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Adaptation to climate stresses through farmers' choice of rice variety

– Findings from a path-analytical model for rice farming in Bangladesh

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AgriFoSe2030

Agriculture for Food Security 2030
- Translating science into policy and practice

Today more than 800 million people around the world suffer from chronic hunger and about 2 billion from under-nutrition.

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Summary

Rice is the primary staple crop in South Asia, where rice farming is a well-known multifunctional system often rainfed by the monsoon. With increasing climatic volatility, exclusively rain-fed rice paddies have experienced a triple threat in droughts, floods and salinity. This study investigates the linkages between these climate stresses impacts on yield and the farmer's decisions to change their rice variety. To find these links, we used a statistical tool that takes into account the rice-yield under the impact of climate stressors, and combines it with different adaptation motives and market exposure, i.e. outputs sold on the market, that drives the farmers to choose a certain rice-variety.

Varietal choice is a major adaptation strategy. Farmers can either adopt a rice variety with strong re-sistance to reduce risks from climate extremes, or rotate a mix of varieties to diversify the risk exposure. The decision process behind changing the crop variety as an adaptation measure has important impli-cations to both farmer livelihoods and food security. While the varietal choice is often identified as an adaptation behavior, the decision to change variety has not been studied in the presence of moderat-ing variables, namely adaptation and market exposure. The inputs to the model are based on 2523 farm household observations from Bangladesh. We find that drought and flood influence both yield and the decision to choose a particular rice variety, but is statistically significant only for salinity. This shows that adaptation to climate stresses and the motivation for a farmer to choose a more resilient rice variety is foremost related to salinity. However, the market response is still the strongest driver behind the varietal choice, which means that the farmer would not choose a rice variety resilient to either drought, flood or salinity if it were not generating income on the market. The amount of output sold on the market is a significant mediator of varietal choice in addition to adaptation, and the farmers' preference for short-term gains and previous exposure to climate shocks predict adaptation motive substantively. While market exposure dominates in terms of magnitude in determining change of rice variety in this case, the varietal development geared towards salinity has still helped the adaptation process to climate stress factors, which is not observed for flood and drought conditions. This showcases the need to investigate other adaptation related solutions to combat flood and drought conditions in Bangladesh.

With respect to choice of rice varieties in Bangladesh in response to climate stresses, we conclude that farmers take salinity into account in their decision-making, but not drought or floods in particular. In addition, the market signals create more pressure on varietal selection than the potential adaptation driven decisions. This highlights the need for policy interventions that could facilitate climate adaptation in rice without jeopardizing the market preferences. We focus on varietal choice with regards to flood, drought and salinity, but for a more complete picture of drivers of varietal choice under climatic changes, other management practices such as water and soil conservation measures should be analyzed as well. Such studies can reveal non-trivial implications for development, which may otherwise be hidden to development planners.

Front picture: [Rice field showing drought-affected soil. Source: IRRI]

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Contents

1. Introduction

Climate impacts on agriculture are important concerns in the context of tropical rice systems, which are affected by climatic stresses, such as drought, floods and salinity. Climate change increases both the vulnerability and exposure of the crop due to its dependency on precipitation at optimal intervals during the season. Drought is the more prevalent threat for rice in the tropics due to high water needs of the rice plants. Flood and salinity are less damaging on the physiology of the plant in comparison to the effect of drought, but water logging conditions and soil structural changes resulting from floods and salinity can lead to significant harvest losses. Farmers have long traditions of using various methods to adapt to these climate shocks. One such approach is choosing varieties of rice tolerant to above conditions. The decision process behind changing the crop variety as an adaptation measure has important implications to famer livelihoods and food security. The present study investigates the farmer decision to change the rice variety in the context of drought, flood and salinity exposure in Bangladesh using a Bangladesh–wide cross sectional survey from 2014/2015. While the varietal choice has been identified as an element of adaptation behavior in the literature (Selvaraj and Ramasamy, 2006), the decision to change variety has not been studied in the presence of moderating variables, namely adaptation and market participation (measured as the percentage of harvest sold). In addition, we estimate the level of adaptation, which is not observable directly, using two observable variables, namely, previous experience of the climatic stress and the farmer preference for short-term gains as opposed to long-term gains.

1.1. Rice in South Asia.

Rice is the major staple food for nearly half of the world's population (Zeigler and Barclay, 2008). In addition to being the main staple food in Asian countries, rice cultivation is also one of the dominant land uses. While it is spread widely in South Asia, concentrated patches of cultivation can be observed in India, Bangladesh, Sri Lanka and Nepal (see figure 1). Within India, three dominant clusters are found in states of Kerala, Tamil Nadu and Odisha. Within Bangladesh, the southern and southwestern provinces form a significant cluster. Sri Lanka features rice cultivations in both low and mid elevations of the country. In South Asian systems, rain-fed (usually from Monsoons) or irrigated (surface or groundwater) or reservoir based cropping patterns exist. A single crop can be of three to four months' duration based on the variety. In water scarce locations, there is only one cropping cycle per year, often coinciding with the rainy season. In water-abundant locations, two cultivation seasons per year (one rain-fed, the other irrigated) are typical. Rarely, three cultivations per year are possible if water is well managed.

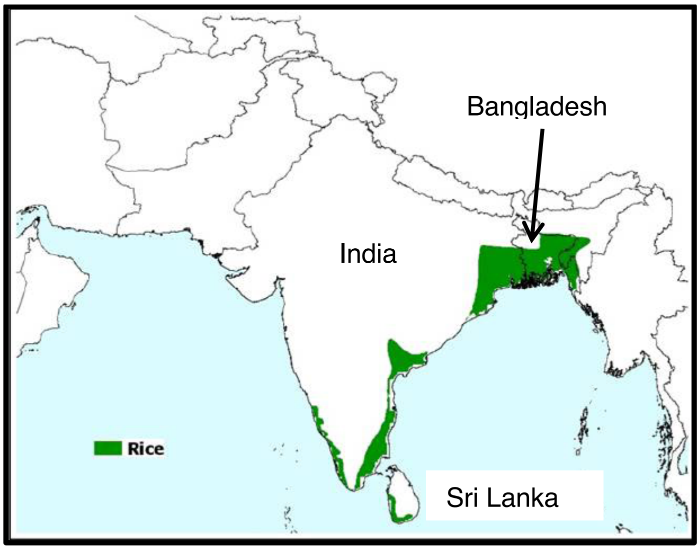

Figure 1. Rice in South Asia (source: IRRI website 2015)

1.2. Bangladesh rice economy

In the southern and southwestern regions of Bangladesh, rice is cultivated extensively from the low lands to moderately high elevations. Rice cultivation benefited significantly from the Green Revolution of the 1960's. The first widely distributed high-yielding rice variety, IR8, was introduced into Bangladesh in 1967. Since then, both foreign and local rice research has resulted in numerous high yielding varieties. The average rice yield has reached the level of 4 tons per hectare in 2012 from an average of 1.7 tons per hectare reported in 1970. In South Asia, the 4 tons per ha yield is typically perceived as a yield milestone and considered a yield plateau for lowland rice. This improvement is largely a result of varietal selection for high-yielding, climate change ready, and short-duration rice varieties. Short-duration varieties have allowed farmers to include a third crop to the cropping schedule, and in addition to genetic improvement of the germplasm, irrigation, fertilizer, and mechanization have also contributed to the yield hikes.

