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DEFAULT RISKS, MORAL HAZARD, AND MARKET-BASED SOLUTION: EVIDENCE FROM RENEWABLE ENERGY MARKET IN BANGLADESH

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Abstract

This paper analyzes a unique case of default risks and associated factors of a solar home system (SHS) program in Bangladesh and, within that context, proposes a theoretical market-based solution to finance a renewable energy (RE) program. The paper first develops a theoretical framework that highlights the problem of moral hazard in a subsidized government-sponsored program and then empirically assesses the default risks under the program. Using a primary survey data of 1,300 households, and applying probit and cox's proportional hazard model, we find that financial constraints, higher prices, natural disasters, and poor after-sales service are the factors that increase the probability of default, but in a different magnitude depending on the nature of customers. The factors that increase the probability of default for the group who are not willing to pay back (about 35% of total defaulters) are linked to adverse selection, perhaps due to moral hazard problems. The proposed market-based solution predicts that if the government uses a spillover revenue-based financing approach, it will increase the rate of return for private investors as well as the efficiency of RE programs.

Keywords: Bangladesh, default risks, renewable energy, market-based solutions, solar homes, spillover tax revenue

JEL Classification: Q41, Q42, Q43, Q47, Q48

Contents

1. INTRODUCTION

Renewable energy (RE) programs play a complementary role worldwide to ensure energy security in addition to providing environmentally friendly clean energy. Spectacular growth in solar electricity and solar plant capacity has been observed in recent years with substantial technological progress in this sector (Taghizadeh-Hesary, Yoshino, and Inagaki 2019). For example, while annual production of solar electricity has increased from 4 TWh in 2005 to 247 TWh in 2015, the accumulated capacity of solar electricity plants has grown from 100,504 MW in 2012 to 368,000 MW in 2017 (IEA 2017). Despite the growing demand for renewable energy, a 2017 estimate shows that global investment in renewables and energy efficiency has declined by 3%. Higher prices for renewable energy, credit default risk, the lack of a proper understanding of the risks and returns of RE projects, and underdeveloped equity and bond markets are some of the difficulties that impede the growth of the RE market (Hossain 2019). Finding a balance between welfare and commercialization is another big challenge for implementing RE projects (Hossain et al. 2018).

Low return and distributional concerns make green energy projects less attractive for private investors in many developing countries, and they are instead being implemented by government organizations with subsidies. However, subsidized government-run programs often suffer from typical problems of redistribution, lack of coordination between various stakeholders, fiscal burden, etc. (Hossain 2019; Barnes and Halpern 2000).

Our knowledge about implementation challenges of country-specific RE programs is still limited. For achieving sustainable development goals, fine-tuning of RE programs is essential in order to up-scale the programs. This paper analyzes the case of a government-sponsored SHS program in Bangladesh, a very successful SHS program in the world in terms of its rapid growth (about 36% annually up to 2013) and coverage, though it is now in peril due to accrual of huge credit default risks.

The SHS program in Bangladesh was implemented by the Infrastructure Development Company Limited (IDCOL), a public non-bank financial institution (NBFI) established in 2003 with donor money channeled through the government. IDCOL has so far installed 4.13 million SHSs, providing access to solar electricity to about 12% of the total population. The program runs through a public-private partnership. IDCOL appoints 56 NGOs (known as partner organizations or POs) to implement the program throughout the country with refinancing facilities and subsidies. Beginning in 2014, the growth of SHS adoption started declining and it was revealed at the end of 2017 that about 50% of total investments of IDCOL for SHS remained outstanding (about Tk 20,000 million), of which one-fourth remained overdue. Customers defaulted for various known or unknown reasons, which made POs also default to IDCOL.[1]

Two issues are considered as the main reasons behind the dwindling situation of the SHS program. One is government expansion of grid electricity through the Rural Electrification Board (REB) in IDCOL's intervention areas without any coordination, resulting in customers who are unwilling to pay back the dues of SHS. The other is the emergence of an unregulated private market of cheap (perhaps low quality) SHSs. Apart from these, we anticipate moral hazard problems as subsidies are attached to the program.

[1] POs sell SHS to customers on credit payable in three years (in 36 equal installments) with 15%–20% downpayment.

The main objective of this paper is to examine the factors behind the default risks in the SHS program in Bangladesh, and to identify market-based solutions. Since IDCOL's SHS program was run by agents (POs), and the default amount accrued to POs was due to the failure of POs to collect dues from SHS customers, we assume that this is a classic principal-agent problem and, therefore, there is a high likelihood of a moral hazard problem. Though moral hazard problems are common in business and commercial credit programs, the issue is quite new in the RE program. Castillo, Mora-Valencia, and Perote (2018) showed by analyzing SMEs that moral hazard problems increase the probability of failure of borrowers, and Gupta and Gregoriou (2018) suggested that market-based finance reduces the likelihood of failure.

The paper makes an important contribution to the literature by analyzing a unique country-specific case of default debt accrued in a solar home program and identifying various risk factors associated with implementing such a program that call for market-based options in order to sustain and scale up RE programs.[2] This paper proceeds in three steps. First, we develop a theoretical model considering the objective functions of the respective parties involved, such as the government (IDCOL), POs, and customers. The model suggests that adoption of a SHS is constrained by customer income as well as the price of a SHS. If the implementing POs go for aggressive marketing from a profit motive (as subsidies are attached) without taking into consideration the financial situation of customers, there is a high likelihood of a moral hazard problem. The complexity of the government's part also arises due to concerns of commercialization and welfarism. Second, this paper empirically assesses the default risks and the associated factors, including the moral hazard problem. For this purpose, we used data from a primary survey of 1,300 households, including both SHS-beneficiary and non-beneficiary households, conducted in 2017 by the Bangladesh Institute of Development Studies (BIDS) for IDCOL. For methodology, in addition to descriptive statistics, we applied Probit and the Cox's proportional hazards regression model, a survival model, to identify the reasons behind debt default as well as to estimate the default risks for the current non-defaulters. We checked the robustness of the results using various specifications of the models. Third, we propose theoretical market-based options based on spill-over revenue generated from the solar electricity projects.

