0.344)	(0.318)	(0.394)			
Income diversification index				0.042**	0.046***	0.049**
				(0.019)	(0.017)	(0.021)
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7964	7964	7964	16,733	16,733	16,733

Note: Bootstrapped robust standard errors clustered by households in parentheses. "*", "**" and "***" denote, respectively, 0.05<=p<0.1, 0.01<=p<0.05 and p<0.01. Instrumental variables: % of households adopting a considered diversification strategy within a union. The full table is available upon request.

Table 6: Robustness of determinants of livelihood diversification (OLS FE)

	(1) Crop diversification (Shannon)		(2) Income diversification (Shannon)	
Share of households adopting crop diversification within the union	0.223***	(0.036)		
Share of households adopting income diversification within the union			0.226***	(0.030)
Flood shock 1-year lag in Kharif	-0.014	(0.017)	0.005	(0.010)
Drought shock 1-year lag in Rabi	0.032**	(0.013)	-0.003	(0.007)
Temperature shock 1-year lag in Kharif	-2.066**	(0.889)	-1.070**	(0.491)
Individual FE	Yes		Yes	
Year FE	Yes		Yes	
Control Variables	Yes		Yes	
Observations	7970		16,857	

Note: Robust standard errors clustered by households in parentheses. "*", "**" and "***" denote, respectively, 0.05<=p<0.1, 0.01<=p<0.05 and p<0.01. The full table is available upon request.

Table 7: Robustness of effect of livelihood diversification (Poisson/OLS FE with IV)

	(1)	(2)	(3)	(4)
	HDDS	Per capita food expenditure (log)	HDDS	Per capita food expenditure (log)
Crop diversification (Shannon)	0.062	0.271**		
	(0.049)	(0.120)		
Income diversification (Shannon)			0.013	0.485***
			(0.051)	(0.159)
Individual FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes
Number of households	7970	7970	16,856	15,604

Note: Bootstrapped robust standard errors clustered by households in parentheses in columns (1), and (3) while robust standard errors clustered by households in parenthesis in columns (2) and (4). Columns (1) and (3) list the results of Poisson regression; columns (2) and (4) list the results of OLS FE with IV regression. "*", "**" and "***" denote, respectively, 0.05<=p<0.1, 0.01<=p<0.05 and p<0.01. Instrumental variables: % of households adopting a considered diversification strategy within a union. The full table is available upon request.

Table 8: Robustness of quantile effect of livelihood diversification on per capita food expenditure (2SRI)

	(1) 0.10 quantile	(2) 0.50 quantile	(3) 0.90 quantile	(4) 0.10 quantile	(5) 0.50 quantile	(6) 0.90 quantile
Crop diversification (Shannon)	0.211	0.098	-0.010			
	(0.201)	(0.144)	(0.208)			
Income diversification (Shannon)				0.568***	0.578***	0.589***
				(0.190)	(0.154)	(0.203)
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7486	7486	7486	16,855	16,855	16,855

Note: Bootstrapped robust standard errors clustered by households in parentheses. "*", "**" and "***" denote, respectively, $0.05<=p<0.1$, $0.01<=p<0.05$ and $p<0.01$. The full table is available upon request.

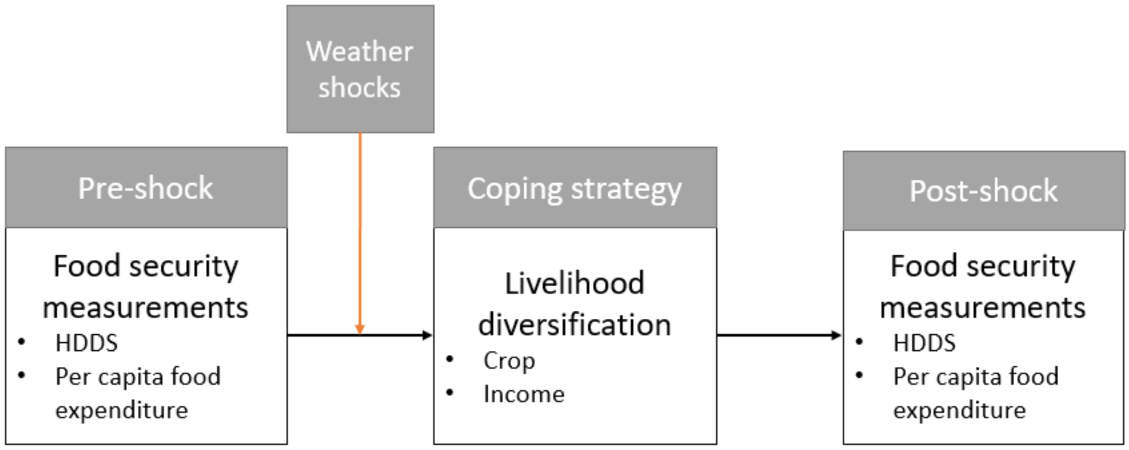
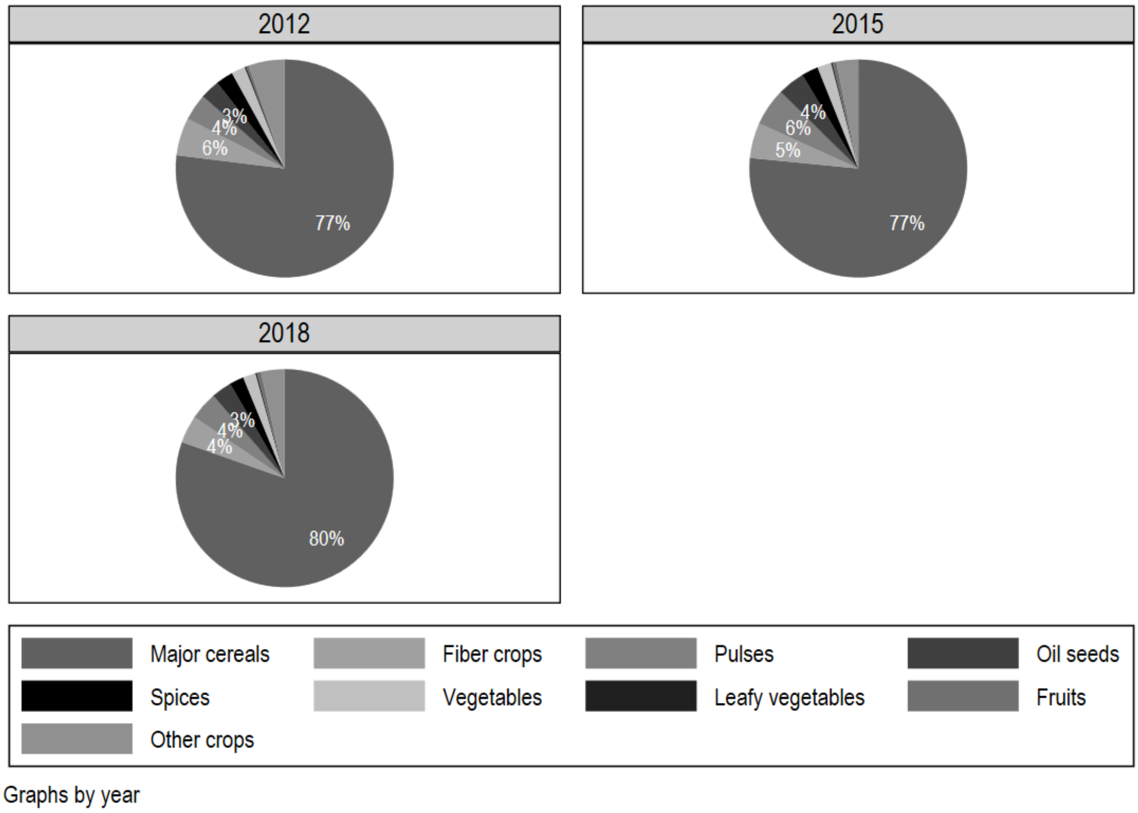