However, the vulnerability of rice is extremely high in Bangladesh vis-a-vis other South Asian countries. According to the literature, droughts affect nearly 50 percent of the land area (Shahid and Behrawan, 2008). Bangladesh has experienced rising temperature, particularly during monsoon, over the past three decades (Rahman and Lateh, 2016) and is likely to experience an increase in overall average temperature up to 1°C by 2030 and 1.4°C by 2050 (FAO, 2006).

1.3. Climate vulnerability of rice systems

Processes influencing vulnerability to climate variation and change are inherently dynamic, and shaped by both climatic and socio-economic factors (Adger 2006). For instance, water-sharing norms form a significant role in adaptation to water shortages in rice cultivation. Other examples of dynamics that involve socio economic components include community tenure and staggered cultivation through collective decision-making. While farming enables system-wide adaptation responses, depending on the scale of the cultivation and the duration of the crop, management practices often take the form of reactive and sector-based responses, diminishing the prospects to realize comprehensive climate adaptation strategies (O'Brien and Hochachka, 2010)

Vaghefi *et al.,* (2011) lists climate change as the long-term challenge to achieve sustainable growth in rice production. The frequency of the extreme climate conditions is predicted to increase in the future posing challenges to agriculture and international food security. The predictions show that total area suffering from drought globally will increase between 15-44 percent over the century (IPCC, 2014). There are no easy alternatives to sidestep these challenges. Increasing weather variability will present challenges for meeting the food demand. There is limited scope for expansion of cropland, given the competition for productive land resources and growing water scarcity.

Of all climate change extremes, drought is not only the most widespread but also the most damaging. Environmental factors such as salinity, submergence, pests and diseases are significant in South Asia but less damaging to the rice crop. According to an estimate by the International Rice Research Institute (IRRI), droughts affect 23 million hectares of rain-fed rice in South and Southeast Asia. In some Indian states, droughts can cause up to 40 percent yield losses (IRRI, 2016).

Rice yield are found to be more sensitive to nighttime temperature, in which each 1 degree Celsius increase leads to a decline of about 10 percent in rice yield (Welch *et al.*, 2010). Droughts and floods cause rice yield losses (Pandey et al 2007), and the expected increase in drought and flood occurrence due to climate change would further add to rice production losses in the future.

The increase in temperature shortens the phenological phases of crops and affects plant growth and development (Roudier et al., 2011). The photosynthesis rate of rice is at a maximum in the 20–32°C temperature range. Even a moderate increase of 1–2°C is likely to have an adverse impact on cereal yields (Schellnhuber et al., 2013). Fluctuations and occurrence of extreme climate events reduce rice yields significantly, particularly at critical crop growth stages (Teixeira et al., 2013).

1.4. Adaptation to climate stress and varietal choice

Variety choice is a major adaptation strategy. In other words, farmers can either adopt a new variety with strong resistance to reduce risks from climate extremes (Selvaraj and Ramasamy, 2006) or rotate a mix of varieties to diversify the risk exposure. In the present study, we consider three forms of climate stressors: drought, flood and salinity. In lowland rice systems, throughout South Asia, these three stress factors remain pervasive. The adoption of varieties with strong tolerance is often advocated by rice research agencies (Westengen and Brysting, 2014). It is a feasible strategy in many rice systems due to the relative abundance of improved varieties, both through agronomic selection trials and genetic improvement.

In smallholder rice systems, the farmers' responses towards the appropriate selection of the adaptation measures are also driven by the extent of their perception about climate change and their access to extension services (Alauddin and Sarker, 2014). Given that the smallholders are locked into rice farming both because of landscape limitations and socio-economic realities, the adaptive responses to climate challenges are non-trivial decisions.

The present study goes deeper into explaining the decision to change the variety via the moderating factors of adaptation behavior and market exposure. The connection between the yield and the change of variety is treated as the default since we hypothesize yield to be the key observable factor that will influence the decision to change the variety. We incorporate the climate sensitivity of varietal change decision by incorporating the damage due to climate stress in the prediction of the yield.

2. Objectives of the study

Our aim is to study the decision on varietal choice in response to climate stress, in a path analytic framework that accounts for key elements of vulnerability in rice farming. To consider rice systems in light of environmental stress and ecosystem vulnerability is the appropriate way to frame the choice of rice variety.

- The overall objective is to understand the varietal choice of paddy by farmers in Bangladesh under influence of three different climate stresses (drought, flood and salinity)
- The specific objectives are to identify partial contribution of factors determining farmer's decision in the varietal choice within a Path Analysis model, which accounts for market participation and adaptation capacity of the farmer. Further, we aim to inform relevant stakeholders including authorities on the determining factors for effective support of rice system development as the main staple food and maintenance of food security in the country.

3. Data and methods

3.1. Data

This study looks into the varietal change in response to climate stresses based on the farm household data from Bangladesh. The dataset is constructed using representative sample surveys conducted by IRRI[1] in Bangladesh during 2014. Each survey instrument looked into different aspects of rice faming households such as farm household characteristics, assets and varietal choice decisions. The data covers 74 wards ('Thana') within 15 districts covering 2523 households (see figure 2).

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[1] Rice Monitoring Survey: South Asia (RMS-SA) Project was implemented by IRRI to monitor rice system that captures varietal turnovers over time.