The paper is organized as follows. After the introduction, Section 2 provides an overview of the SHS market in Bangladesh. Section 3 develops a simple theoretical framework to discuss how the SHS market could indulge in a moral hazard with subsidies. Section 4 discusses the data and variables, while Section 5 discusses the empirical estimation strategies and results. Section 6 presents a theoretical model of market-based financing solutions for RE projects and Section 7 provides the conclusion and policy implications.

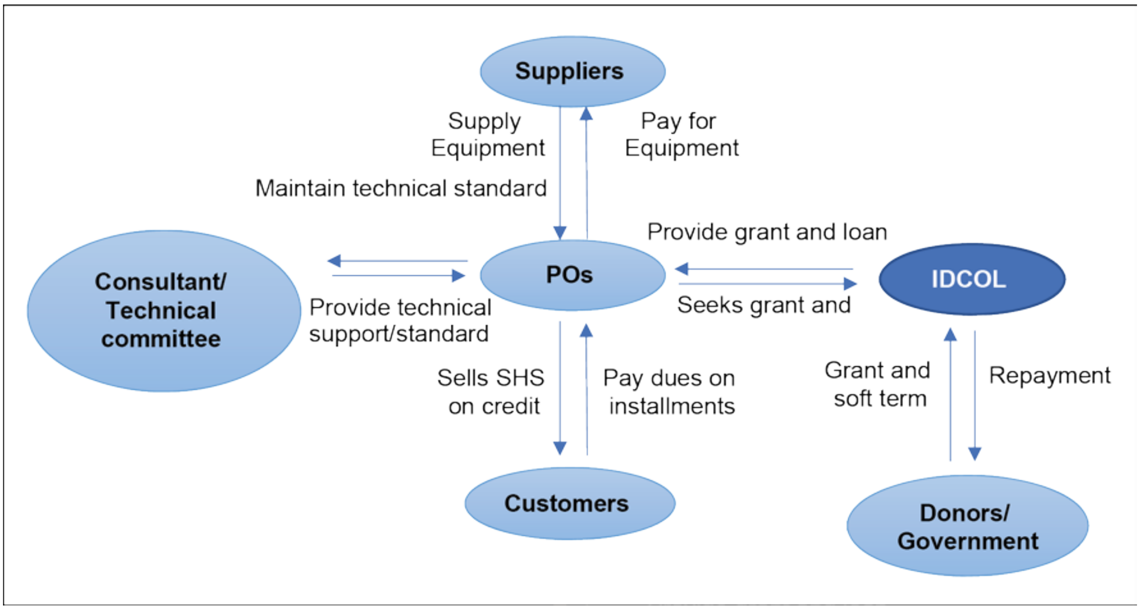
[2] A lack of policy and regulatory framework, investor inexperience, new technology, and a lack of suitable market-based financing vehicles and instruments are some of the main impediments for implementing RE programs. The low rate of return and the associated risks are the main reasons that deter private investors from entering into long-term financing of infrastructure projects, including green energy projects (Yoshino and Taghizadeh-Hesary 2018).

2. SOLAR HOME SYSTEM MARKET IN BANGLADESH

2.1 Market Structure

With notable off-grid areas and unreliable grid electricity, Bangladesh is a potential market for solar electricity. A strong solar home market has emerged with annual sales of approximately 0.3 million units, most of which have been installed by IDCOL in the absence of a private market for SHSs. IDCOL started a subsidized solar homes program in 2003 with financing support from donor agencies, particularly from the World Bank. IDCOL has engaged 56 NGOs (POs) that have good networks in rural Bangladesh to run the program with refinancing credit facilities and subsidy support for marketing SHSs. IDCOL has so far implemented 4.13 million SHSs in rural Bangladesh, providing access to solar electricity for about 12% of the total population. IDCOL provides credit to POs with a refinancing approach at an interest rate of about 6%−8% (lower than the market rate, which is about 12%–15%), and POs sell the SHS to customers on credit that is payable in installments over a 3-year period at a 12% interest rate. The structure of IDCOL's SHS market is shown in Figure 1.

Figure 1: Structure of IDCOL's SHS Market



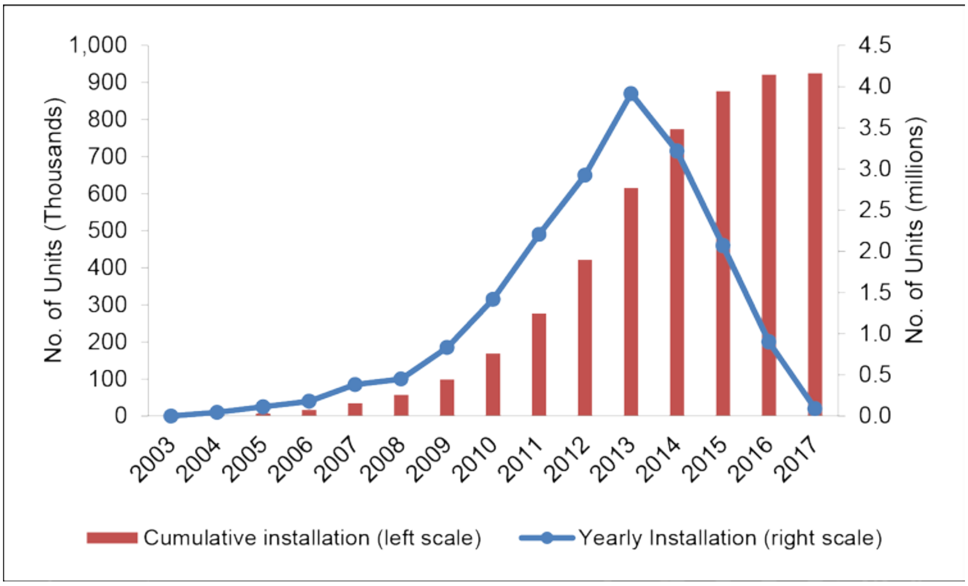
Source: IDCOL.