Figure 1 Conceptual framework for identification of effective livelihood diversification



Note: Calculated by the authors
Source: BIHS 2011/12, 2015, 2018/19

Figure 2 Farmland allocation of each crop

Note: Calculated by authors
Source: BIHS 2011/12, 2015, 2018/19

Figure 3: Breakdown of household income by source

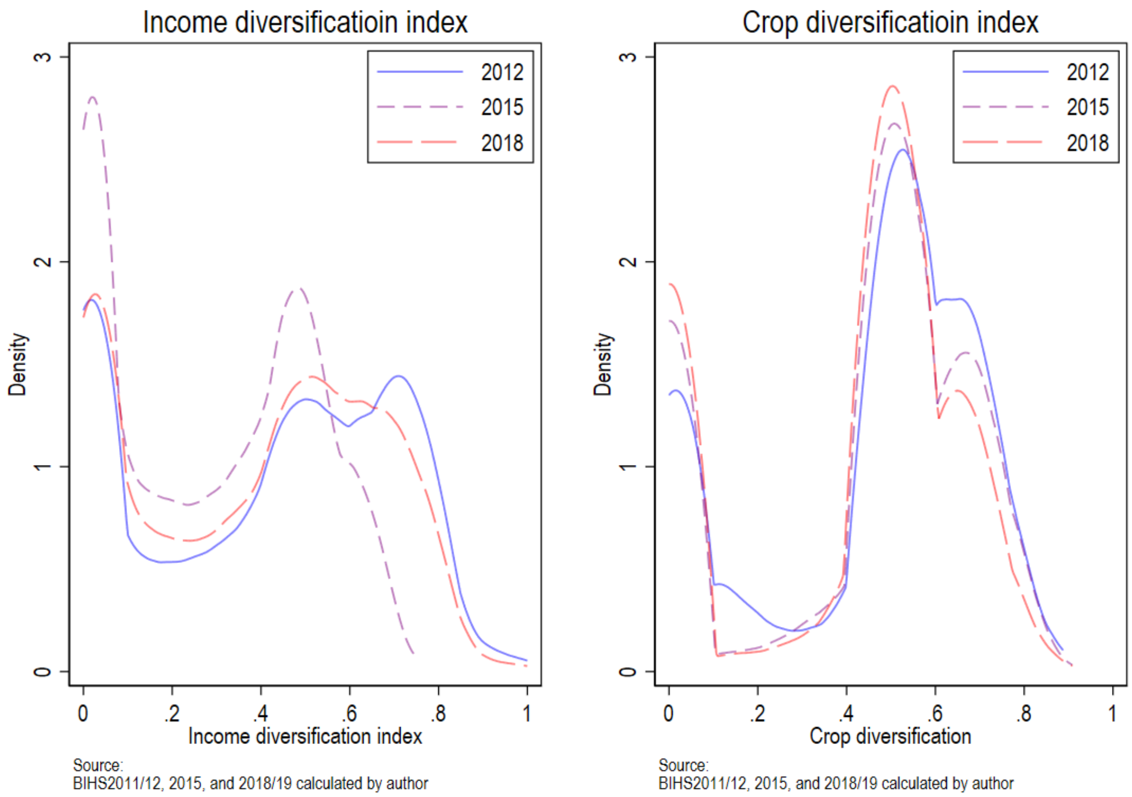


Figure 4: Density distribution of diversification index

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