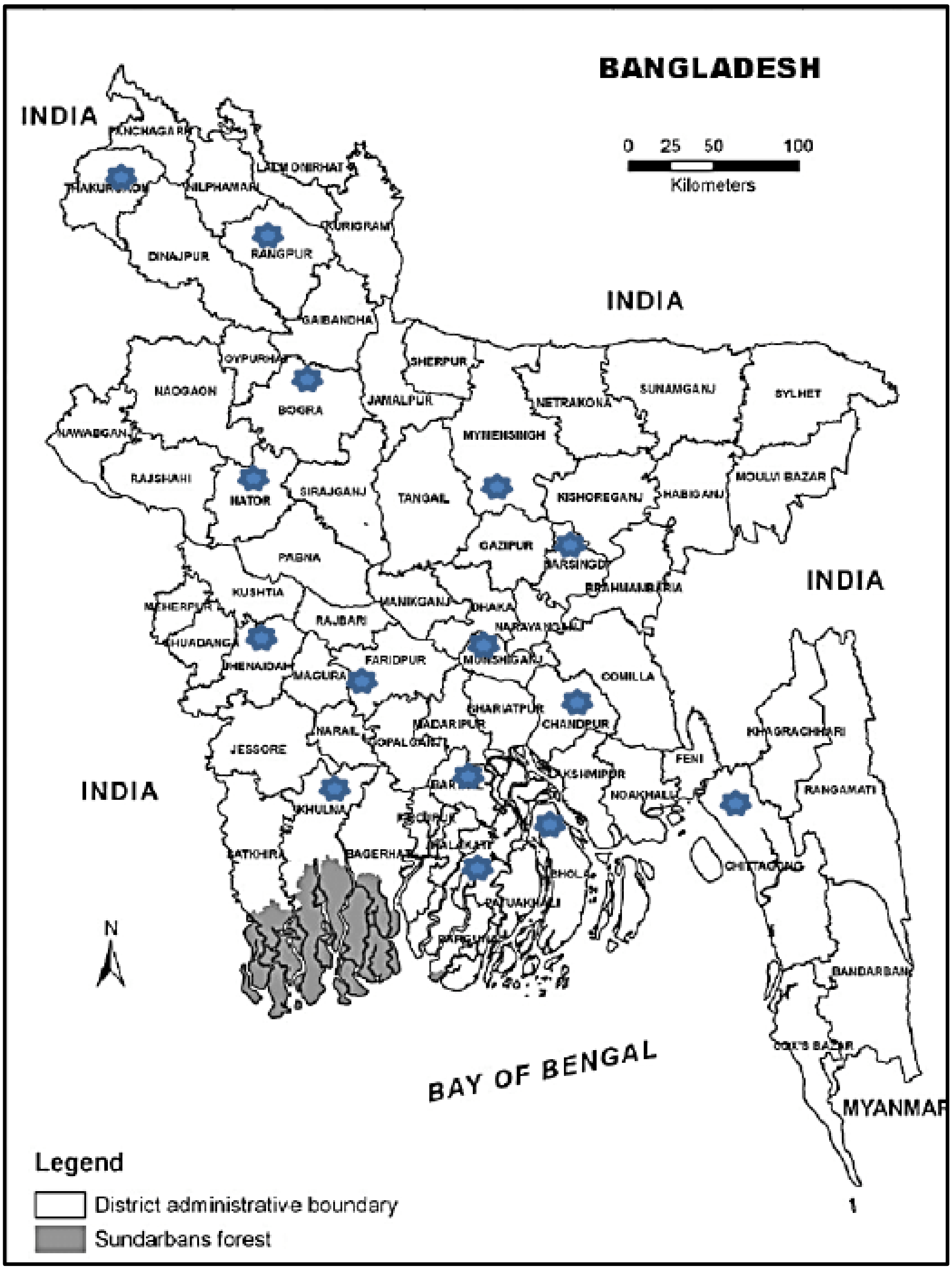

Figure 2: Districts included in the household survey

The key variables used in the study are as follows. The outcome variable is the change of variety from 2013 to 2014. Climate related stresses considered in the present study are drought, flood and salinity. The percentage damage of the harvest due to respective stress-factor was enumerated in the farmer survey. The survey also evaluated the previous exposure to the stress factors during the five-year period before the survey-year. The gender of the farmer, the level of education, the nature of decision making within the family with respect to the choice of variety (whether partners jointly decide or not) were the other variables enumerated with respect to the household. The yield is reported in kg per ha. Time preference was measured on a scale from 1 to 10. This indicator is calibrated on a series of offers of money values with the option given to the respondent to take the offer now or delay it for the next period (The future payment is larger than the present period offer by the degree of trade-off captured in the interest rate). The higher the value on the scale, the higher is the preference for ‘now’.

Our research question considers the varietal change decision in its connection to the yield. Yield in turn is modeled as an outcome of climate related damage and socio economic variables. The first variable used for prediction of adaptation capacity is time preference (a proxy for patience in financial planning horizon). For instance, high time preference captures the case in which the farmer wishes to switch rice variety giving priority to short-term financial considerations. The second predictor of adaptation is the experience of drought, floods or salinity within the last 5 years. Table 1 lists the key variables and their descriptive statistics in order to provide background to the sample.

3.2 Path Analysis

A path analytical framework essentially facilitates modeling the connection between the key outcome variable, i.e. change of variety, to important observed factors such as yield and market participation of the farmer. Adaptation is an important concept for this study but it is not observable. In a path analytical model, an unobservable variable such as ‘adaptation’ is included as a latent variable. Statistically, such a latent variable is predicted by other observable variables, which are conceptually linked to the realization of the latent variable.

The central linkage in the path model is between the yield and the decision to change the variety. A number of variables specific to farmer household in turn predicts yield. The model that we adopt hypothesizes those two variables, namely market participation of the farmer and adaptation as moderating variables. That is, these two variables moderate the linkage between yield and change of variety. The ability to incorporate multiple moderating effects and the ability to instrument for ‘latent’ variables is a key advantage of path modeling in contrast to standard regression analysis.

3.3 Steps and factors considered in the analysis

Literature on adaptive capacity highlights the concept of ‘integrated vulnerability’, which looks into vulnerability of systems as partly determined by exogenous change and physical risks, partly on the localization and quality of the socio–technical infrastructure (Leichenko and O’Brien 2008). Alternatively, integrated vulnerability is conceived as a function of three interlinked components: exposure, sensitivity, and adaptive capacity (Gallopin, 2006). That is, (1) how a system is exposed to existing and future climatic stress, (2) how sensitive the system is to the changes, and (3) the capacity of the system to adapt to these stresses.

This conceptual framing of system resilience provides the basis for rationalizing the connection between climate related stress factors, yield and varietal change decisions that we are interested in with respect to rice systems of Bangladesh. We explicitly identify ‘exposure’ using the percentage damage due to drought, floods and salinity. The ‘sensitivity’ of varietal change decision is captured in the indirect channel mediated by adaptation motive (and/or the market motive[2]). The intensity of stress is absorbed differentially by the farmer based on the degree of adaptation. The varietal choice decision is thus ‘sensitive’ to the path of mediation. In order to identify ‘adaptive capacity’, we use the two variables: previous experience of the same shock (i.e. the experience of the shock in the last 5 years) and farmer’s time preference. Farmer’s time preference indicates the relative prioritization of the present in terms of time value of money.

In this study, we consider the impact of climate stresses on the rice yield in the presence of other socio-demographic factors and link the yield to varietal choice in the presence of two indirect pathways. The first is the adaptation motive of the farmer, conditional on her previous exposure to the relevant climate shock and her time preference. The second pathway is the market exposure of the farmer. The logic behind the selection of the two pathways was to control for psychological adaptive motive, which is internal to the farmer and to control for the effect of market on the varietal choice, which is external to the farmer.

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[2] Further details are included in the sections 3.4 and 3.5.

3.4. Structure of the Statistical model

The statistical model structure is as follows. The first structural equation is used to explain the famer yield level using five variables.

$$Yield \ = f(percentage\ damage\ by\ climate\ stress, farmer\ age, farmer\ education, gender, joint\ decision\ making) \quad \text{(Eq.1)}$$

The second structural equation connects the yield explained above to the decision to change rice variety in the presence of market pressure and adaptation capacity.

$$Decision\ to\ change\ variety \ = f(yield, market\ exposure, farmer\ adaptation\ to\ climate\ stress) \quad \text{(Eq.2)}$$

A supplementary structural equation instruments for adaptation capacity, which is an unobservable variable.

$$Adaptation\ capacity \ = f(previous\ exposure\ to\ climate\ stress, time\ preference) \quad \text{(Eq.3)}$$

In each of the above structural equations, coefficients are estimated capturing the relationship between the outcome variable and the respective explanatory variable.

The model adopted enables to extend the standard yield estimation to the latent factors of adaptive capacity in order to explain the varietal choice. We take each of the climate stresses, namely, drought, floods and salinity, separately within a single path-analytical model structure. The first model includes the yield responses to drought effects and farmer adaptation to drought stress through previous experience of drought impacts and degree of time preference. Behavioral response is assessed through observation of change in the variety cultivated from the previous season to the season of enumeration. As exogenous determinants of yield, we include farmer specific variables such as age, education, gender, how varietal choices are made (a household decision after consulting the spouse or not) and the drought damage. In particular, this approach does not constitute an estimation of a production-function where yield is considered a function of inputs. Instead, we pick the truly exogenous variables to yield in order to isolate the effect of climate/climate stress for subsequent path analysis. The path analysis emerges critical here given the latent properties of the mediating variable, adaptation capacity. Farmers' experience of the respective stress factor and the time preference are used to instrument for the latent variable.

A similar estimation is carried out for floods and salinity. The only difference to the drought model in each case is to consider the percentage damage by floods/salinity in the determination of the yield and to replace the instrumentation of the latent variable using the respective exposure (floods/salinity) during the last five years.