In addition to refinancing credit facilities to POs, the IDCOL program involves subsidies in the form of a capital buy-down grant and an institutional development grant. IDCOL's SHS program started with a total subsidy of $90 per system in 2003, including $70 as a capital buy-down grant and $20 as an institutional capacity development grant. IDCOL started gradual phase-out of the subsidy amount per system. As a result, the institutional development grant was withdrawn in 2012, and the capital buy-down grant subsidy of $20 was made applicable to only smaller systems (less than or equal to 30Wp). Although 56 POs were involved in SHS marketing and distribution, the aggregate share of two POs was 52.7%—Grameen Shakti at 38.2% and the Rural Services Foundation (RSF) at 14.5%.

2.2 Growth of the SHS Market

The growth of SHS installation was exemplary for any RE program. While the number of SHS units installed up to 2005 was 0.1 million units, the number increased to a total of 4.13 million in June 2018. During this time period, the installation of SHS units increased by 36.3% annually (Figure 2). Note that the highest number of SHS units was installed in 2013, and after that the installation rate started to decline.

Figure 2: Number of SHSs Installed Over Time



Source: IDCOL.

It is to be noted that the SHS market saw a surge in sales of smaller SHSs, in particular the 20 Wp-sized SHS which accounted for about 50% of total sales after 2010 mainly due to subsidies attached to this type of SHS. On the other hand, the 40 Wp and 50 Wp sizes lost their market share during the same period—their shares decreased from 21% and 16% in 2010 to 12% and 9% in 2014, respectively. The market share of bigger sized SHSs (over 60 Wp) remained more or less resilient during the period.

2.3 Pricing of a SHS

The pricing of a SHS has been a tricky issue for ensuring the demand for SHSs in rural areas. For example, the IDCOL subsidy reduction has been reflected in price escalation of IDCOL's SHS (Hossain 2019). Without any further reduction in subsidies, the price of a SHS further declined, mainly due to technological improvement in the quality of PV modules and reduction in deep cycle battery prices, along with withdrawal of VAT and entrants of new POs in the market.

Despite the conundrum of regulatory issues and the private market price situation, most of the dominant sizes of IDCOL's SHSs have experienced a decline in price over time, though the price is higher than in the private market (Table 1). However, such a decline has not been enough to compete with the private market. A comparison of prices of different Wp SHSs in Table 1 indicates that the price of SHSs in the private market is relatively much lower than that in the IDCOL market mainly due to the fact that the private market, which is unregulated, sells low-quality PV modules without commitments for after-sales service.

Table 1: Prices of SHS in Both IDCOL and Non-IDCOL Market (in Tk)

		Yearly Mean Price of SHS					
Categories	**SHS**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
IDCOL	20 Wp	15,207	15,093	15,813	12,779	10,508	
	30 Wp		18,851	19,937	17,847	12,828	
	40 Wp	26,589	27,248	28,716	23,188		
	50 Wp	48,501	32,736	35,517	26,000		
	60+ Wp	45,538	43,376	46,419	35,156		
	Total	34,551	22,926	24,922	20,360	12,165	
Non-IDCOL (open market)	20 Wp	10,250	10,500	5,800	5,416	6,305	6,104
	30 Wp			11,138	11,125	8,013	8,833
	40 Wp	28,000	18,375	15,750	8,943	11,150	9,270
	50 Wp	30,000	20,500	14,750	13,767	13,477	11,150
	60+ Wp	27,000	27,143	23,778	14,188	17,161	23,263
	Total	19,125	22,056	14,425	11,016	10,881	12,344

Source: BIDS Survey, 2017.

2.4 Default Risks and Moral Hazard

IDCOL has so far invested a total amount of Tk45,447 million for its SHS program. As Table 2 shows, the amount of outstanding loans to POs that are classified as bad (non-recoverable) stands at Tk1,243.93 million (as of December 2017), of which Tk1,030.89 million remained overdue. That is, over 83.44% of total outstanding loans remained overdue, mostly owed to two large POs (GS and RSF) with a market share of over 50%.

Table 2: Default Loan by POs as of December 2017 (in Tk)

Classification Status	**Number of Loan Accounts**	**Total Loans Outstanding**	**Total Loans Overdue**	**Overdue as % of Total Outstanding**
Standard	27	2,942,691,191	312,155,531	10.61
SMA	20	15,513,167,279	3,369,515,051	21.72
Sub-standard	0	24,835,013	6,294,186	25.34
Doubtful	1	1,053,692,697	274,927,965	26.09
Bad	2	1,243,935,054	1,037,885,165	83.44
Total	50	20,778,321,234	5,000,777,897	24.07

Note: SMA = Special Mention Account.

Source: IDCOL (2018).

In the context of a dwindling SHS market, a large number of POs have failed to repay their loans to IDCOL. Some POs seem reluctant to collect their dues from customers and repay IDCOL due to weaker financial contracts between POs and IDCOL.[3] The total amount due from POs to IDCOL stands at about Tk20778 million, which is about three times the amount of IDCOL's paid-up capital. However, amounts due to POs from customers may not be equal to the amounts due to IDCOL from POs. An attempt has been made to estimate the default amount accrued to POs from data in the BIDS survey of households (Hossain et al. 2018). According to survey results, there were 36.47% unpaid amounts out of an average Tk24,890 payable by each customer. The average default amount for each customer is thus estimated at Tk9,077.38. Assuming the total number of default customers provided by IDCOL is correct at about 1.2 million, the estimated total default amount stands at Tk10,680 million, which is half of the reported estimation (Table 2). Since 65% of default customers would like to repay (as per survey responses, which might in reality be lower), the recoverable amount is then estimated to be Tk6,940 million, assuming that POs will make an intense effort to collect the past due amount. A conservative estimate based on the 35% of customers who are unwilling to pay plus half of the 65% who committed to pay during the survey predicts that roughly Tk7,210 million would remain unrecoverable, which is close to the PO estimates in Table 2.