The above conceptualization of adaptation makes sense in terms of famer specific factors only. Given that varietal choice is arguably influenced by market orientation of the farmer and the market signals related to the variety, inclusion of the market orientation as a mediating factor between the yield and the decision to change the variety is appropriate. However, there are limitations to identify the above indirect path since it is difficult to measure the market orientation of the farmer. To sidestep this empirical challenge, we include the proportion of the harvest sold in the market as a proxy variable. This is an observed variable and, in contrast to the latent variable on adaptation, we can include the proxy variable directly into the model as a mediator. We name this variable "market response". Thus, in the augmented model, two indirect pathways are in operation supplementing the direct connection between yield and the decision to change the variety in response to climate shocks. The first is the adaptation pathway. The second is the market response pathway. Figure 3 displays the model schematically.

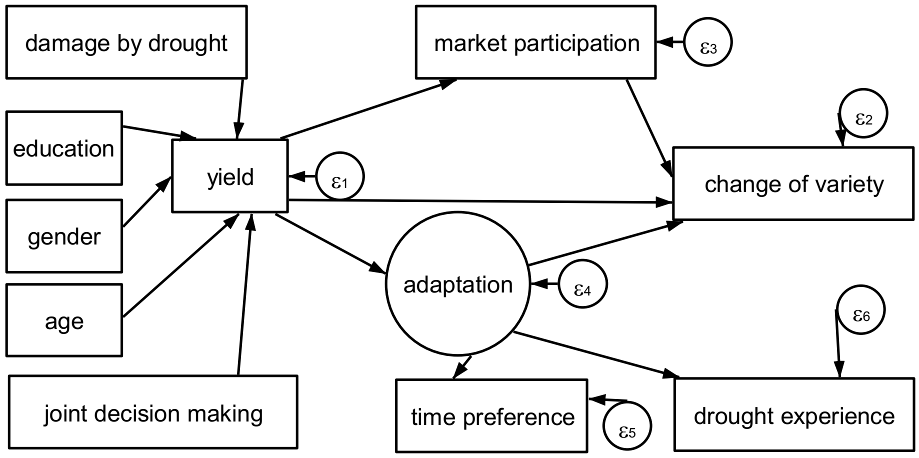


Figure 3. Augmented conceptual model and empirical path specification for the drought impact on varietal choice (note: large circle shape signifies the latent construct and small circles represent statistical error. The rectangles indicate the observed /measured variables.)

3.5 Statistical software for analysis

The estimation was conducted in STATA version 13. The raw data from IRRI survey was restructured to facilitate the path modeling and to be compatible with STATA data requirements.

3.6. Limitations

In this study, we considered two alternative mediating pathways to explain the connection between yield and varietal choice, namely, adaptation and market pressure. However, the market exposure of the farmer cannot always be adequately proxied by the proportion of the harvest sold. In such instances, an alternative approach may be to treat market exposure also as a latent variable and instrument the same using other observables. One limitation that we face is that we do not have other variables, which are able to explain the latent construct of market orientation adequately in the survey data.

Another possibility that could theoretically be relevant to our research question is that the market exposure is potentially codetermined along with adaptation motive (or co-varying with the adaptation motive). That is, both adaptation motive and market orientation is codetermined. The codetermination of latent variables, however, needs to be tested empirically in a more detailed empirical framework than what is adopted here and cannot be taken purely on the merits of logic.

4. Results

4.1. Key descriptive findings

Percentage damages by each of the three stressors indicate that 2014 is not an abnormally unfavorable year for rice in Bangladesh. Mean values of drought and salinity damage is recorded at less than 1 percent of the area cultivated while that for flood related damage is around 6 percent. It is noteworthy that the exposure to drought in particular is lower than in most South Asian rice settings on average.

Education, gender and age were included in the analysis as typical demographic variables. Since our key interest is in explaining the varietal change decision, we included joint (with spouse) decision making in farming as a social factor explaining yield. This variable considers if the respondent discussed with the partner before the decision to change the variety was arrived at. Given the predominance of male respondents, this variable is also a proxy on how empowered the women may be in the localities studied. The incidence of joint decision making slightly surpasses the incidence of females in the sample indicating, on average, minimal presence of consultation of women for varietal change decision.

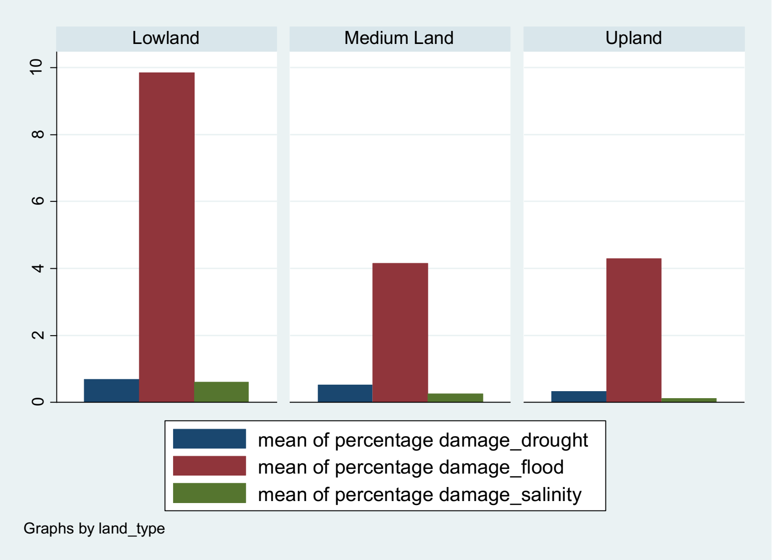
Among the variables explaining the latent construct of adaptation, we find time preference to be at a moderately high value indicating that majority of the sample valued the present gains (short term) to future gains (long term) given a comparable distribution of revenues. This observation sits well with the fact that these are farmers cultivating an annual crop of 3.5-month duration. The other variables were the respective experience in years of drought, floods and salinity during the previous 5 years. The mean exposure to floods and droughts were around 1 in 5 years while the salinity incidence was less common in the sample. Finally, the key variable of interest in this analysis, the change of variety from last season to the present, was on average quite common within the sample with a mean value of 0.65.

Table 1: Descriptive statistics of the variables

Variable	**Unit**	**Min**	**Max**
Percentage damage from drought	%	0	50
Percentage damage from floods	%	0	100
Percentage damage from salinity	%	0	40
Education	years	0	16
Gender	Female=1(otherwise 0)	0	1
Age	Years	30	85
Varietal decision jointly made	Joint decision=1(otherwise 0)	0	1
Yield	(metric tons/ha)	0	12
Time preference	index	1	10
Experience of drought (last 5 years)	Number of years	0	5
Experience of floods (last 5 years)	Number of years	0	5
Experience of salinity (last 5 years)	Number of years	0	5
Change of ricevariety	Change of variety=1(otherwise 0)	0	1

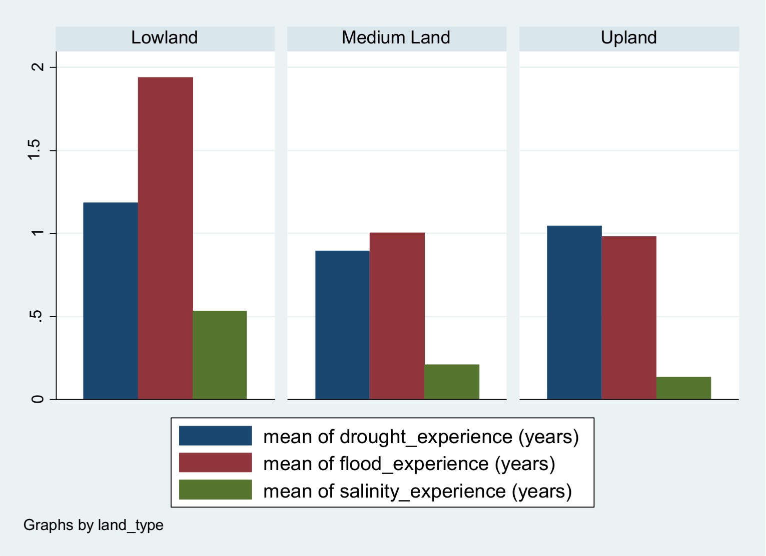
4.2 Exposure of rice system by topographical condition

While the climate related stresses operate at large spatial scales, the topography and elevation of paddy fields have differential level of exposure in terms of intensity of damage. It is observed that the lowland cultivations are disproportionately vulnerable, especially to floods. While there is no visible variation of exposure or damage across elevation with respect to droughts and salinity, the exposure and the damage related to floods vary across the elevation of rice fields. This observation is evident in the following disaggregation of percentage damage by each climate stress factor by the land elevation class (figure 5) and the farmer experience of the respective shock within the last five years by the land elevation class (figure 6). Low, medium and high elevations carry 670, 1571 and 282 households in the sample. This division approximates the distribution of elevation of the respective agricultural land elevation types in Bangladesh where low, medium and high elevation lands are classified 29%, 60% and 11% of total land area respectively.



Note: The bars show the mean values of the percentage damage to the crop establishment segregated by topographical class. The survey included 670 lowland households, 1571 medium elevation households and 282 upland households. This distribution is representative of land topographical classes of Bangladesh where low, medium and high elevation lands are classified 29%, 60% and 11% of total land area respectively.

Figure 4: Degree of damage due to climate stresses



Note: the bars show the mean values of the farmer experience to the different climatic stresses by topographical class

Figure 5: Degree of Exposure to climate stresses

4.3. Impact of drought to varietal choice

Figure 6 displays the estimated relationships with the sign and magnitude of the path coefficients. The estimated relationships provide evidence on the salience of drought stress on the decision to change the variety, mediated by farmer's adaptation to drought. The statistical significance is not reported on the diagram but included in table 2. Drought model highlights the expected relationship between the drought exposure and yield. Further, the direct effect of yield on varietal change potential is as conceptually anticipated.

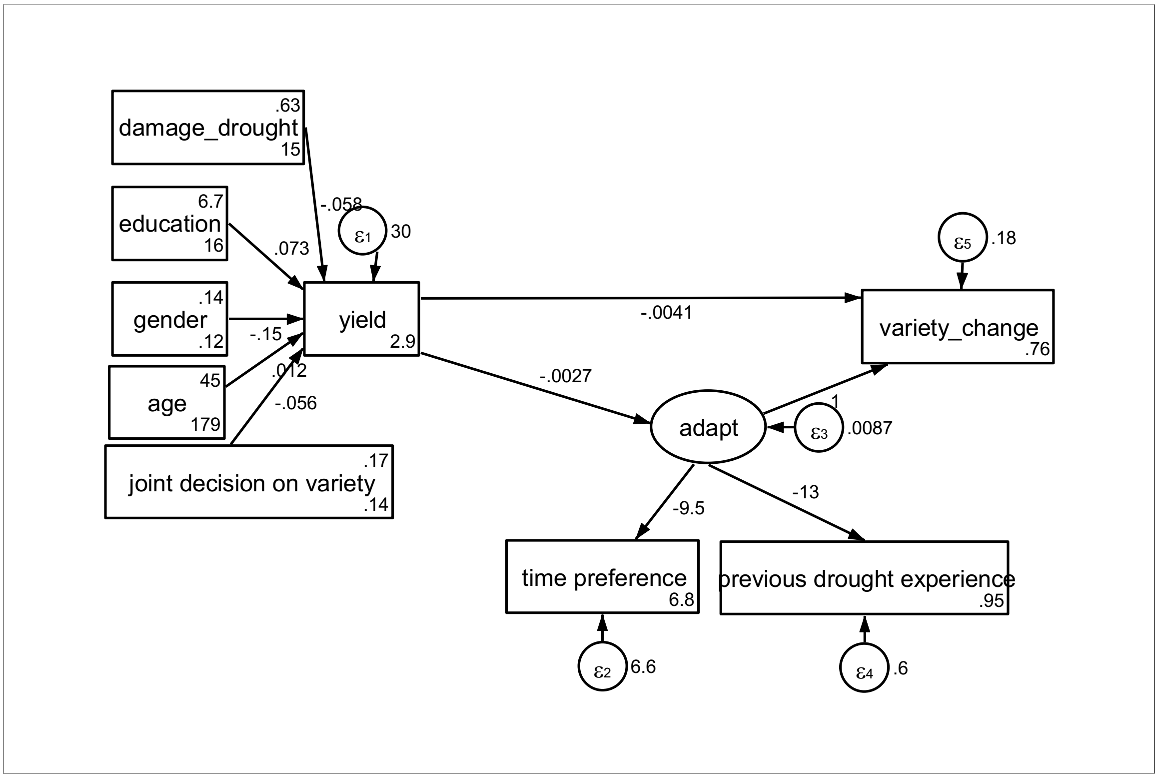


Figure 6: Estimated path analytic model for varietal change under drought impacts

The structural model essentially includes two steps. The first is the determination of yield in response to the demographics and drought incidence. Drought incidence has statistically significant negative impact on the yield (see Table 2). This is straightforward. Among the demographic factors, education is positively related to the yield but gender and joint household decision making on varietal choice are not. Age is associated positively but not statistically significant.

The second step of the model considers the varietal change decision given the yield, either directly or indirectly (mediated through 'adaptation motive'). The findings on the indirect channel show that the shorter the planning horizon of the farmer (indicated by high time preference), the lower the change of adaptation. Similarly, the longer the drought experiences during the last five years, the lower the likelihood of adaptation. Drought is a volatile condition and seems to discourage adaptation with respect to varietal change. Thus in the presence of drought, the adaptation-driven varietal change is not observable prominently.

Table 2: Estimated path coefficients for drought influenced varietal choice

Variables (by model components)	Coef.	Std.Err.	z	P>z
	Yield_path			
Damage(drought)	-0.058	0.013	-4.450	0.000
Education	0.073	0.031	2.340	0.019
Gender	-0.150	0.374	-0.400	0.688
Joint_decision_with_spouse	-0.056	0.336	-0.170	0.869
Age	0.012	0.010	1.190	0.235
	Variety_change			
Yield	-0.004	0.002	-2.050	0.041
	Adaptation			
Yield	-0.003	0.001	-2.990	0.003
Time_preference	-9.531	1.329	-7.170	0.000
Experience (drought)	-12.989	3.858	-3.370	0.001

Notes: The path model is estimated using maximum likelihood method and each partial coefficient (i.e relationship between two variables) is tested using a Z test against the null hypothesis of no relationship (i.e. independence of the two variables).

4.4. Impact of flood to varietal choice

In this section, we estimate the corresponding impact of flood on decision to change variety. In this instance, however, we do not include the time preference to instrument for the latent variable (i.e. adaptation), since flood episodes are more volatile than droughts and arguably have no direct bearing on the farmers planning horizon. Figure 8 displays the estimated path relationships.