The anomalies in reporting the total due from POs to IDCOL is also evident from the audited reports of the two largest POs (Hossain et al. 2018). The audited reports of GS and RSF reveal that, despite retrenching a large amount of field staff by POs, operating expenses of both POs increased substantially, particularly for salary expenses, which implies that these two POs divert IDCOL's money to other activities. Thus, PO reluctance in recovering amounts due is somehow linked to a moral hazard problem.

3. THEORETICAL MODEL FRAMEWORK

In this section, we develop a simple theoretical framework considering a household's utility function and PO profit functions for SHS adoption.

3.1 Household

Consider the utility function of a household as follows:

$$U(C,Y^s) = logC_t + \beta logY_t^s \quad (1)$$

subject to: $C_t + P_tY_t^s \leq Y_t^I$ (2)

Where C_t: Consumption, Y_t^s: Solar and Y_t^I: Total income of household.

Using Lagrange approach, we obtain

$$\mathcal{L} = [logC_t + \beta logY_t^s] - \lambda[C_t + P_tY_t^s - Y_t^I] \quad (3)$$

[3] IDCOL signed participation agreements with POs in a weak format making a condition of 10% down payment of total credit with no pledges of collateral as the POs are non-profit NGOs. The Agreements do not have any provisions that empower IDCOL to intervene for repayment of the loan in case there is any default (Hossain et al. 2018). It seems that IDCOL did not think of the emergence of this kind of situation, although they later added some stringent conditions that have not proved sufficient.

Now, $\frac{\delta \mathcal{L}}{\delta C_t} = \frac{1}{C_t} - \lambda = 0$,

$$=> \lambda = \frac{1}{C_t} \quad (4)$$

Again, $\frac{\delta \mathcal{L}}{\delta Y_t^s} = \beta \frac{1}{Y_t^s} - \lambda P_t = 0$,

$$=> \frac{\beta}{Y_t^s} = \lambda P_t = \frac{1}{C_t} P_t \quad (5)$$

Again, $\frac{\delta \mathcal{L}}{\delta \lambda} = C_t + P_t Y_t^s - Y_t^I = 0$ (6)

$$=> C_t = Y_t^I - P_t Y_t^s \quad (7)$$

From (5), $Y_t^s = \frac{\beta C_t}{P_t}$ (8)

Substituting (7) into (8), we obtain

$$Y_t^s = \frac{\beta (Y_t^I - P_t Y_t^s)}{P_t} = \beta \frac{Y_t^I}{P_t} - \beta Y_t^s \quad (9)$$

$$(1 + \beta) Y_t^s = \beta \frac{Y_t^I}{P_t}$$

$$=> Y_t^s = (\frac{\beta}{1+\beta}) \frac{Y_t^I}{P_t} \quad (10)$$

Therefore, adoption of SHS depends on household income and price of SHS. By taking logarithm of Eq 10, the demand for SHS can be expressed as follows:

$$log Y_t^s = log(\beta Y_t^I) - \log\,[(1+\beta) P_t]$$

3.2 Partner Organization (PO)

The profit function of a PO can be written as follows:

$$\pi^{PO} = P_t^s(Y_t^s) * Y_t^s + SUB(\theta_{t-1}^s, Y_t^s) + Fee(Y_t^s) - \tilde{P}_t^s Y_t^s - \theta_t^s Y_t^s \quad (11)$$

where *SUB* represents government subsidies to SHS programs, *Fee* represents consultant fees, $\tilde{P}_t^s$ represents suppliers' price of SHS and θ_t^s is the default amount associated with SHS. It is assumed that SUB is a function of the previous period's default and the amount of SHS sold out because the program runs on a refinancing scheme.

Taking first derivative of Eq 11 w.r.to Y_t^s, we obtain

$$\frac{\delta \pi^{PO}}{\delta Y_t^s} = \left(\frac{\delta P_t^s}{\delta Y_t^s} Y_t^s + P_t^s \right) + \frac{\delta SUB}{\delta Y_t^s} + \frac{\delta Fee}{\delta Y_t^s} - \tilde{P}_t^s - \theta_t^s - \frac{\delta \theta_t^s}{\delta Y_t^s} Y_t^s = 0$$

$$=> (-\delta) Y_t^s + P_t^s + \frac{\delta SUB}{\delta Y_t^s} + \frac{\delta Fee}{\delta Y_t^s} - \tilde{P}_t^s - \theta_t^s - \frac{\delta \theta_t^s}{\delta Y_t^s} Y_t^s = 0$$

Finally, $\left(\delta + \frac{\delta\theta_t^s}{\delta Y_t^s}\right) Y_t^s = P_t^s - \tilde{P}_t^s - \theta_t^s + \frac{\delta SUB}{\delta Y_t^s} + \frac{\delta Fee}{\delta Y_t^s}$ (12)

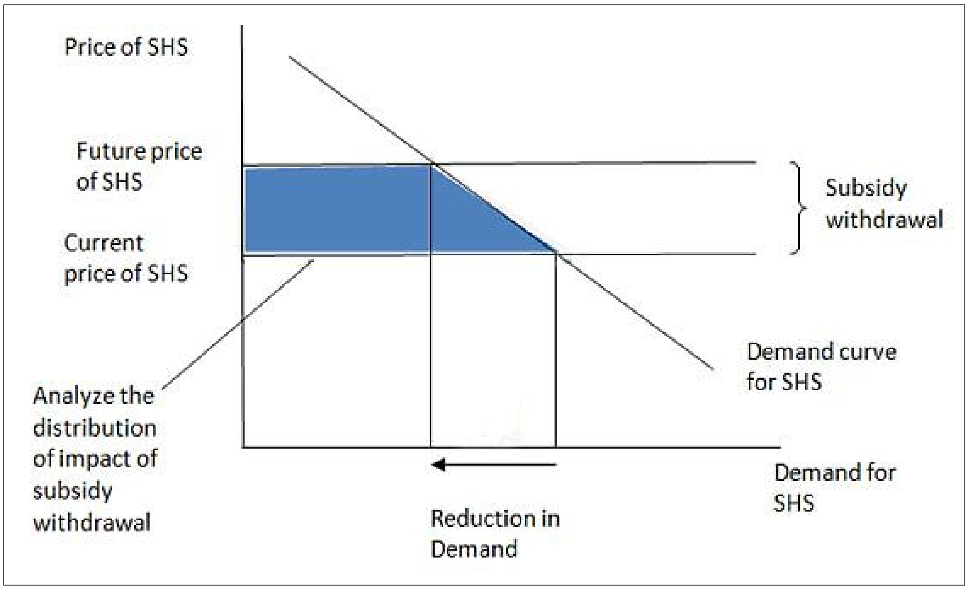
From Eq. 12, it is possible that if sales of SHS increase, the subsidy component will increase and, therefore, POs will likely enhance their effort to sell SHS in order to get more subsidies. As a result, it is likely that default risk will increase depending on the nature of contract enforceability. This situation is linked to a moral hazard problem as:

$$\theta_{t-1}^s \uparrow \rightarrow SUB_t \uparrow \rightarrow Y_t^s \uparrow \rightarrow \theta_{t+1}^s \uparrow \rightarrow SUB_{t+1} \uparrow$$

The model framework here simply expresses that while SHS adoption by households depends on income as well as the price of SHS, a subsidized program will encourage POs to sell more and more SHS to households to enjoy subsidies in the absence of a strong contract. This situation will likely indulge in adverse selection as a result of moral hazards arising out of weak contracts between the PO (agent) and the government (principal).

Both weak contracts and subsidy issues are linked to the trade-off between commercialization and welfare concerns of the government. The following graph explains the complexity of a government-sponsored program. Since supply is fixed, a vertical supply line for SHS can be assumed (Figure 3). If a subsidy is withdrawn, the price of SHS will go up, which will also affect distribution concerns, particularly the government objective to provide access to electricity to all at an affordable price, including the poor in off-grid regions. Such a trade-off has the danger of a moral hazard problem, which is highlighted in the theoretical framework described above.

Figure 3: Government-sponsored SHS Market



Source: Authors' compilation.

4. DATA AND VARIABLES

4.1 Data

Both primary and secondary data are used for analyzing default debt risks and associated factors. To understand the situation of the SHS market, we used data from the BIDS survey of SHS beneficiary and non-beneficiary households conducted in 2017. Four categories of households were surveyed: default households; non-default households; households that used private market SHSs; and non-users of SHS (Table 3).

Table 3: Distribution of Sample Households

Category	Sample Size
Default households	400
Current user households (Non-default)	300
Users of non-IDCOL (private market) SHS households	300
Non-user households	300
Total	1,300

Source: BIDS Survey, 2017.

Categories (i) and (ii) together are beneficiary (treatment) households, and (iii) and (iv) are control households. Thus, a total of 1,300 households were surveyed from 13 administrative districts of Bangladesh. These 13 districts, consisting of at least 30% of total defaulters, were chosen for the survey in view of the fact that concentrations of default households are substantively higher in these districts.

For sample selection, a cluster sampling approach was adopted with villages as the primary unit. Villages were randomly selected across selected districts from the list provided by the POs. From a complete list of beneficiaries of a village, including default and non-default, a systematic random sampling method with proportional allocation of households was applied to survey the desired number of households.

The key outcome variables were SHS adoption (1=yes, 0=no) and default (1=yes, 0=no). We further categorized default groups into two more groups, default1 (1= those who are willing to pay back, 0=otherwise) and default2 (1=those who are not willing to pay back, 0=otherwise). There were 262 cases in deafult1 group and 139 cases in default2 group. For cox's PH model, time elapsed (months) since the last installment paid was entered into the model for estimating instantaneous rate of default.

5. ESTIMATION STRATEGY AND EMPIRICAL RESULTS

5.1 Determinants of SHS Adoption

Given the importance of the household selection process for the SHS program, we examined what determines household access to IDCOL's SHS program. We estimated the reduced form equation as follows:

$$S_i = \alpha + \beta X_i + \varepsilon_i \quad (13)$$

where S_i is household's SHS adoption, X_i is a set of household-level characteristics, ε_i is unobserved random error term. β are unknown parameters to be estimated.

Table 4: Determinants of SHS Adoption

Variables	(1) IDCOL's SHS Adopters (Including Defaulters)	(2) Only Defaulters (IDCOL Market)	(3) Private SHS Adopters
Log (income in	0.027	0.037	0.027
last year)	(0.032)	(0.030)	(0.023)
Household size	–0.003	–0.010	–0.001
	(0.010)	(0.011)	(0.007)
Agri. Land (decimal)	–0.0002*	–0.0001	0.0002***
	(0.0001)	(0.0001)	(0.00009)
Log (distant to Zilla)	0.020	0.040**	0.0065
	(0.020)	(0.019)	(0.014)
Log (distance to Upazila)	0.004	–0.036	–0.023
	(0.030)	(0.028)	(0.021)
No. of rooms in the house	0.008	0.020	0.018
	(0.023)	(0.022)	(0.015)
Cooking area (1= inside house; 2=open space)	–0.050	–0.083*	0.059*
	(0.048)	(0.050)	(0.032)
Gender (1=male; 0=female)	–0.076	–0.027	0.059
	(0.086)	(0.096)	(0.058)
Age (years)	–0.002	–0.002	0.001
	(0.001)	(0.001)	(0.001)
Marital status (1=married, 0=unmarried)	0.054	0.000	–0.026
	(0.094)	(0.094)	(0.067)
y2013	0.493***	0.661***	0.144**
	(0.023)	(0.039)	(0.065)
y2014	0.521***	0.607***	0.156***
	(0.024)	(0.041)	(0.058)
y2015	0.475***	–0.175***	0.270***
	(0.030)	(0.043)	(0.055)
y2016	0.286***	–0.296***	0.539***
	(0.043)	(0.027)	(0.053)
y2017	–0.109	–	0.810***
	(0.077)		(0.026)
w20	0.332***	0.240***	–0.086***
	(0.037)	(0.048)	(0.029)
w30	0.104**	0.349***	0.015
	(0.053)	(0.083)	(0.041)
w50	0.195***	0.236***	0.056
	(0.048)	(0.067)	(0.041)
Pseudo-R^2	0.35	0.45	0.28
Observations	1,299	1,200	1,299

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimation.