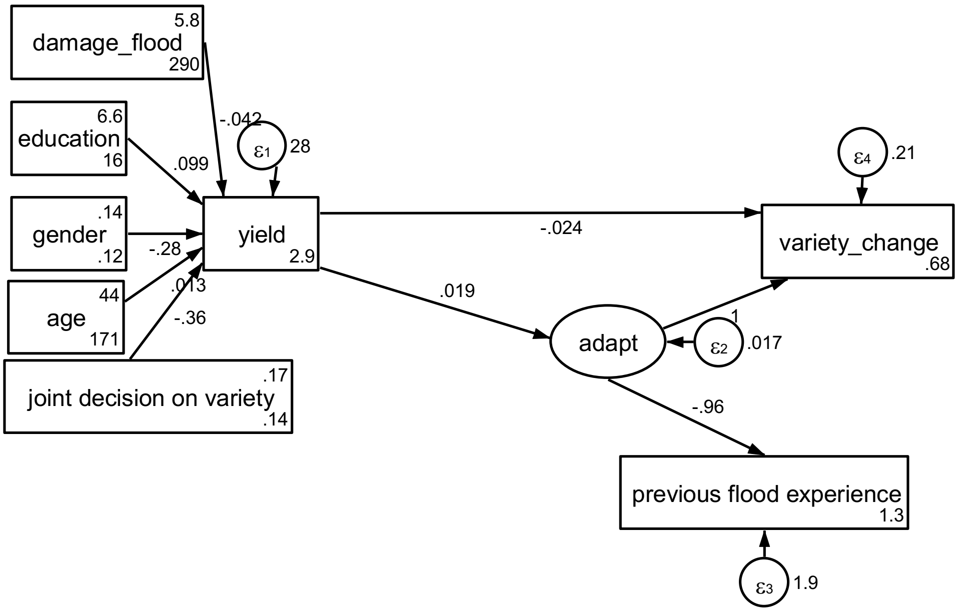


Figure 7: Estimated path analytic model for varietal change under flood impacts

The direct effect of yield increase on the change of variety is statistically significant (1 percent) and negative. This is similar to what is observed in the case of drought. The difference to the drought impact path is in the likelihood of adaptation. In the case of flood, yield has a positive (statistically significant at 1 percent) effect on the adaptation. Thus, in flood affected rice systems, varietal change is positively influenced by adaptation. Instrumentation of adaptation motive by flood exposure during the last five years is statistically significant (table 3).

Table 3: Estimated path coefficients for flood-influenced varietal choice

Variables (by model components)	**Coef**	**Std error**	**z**	**P>z**
	Yield_path			
Damage(flood)	-0.042	0.003	-12.840	0.000
Education	0.099	0.028	3.540	0.000
Gender	-0.280	0.327	-0.860	0.391
Joint decision_with_spouse	-0.363	0.294	-1.230	0.217
Age	0.013	0.009	1.440	0.150
	Variety_change (direct effect)			
Yield	-0.024	0.003	-7.850	0.000
	Adaptation (indirect effect)			
Yield	0.019	0.002	7.720	0.000
Experience (flood)	-0.961	0.085	-11.340	0.000

4.5. Impact of salinity to varietal choice

Salinity model indicates relationships, which are different to both droughts and floods (Figure 8). Unlike in the case of droughts and floods, where the direct effect of yield on change of variety was statistically significant, the direct effect of yield on change of variety is not statistically significant for salinity. Salinity is a more stable (non-volatile) phenomenon compared to floods, and we find that the adaptation is negatively linked to higher yields in the presence of salinity. In contrast to drought impacts, previous experience of salinity positively affects the adaptation. The presence of salinity resistant varieties and various soil and agronomic practices to mitigate salinity impacts on paddy soils aid such adaptation.

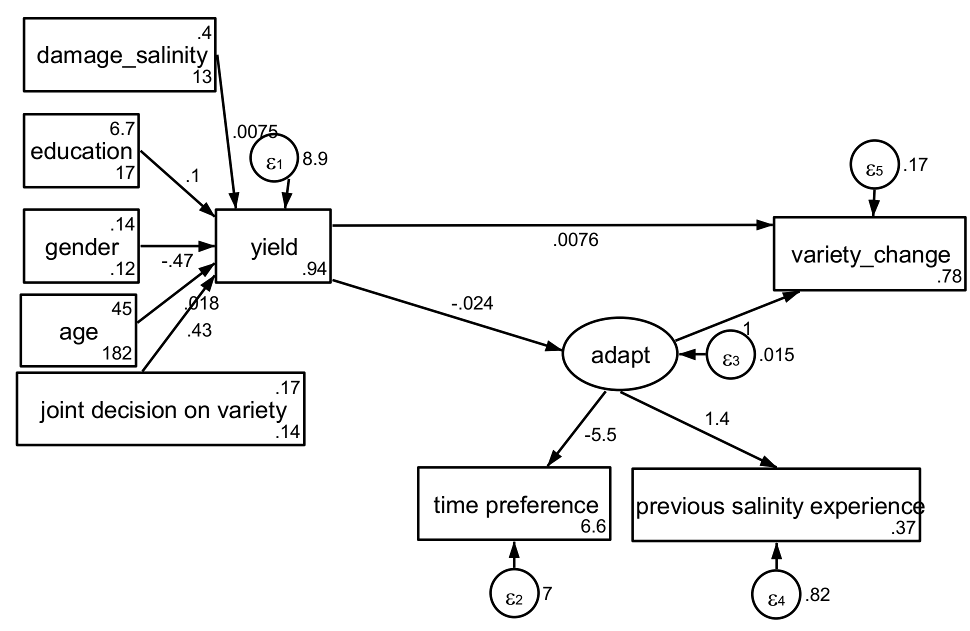


Figure 8: Estimated path analytic model for varietal change under salinity impacts

Salinity impact on yield is not statistically significant (table 4). This finding can be reasoned out as follows. If there is experience-driven adaptation with respect to salinity in the past, the incidence of salinity may not necessarily result in a reduction of yield.

Table 4: Estimated path coefficients for salinity-influenced varietal choice

variables (by model components)	**Coef.**	**Std.Error**	**z**	**P>z**
	Yield_path			
Damage (salinity)	0.007	0.016	0.460	0.646
Education	0.104	0.019	5.590	0.000
Gender	-0.470	0.183	-2.570	0.010
Joint_decision_with_spouse	0.428	0.229	1.870	0.061
Age	0.018	0.006	2.980	0.003
	Variety_change (direct effect)			
Yield	0.008	0.012	0.630	0.530
	Adaptation path (indirect effect)			
Yield	-0.024	0.012	-2.080	0.037
Time_preference	-5.482	2.722	-2.010	0.044
Experience(salinity)	1.434	0.670	2.140	0.032

4.6 Influence of market opportunity to varietal choice

An alternative conceptualization of the reasoning behind the farmer's decision is as follows. As in the previous analysis, the adaptation is present as a mediating factor. However, in addition, market priorities emerge as another factor determining varietal choice. We use the proportion of the harvest sold by each farmer as a proxy variable for degree of exposure to markets. A higher ratio for the above proportion implies that the farmer is more concerned about market perception of his varietal choice vis-à-vis a more subsistent farmer who don't need to worry about if the chosen variety is demanded by the market or not. This variable is named 'market response'. Incorporation of market linkage frames the varietal choice decision more completely than in the previous analysis. Therefore, we augment the path analysis model tested in section 5 by incorporating the market linkage (denoted by the path that connects yield and varietal choice through 'market response').