We considered the household's adoption of SHS as the outcome variable. Since adoption of SHS was a dummy variable, we applied *probit* model to determine the factors that explain SHS adoption. The results are reported in Table 4. We considered age, gender, and marital status of owner; household size; agricultural land ownership; income; dwelling conditions; and year dummies of purchase of SHS and capacity of SHS (watt-peaks) as control factors. To assess the characteristics across user type, we ran several regressions based on characteristics of SHS adoption, such as for all IDCOL users, for users who are now in default, and for users of private market SHSs. Some of the characteristics are discernible here. The results suggest that only agricultural land appears to be an important wealth-based determinant of SHS adoption. The coefficient on agricultural land is significant but negative for IDCOL users and positive for private SHS users. Thus, households that are better-off have a higher probability of adopting SHS from the private market compared to IDCOL users. Less than Wp50 SHS are common among IDCOL users, and defaulters are also among these watt-peak users. Those who bought SHS in 2013 and 2014 have a higher probability of being a defaulter. We also found that remote area customers (far distance from Zila/district) have a higher probability of being a defaulter.

5.2 Perceived Factors Associated with Default

The similar specification in Eq. 13 was used to determine the factors that explain the reasons for default. In addition to the control factors used in Table 4, we added some variables representing customer perceived reasons for default. When default customers were asked about their possible reasons for default, they identified factors such as "financial constraints"; "lack of after-sales service"; "frequent problems"; "a disaster caused delay in payment"; and "high price of IDCOL SHS. As shown in Table 5, we ran the regressions for all defaulters (n=401) and for defaulters who use the Wp20 system, Wp30. and Wp50 system. We found that across different capacity watt-peak SHS users, financial constraints, lack of after-sales service, and higher price of IDCOL SHS are the key determinants of default. We didn't find significant variations among the defaulters of different capacity SHS users.

Next, we categorized the defaulters into two groups in terms of their willingness to repay. Those who said they wanted to repay the credit were categorized as "defaulter1" and those who denied repayment were categorized as "defaulter2". Thus, defaulter1 appeared to be better than defaulter2. We ran regressions for each of the categories and sub-categories with respect to capacity of SHS (wp20 and wp30). The results are reported in Table 6. For the default1 group, no specific pattern was observed in terms of reasons for default. Financial constraint and distance to Upazila (remoteness) were found to be the significant determinants. However, for default group 2, after-sales service and "closer to Upazila" (sub-district head-quarters) were found to be significant. Moreover, financial constraint did not increase the probability of default in this group of defaulters. The reasons for this group appear to be associated with adverse selection of these customers, which may be related to a moral hazard problem.

Table 5: Determinants of Default in SHS Payment

Variables	(1) Default	(2) Default (Only for wp20 Users)	(3) Default (Only for wp30 Users)	(4) Default (Only for wp50 Users)
Log (income in last year)	0.057	–0.003	–0.334*	0.018
	(0.042)	(0.056)	(0.186)	(0.146)
Household size	0.005	0.034*	0.007	–0.030
	(0.013)	(0.020)	(0.045)	(0.033)
Agri. Land (decimal)	0.0001*	0.0001	0.001**	0.001
	(0.00001)	(0.0001)	(0.000)	(0.000)
Log (distant to Zilla)	–0.038	–0.037	–0.039	–0.040
	(0.025)	(0.040)	(0.109)	(0.070)
Log (distance to Upazila)	0.004	0.022	0.165	–0.056
	(0.037)	(0.059)	(0.142)	(0.135)
No. of rooms in the house	–0.022	–0.050	0.047	–0.139**
	(0.026)	(0.044)	(0.135)	(0.063)
Cooking area (1= inside house; 2=open space)	–0.019	–0.090	0.227	0.232
	(0.059)	(0.089)	(0.176)	(0.143)
Gender (1=male; 0=female)	0.069	0.094		
	(0.110)	(0.160)		
Age (years)	0.003*	0.004	–0.001	0.010*
	(0.002)	(0.003)	(0.006)	(0.005)
Marital status (1=married, 0=unmarried)	0.018	–0.049		
	(0.113)	(0.151)		
wp20	–0.080*	–	–	–
	(0.048)			
wp30	–0.135*	–	–	–
	(0.070)			
wp50	–0.028	–	–	–
	(0.061)			
Financial constraint	0.258***	0.288***	0.252*	0.457***
	(0.047)	(0.070)	(0.144)	(0.125)
Lack of after-sales service	0.250***	0.245***	0.414**	0.314**
	(0.050)	(0.075)	(0.161)	(0.125)
Frequent problems	0.034	–0.108	–0.324**	0.312***
	(0.066)	(0.102)	(0.157)	(0.118)
Disaster	0.050	–0.099	0.347*	0.197
	(0.054)	(0.083)	(0.199)	(0.139)
Higher price of SHS	0.236***	0.199***	0.720***	0.154
	(0.045)	(0.076)	(0.089)	(0.130)
REB expansion	0.100	0.122		0.098
	(0.098)	(0.131)		(0.266)
Satisfaction (1=satisfied, 0=not satisfied)	–0.060	–0.062	–0.496***	0.044
	(0.047)	(0.071)	(0.142)	(0.127)
Pseudo-R^2	0.12	0.13	0.32	0.25
Observations	696	294	72	110

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Authors' estimation.