4.6.1. Under drought condition

In the case of drought, the inclusion of market exposure via an additional path does not lead to substantive changes in the key relations observed in the model estimated in section 5.1. However, market response pathway adds to the explanatory power and the model fit. The market exposure mediates the relationship between yield and varietal change statistically significantly. The significant impact of market exposure convinces us that both adaptation motive and the market pressure act in unison and in the same direction in the case of drought affected rice in Bangladesh (see figure 10 and table 5).

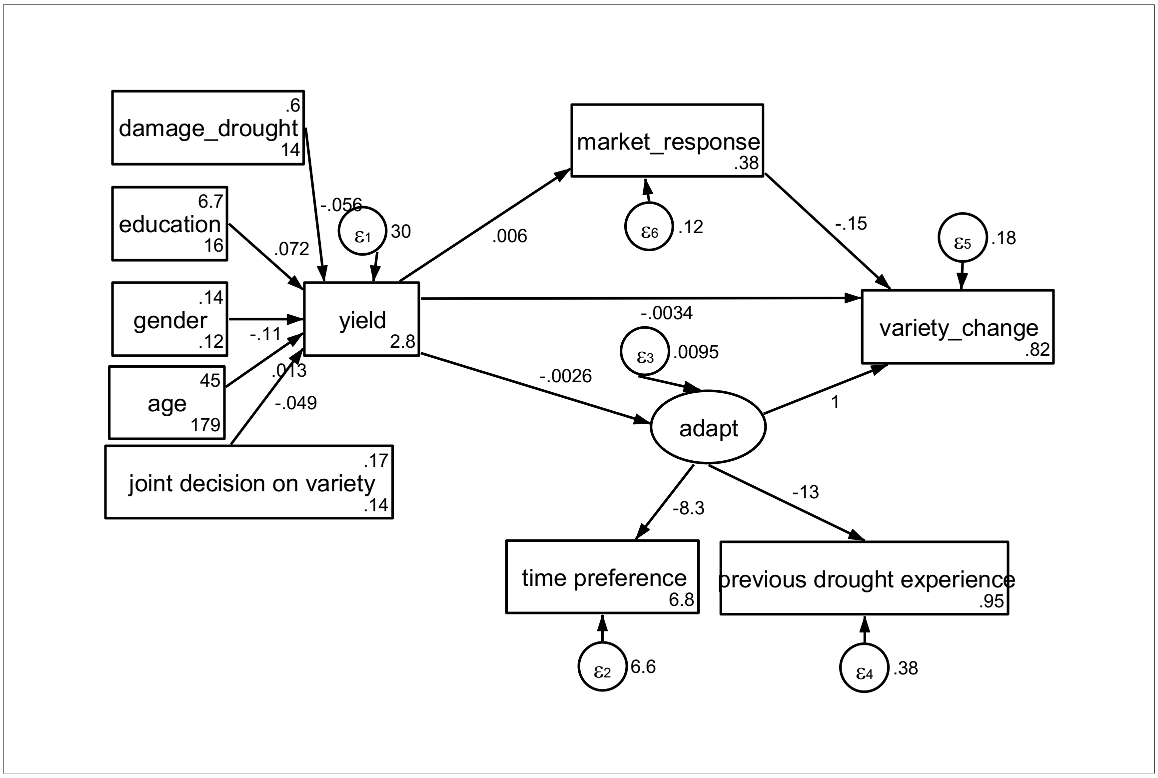


Figure 9: Augmented path analytic model for varietal change under drought impact

Table 5: Estimated path coefficients for drought-influenced varietal choice-augmented model

Variable	**Coef.**	**Std. Err.**	**z**	**P>z**
Yield_path				
Damage_drought	-0.056	0.014	-3.920	0.000
Education	0.072	0.031	2.310	0.021
Gender	-0.108	0.378	-0.290	0.774
Joint_decision_with_spouse	-0.049	0.339	-0.150	0.884
Age	0.013	0.010	1.290	0.196
Variety_change (direct effect)				
Yield	-0.003	0.002	-1.680	0.093
Market_response	-0.155	0.026	-5.860	0.000
Market_response (indirect effect)				
Yield	0.006	0.001	4.310	0.000
adaptation (indirect effect)				
Yield	-0.003	0.001	-2.750	0.006
Time preference	-8.287	1.054	-7.860	0.000
Experience (drought)	-13.390	4.235	-3.160	0.002

4.6.2 Under flood condition

In the case of flood, the inclusion of market exposure as a mediating variable of varietal change decision fails to provide additional explanatory power to the model estimated in section 5.2 (on flood effect). Therefore, we conclude that adaptation motive (conditioned by previous experience of floods) remains the only statistically valid mediator of varietal change decision in the case of flood impacts.

4.6.3 Under Salinity condition

Similar to the case of floods, the inclusion of market exposure as a second channel of explaining yield to varietal change path does not alter direct effects observed in section 5.3 (on salinity). The statistically insignificant direct effect remains but a positive (significant at 1 percent) linkage between yield and market exposure and a negative linkage (significant at 1 percent) between market exposure and varietal chance decision exist. In essence, the augmented model reinforces the negative mediated effect between yield and varietal change observed previously for salinity (see figure 11 and table 6).

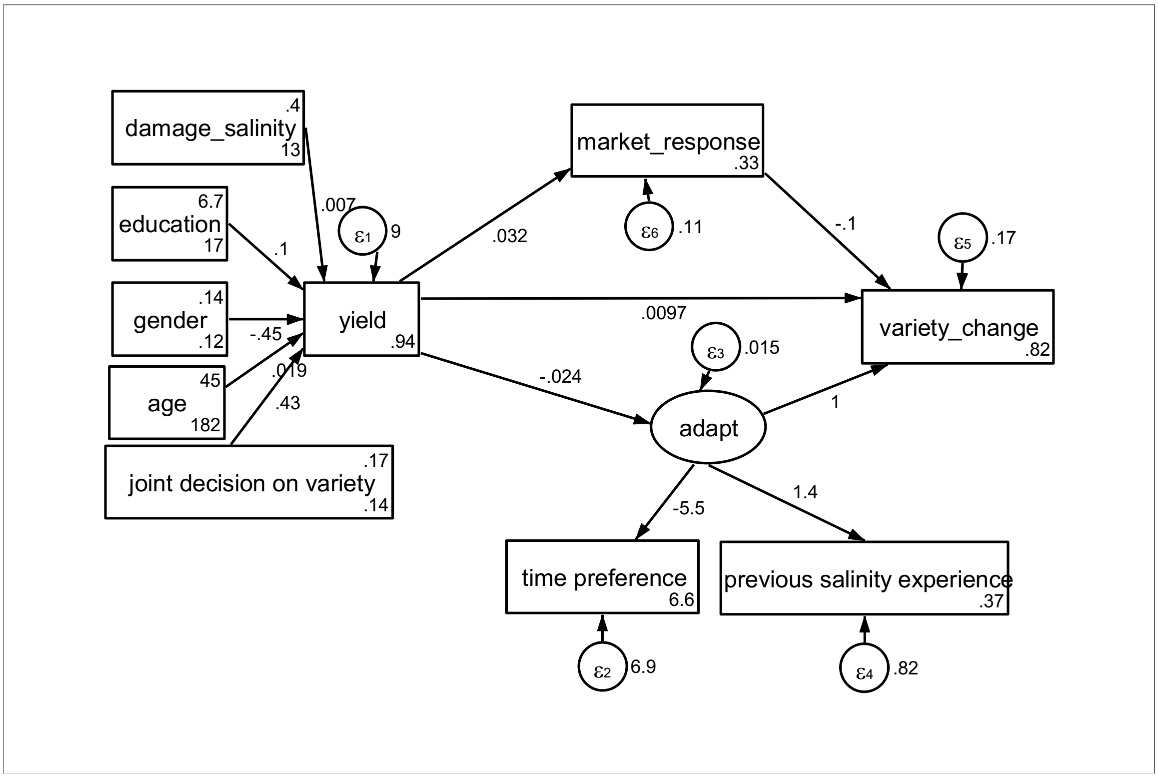


Figure 10: Augmented path analytic model for varietal change under salinity impacts

Table 6: Estimated path coefficients for salinity-influenced varietal choice-augmented model

Variables	**Coef.**	**Std. Err.**	**z**	**P>z**
Yield_path				
Damage_salinity	0.007	0.016	0.430	0.669
Education	0.103	0.019	5.540	0.000
Gender	-0.450	0.184	-2.440	0.015
Joint_decision_with_spouse	0.431	0.230	1.870	0.061
Age	0.019	0.006	3.080	0.002
Variety_change (direct effect)				
Yield	0.010	0.012	0.800	0.424
Market_response	-0.100	0.029	-3.430	0.001
Market_response (indirect effect)				
Yield	0.032	0.003	12.000	0.000
Adaptation (indirect effect)				
Yield	-0.024	0.012	-1.990	0.047
Time preference	-5.482	2.814	-1.950	0.051
Experience (salinity)	1.417	0.696	2.040	0.042

4.7. Model estimation under log-transformed climate damage variable

In order to make our statistical results robust, the above estimation was repeated after transforming the percentage damage variables logarithmically. This was carried out to remove potential implications of the skewness of the percentage damage variables. The models were re-estimated for all the three climate stresses. Based on the estimation after log transformation, the only difference observed was in the linkage between yield and the change of variety under flood condition. The relationship becomes statistically insignificant after log transformation of flood damage variables. All the other relationships remain unaffected. Therefore, we do not provide the detailed findings of the log-transformed model.

5. Implication from the results

The findings of the study carries important implications to our understanding of how climate stresses are handled by farmers who face the pressures of markets and varying capacities to adapt at the same time. It is perhaps the quintessential challenge faced by the low-income smallholders. While there are many incentives such as fertilizer subsidies and safeguards such as social insurance, the adaptation mechanism to multiple perils is a unique problem faced by individual farmers. The related decision process is multifaceted but we look at a single aspect of the behavioral responses to climate stresses in this study, namely, the change of cropping variety. This choice is conditional on the yield level of the existing variety, the level of market participation of the farmer and the adaptation capacity of the farmer. While many policy interventions primarily target yield stability, very little policy attention falls on the other two elements directly. One could argue that market participation is addressed in many supply chain support and marketing support programs but these measures are usually generic and not conditional on different climate stress factors that farmers face. On the other hand, adaptation capacity is internal to the smallholder with relation to varietal choice. Here, we explicitly assume that varietal choice is an independent decision of each farmer. Therefore, the settings of group decision making and wide area cropping programs are outside the scope of the method utilized in the present study. The literature following similar lines of the present study, namely varietal choice decision making under moderating factors in response to climate change is very limited, with respect to Bangladesh or in relation to tropical rice farming.

6. Conclusions and ways forward

This study looks at the connection between rice yield and varietal choice by farmers under climate pressure. We capture the richness in the farmer's decision-making of varietal choices in a path analytical model, estimated as a structural equation system. In particular, we rationalize the farmer's decision-making process based on the concept of integrated vulnerability. Integrated vulnerability means in this case to include the aspects of vulnerability and the adaptation potential. The first concept is directly instrumented by a variable in our model. The second concept is included in the model as a latent variable, which is estimated using other behavioral variables.

Our results reveal that drought, flood and salinity damages have a negative impact on yield in the selected random sample of farming households across Bangladesh. This finding validates our research question and poses important implications to climate change management and food security policies of Bangladesh. Among the socio-demographic variables, education level has a positive relationship with the yield. Interestingly, gender, age and joint decision making (with spouse) have no impacts on yield in the case of drought and floods, but display a positive impact on yield in the case of salinity. Therefore, in the context of droughts and floods, there is potential to incorporate demographic and farmer household's factors in yield improvement programs. Instrumenting the adaptation motive provides useful findings. Farmers' time preference (preference for short-term gains vis-á-vis long-term benefits) and level of yield have negative associations with the adaptation motive. This finding implies that Bangladesh's rice farmers' preference for short-term solutions and the existing yield levels discourage efforts towards climate change adaptation. However, the years of experience of droughts and floods within the last 5 years also have negative association to the adaptation motive. For salinity, on the other hand, the effect of previous exposure contributes positively to adaptation. Therefore, rice development in salinity-affected areas can harness the increased adaptation potential in furthering food security through salinity tolerant rice varieties. In contrast, the failure of previous experience in drought and floods to generate adaptation trends implies that these two stresses do not propel farmers to adapt through change of varieties. The varietal development process has not been successful in providing solutions to drought and flood conditions and future policy interventions in climate change adaptation need to focus other solutions to combat drought and flood conditions in rice.

In the models that include both the market response and adaptation, in addition to the previous results, we find that, in the case droughts and salinity models, the higher the market exposure of the farmer in terms of proportion sold from the harvest, the lesser the chance of changing the variety. This is to be expected given that higher sales signify that farmers are adopting a variety with a higher market preference that can offset potential implications of drought or salinity. In the case of floods, the model fails to converge making it impossible to reach a conclusion on the market impact on varietal change.

In summary, with respect to choice of rice varieties in Bangladesh in response to climate stresses, we can conclude that farmers take salinity into account in their decision-making, but not drought or floods in particular. The statistical models fail to substantiate any varietal change impact in the case of droughts and floods. A possible reason for this finding is the nature of unpredictability of impact of floods and droughts which makes adaptation through varietal change more difficult compared to the case of salinity. Salinity tolerant varietal selection thus appears to be more successful and relevant to farmers. Rice germplasm development and varietal selection programs targeting salinity tolerance rather than drought and flood tolerance are revealed to be successful means of climate change adaptation. Our findings can also be interpreted as evidence of a lack of successful drought and flood tolerant varieties in Bangladesh or poor farmer adoption of flood and drought tolerant varieties. Further, the conceptualization of varietal change decision in the present study generates new information. The time preference of farmers and the previous exposure to climate shocks add explanatory power to the model and therefore we conclude that these variables are valid predictors of adaptation process. Perhaps, the most significant policy implication is the finding that market preference for varieties overshadows the adaptation pathway. Thus, in the context of Bangladesh rice farming, the market signals create pressure on varietal selection more than the potential adaptation driven decisions. This highlights the need for policy interventions that could facilitate climate changes adaptation in rice without jeopardizing the market preferences.

The study opens new avenues of investigating food security in landscapes prone to climate stresses. While food security is ensured through efficient use of resources under appropriate technologies, the behavioral aspects of food production need careful analysis. While our findings show famers adaptation processes as distinctly different when the type of climate stress varies, we look only at one form of adaptation, i.e. choice of variety. Future research can incorporate the interdependencies of various adaptation instruments in multifunctional landscapes. Such interdependencies are possible between varietal choice and other management practices such as water and soil conservation measures, irrigation methods. However, combining different instruments will necessitate complicated statistical methods of data analysis, but such analytical studies can reveal non-trivial implications, which may otherwise be hidden to the development planners.

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