Table 6: Determinants of Default in SHS Payment

Variables	(1) Default1	(2) Default1 (Only for wp20 Users)	(3) Default1 (Only for wp30 Users)	(4) Default2	(5) Default2 (Only for wp20 Users)	(6) Default2 (Only for wp30 Users)
Log (income in last year)	0.075*	0.071	–0.044	0.002	–0.036	–0.002
	(0.039)	(0.053)	(0.146)	(0.030)	(0.038)	(0.011)
Household size	0.001	0.020	0.008	0.000	0.009	0.000
	(0.012)	(0.018)	(0.056)	(0.009)	(0.013)	(0.000)
Agri. Land (dec.)	0.0001	0.00001	0.001*	–0.0001	–0.0001	–0.0001
	(0.0001)	(0.0001)	(0.001)	(0.0001)	(0.0001)	(0.0001)
Log (distant to Zilla)	–0.026	–0.017	–0.149	–0.006	–0.020	0.001
	(0.024)	(0.038)	(0.100)	(0.018)	(0.026)	(0.003)
Log (distance to Upazila)	0.079**	0.117**	0.225*	–0.079***	–0.099**	–0.001
	(0.037)	(0.058)	(0.123)	(0.026)	(0.041)	(0.005)
No. of rooms in the house	–0.045*	–0.034	–0.153	0.020	–0.019	0.002
	(0.026)	(0.041)	(0.105)	(0.019)	(0.032)	(0.008)
Cooking area (1=inside house; 2=open space)	–0.062	–0.116	0.155	0.037	0.012	–0.010
	(0.057)	(0.089)	(0.123)	(0.042)	(0.062)	(0.033)
Gender (1=male; 0=female)	0.143	0.270*	0.432**	–0.054	–0.211*	–0.001
	(0.102)	(0.144)	(0.204)	(0.089)	(0.117)	(0.003)
Age (years)	0.001	0.002	–0.002	0.002	0.001	–0.000
	(0.002)	(0.002)	(0.006)	(0.001)	(0.002)	(0.000)
Marital status (1=married, 0=unmarried)	0.176**	0.125	–	–0.185	–0.320*	–
	(0.083)	(0.123)		(0.121)	(0.177)	
wp20	0.286***	0.283***	0.216*	–0.041	–0.004	0.000
	(0.039)	(0.061)	(0.116)	(0.035)	(0.048)	(0.001)
wp30	0.141***	0.102	0.315	0.116***	0.145**	0.047
	(0.053)	(0.076)	(0.206)	(0.043)	(0.059)	(0.086)
wp50	–0.007	0.055	–	0.033	–0.080	–0.000
	(0.062)	(0.100)		(0.049)	(0.051)	(0.002)
Financial constraint	0.114**	0.101	0.132	–0.063*	–0.150***	0.000
	(0.052)	(0.079)	(0.169)	(0.037)	(0.039)	(0.001)
After–sales service	–0.017	–0.053	0.259	0.290***	0.283***	0.999***
	(0.047)	(0.075)	(0.198)	(0.049)	(0.081)	(0.004)
Frequent problems	0.015	–0.063		0.040	0.161	
	(0.090)	(0.117)		(0.073)	(0.117)	
Disaster	0.030	0.066	–0.092	–0.079**	–0.096*	–0.160
	(0.045)	(0.069)	(0.145)	(0.034)	(0.049)	(0.167)
REB	0.015	–0.063	–	0.040	0.161	–
	(0.090)	(0.117)		(0.073)	(0.117)	
Pseudo-R^2	0.09	0.11	0.28	0.15	0.20	0.63
Observations	696	294	67	696	294	76

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; wp = watt-peak.

Source: Authors' estimation.

5.3 Analysis of Default Risk: Cox's PH Model

The Probit analysis in the previous section identified the determinants of default irrespective of time of default. However, the Cox proportional-hazards model is one of the most useful methods used for modeling survival (failure) analysis taking into considerations instantaneous failure at a point in time. The model is used to evaluate simultaneously the effect of several factors on survival (failure). In other words, it allows us to examine how specified factors influence the rate of a particular event happening (e.g., default in installment payment) at a particular point in time. This rate is commonly referred as the hazard (failure) rate. Though we could not observe factors of default (failure) over time, the model at least could estimate the associated factors, assuming that they remained the same over time, and provide an estimate of hazard rate at a point in time. This type of analysis is useful to obtain failure rate at a point in time and predict the failure rate of current users in the foreseeable future.

In this model, the random variables $\mathrm{T_1, T_2, \dots, T_n}$ represented the number of payment installments that needed to be made for the SHS purchase by n number of households. A defaulter household was defined as one that had paid a certain proportion of installments but was no longer continuing the rest of the payments. For the defaulter households, complete observed values for $\mathrm{T_i}$ were possible, and time $\mathrm{t_i}$ was used for non-defaulting households (households that are currently using SHS and are paying the installments). Instead of the observed values for each $\mathrm{T_i}$, however, we have a time $\mathrm{t_i}$, which we know is either the actual observed time or a censoring time.

A variable δ_i was defined as $\delta_i = I(T_i = t_i)$, which equals 1 if $T_i = t_i$and 0 if $T_i > t_i$. The observed data then consists of $(t_i, \delta_i, x_{1i}, x_{2i}, \dots, x_{pi}), i = 1,2, \dots, n$, where $x_{1i}, x_{2i}, \dots, x_{pi}$are the associated covariates of ith household. The hazard function, $\mathrm{h(t)}$, which is a very vital concept in survival data analysis, was defined as the instantaneous rate of failure at time t, given that the individual survives up to time t. The hazard function has a particularly important characteristic of a survival distribution and indicates the way the risk of failure varies with covariates. The Cox proportional hazards regression model can be written as Eq.14.:

$$h(t) = h_o(t) exp\ (\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p) \tag{14}$$

where $\mathrm{h(t)}$ is the expected hazard at time t, $\mathrm{h_o(t)}$ is the baseline hazard and represents the hazard when all of the predictors $x_1, x_2, \dots, x_p$are equal to zero. The estimation and test for β_j was made based on the method proposed by Cox (1972).

The instantaneous hazard rate is the limit of the number of events per unit time divided by the number at risk as the time interval approaches 0.

$$h(t) = \lim_{\Delta t \to 0} \frac{observed\ defaulter\ in\ interval\ [t, t+\Delta t]/N(t)}{\Delta(t)} \tag{15}$$

In Eq.15, N(t) is the number of households at risk at the beginning of an interval. A hazard is the probability that a household becomes a defaulter between t and t+Δt, given that the household continues payment up to time t, divided by Δt as Δt approaches zero.

5.4 Factors Associated with Default

Table 4 presents the results of several specifications of the Cox proportional hazards model regressions including perceived possible risk factors of default and household characteristics and capacities of SHS as covariates. Columns 1–3 present results for all default customers and default customers having wp20 SHS and having wp50 SHS, respectively. Columns 4–6 present results for default 1 categories and columns 7–9 present results for default 2 categories. The results in columns 1–3 suggest that REB grid expansion was the main factor behind the default, indicating that as customers got REB electricity, they were no longer willing to pay back the amount due, which is a non-monetary cause. Overall, financial constraint was a significant cause of default for all the defaulters as well as for defaulter type 1; however, financial constraint was not the reason for type 2 defaulters. For type 2 (bad) defaulters, the REB expansion and high price of SHS were the significant determinants of default, meaning that they were just citing some reasons not to pay back the amount due. It also indicates that this group is adversely selected. The findings in Table 7 from *probit* analysis are not fully consistent because Cox's model takes into account time to default.

Table 7: Cox's PH Model Estimates: Determinants of SHS Default

Variables	(1) Default	(2) Default (wp=20)	(3) Default (wp=50)	(4) Default1	(5) Default1 (wp=20)	(6) Deafult1 (wp=50)	(7) Default2	(8) Default2 (wp=20)	(9) Default2 (wp=50)
Financial constraint	0.307**	0.133	0.436	0.752***	0.410	0.798	–0.281	–0.255	–1.174
	(0.143)	(0.223)	(0.414)	(0.199)	(0.304)	(0.547)	(0.225)	(0.350)	(0.911)
High price of SHS	0.189	0.218	0.654*	–0.230	–0.027	0.416	0.941***	0.577*	2.589***
	(0.121)	(0.189)	(0.347)	(0.161)	(0.254)	(0.428)	(0.197)	(0.300)	(0.924)
Poor after-sales service	–0.178	–0.339*	0.092	–0.262	–0.468*	–0.095	0.040	–0.111	0.059
	(0.137)	(0.200)	(0.327)	(0.166)	(0.243)	(0.399)	(0.255)	(0.375)	(0.807)
Disaster	–0.261**	–0.225	0.161	–0.128	–0.001	0.193	–0.673**	–0.726	0.063
	(0.133)	(0.213)	(0.345)	(0.155)	(0.247)	(0.401)	(0.276)	(0.469)	(0.819)
REB expansion	0.525**	0.546*	1.976***	0.483	0.046	1.964***	0.387	0.895**	–69.944
	(0.218)	(0.302)	(0.606)	(0.312)	(0.498)	(0.672)	(0.322)	(0.414)	(0.000)
Satisfaction	–0.028	0.094	–0.261	0.083	0.264	–0.236	–0.253	–0.294	–0.614
	(0.125)	(0.189)	(0.339)	(0.152)	(0.229)	(0.409)	(0.227)	(0.361)	(0.695)
Frequent problem faces	–0.067	–0.023	0.072	–0.123	0.204	0.296	–0.032	–0.473	1.073
	(0.154)	(0.259)	(0.396)	(0.209)	(0.322)	(0.475)	(0.236)	(0.442)	(0.859)
w20	0.067	–	–	0.019	–	–	0.118	–	–
	(0.125)			(0.156)			(0.215)		
w30	0.388**	–	–	0.165	–	–	0.766**	–	–
	(0.193)			(0.251)			(0.309)		
w50	–0.022	–	–	0.018	–	–	–0.154	–	–
	(0.156)			(0.185)			(0.297)		
Gender (1=male; 0=female)	0.436	0.571	–0.980	0.311	0.949	–1.181	0.686	–0.450	–7.942
	(0.325)	(0.563)	(1.614)	(0.399)	(0.611)	(1.552)	(0.588)	(1.335)	(0.000)
Age (years)	0.004	0.011	0.005	0.002	0.011	–0.005	0.008	0.008	0.077**
	(0.004)	(0.007)	(0.013)	(0.006)	(0.008)	(0.016)	(0.007)	(0.012)	(0.034)
Marital status (1=married, 0=unmarried)	–0.052	0.378	–0.250	0.103	0.089	0.734	–0.183	1.291	–35.123
	(0.308)	(0.451)	(1.224)	(0.370)	(0.502)	(1.021)	(0.582)	(0.911)	(0.000)
Household size	–0.005	0.059	0.004	0.009	0.050	0.074	–0.043	0.058	–0.580**
	(0.031)	(0.052)	(0.070)	(0.039)	(0.066)	(0.076)	(0.051)	(0.089)	(0.242)
Log (total land)	0.026	0.002	0.117	–0.011	0.005	–0.001	0.115*	–0.006	0.660***
	(0.037)	(0.060)	(0.092)	(0.046)	(0.073)	(0.113)	(0.067)	(0.107)	(0.200)
Log (income in a year)	–0.033	0.057	0.266	0.067	0.176	0.418	–0.195	0.049	1.141
	(0.103)	(0.159)	(0.307)	(0.128)	(0.195)	(0.378)	(0.183)	(0.302)	(0.710)
Log-likelihood ratio test (χ^2)	33.00***	20.65*	22.13**	39.54***	20.73*	18.58	62.92***	28.31***	30.78***
Observations	657	277	108	657	277	108	657	277	108

Note: Standard errors in parentheses;*** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimation.

5.5 Sensitivity of Risk Factors and Survival Probability

To assess the sensitivity of the factors that determine default, we estimated hazard ratios against each of the four main factors of financial constraint, high price, lack of service, and disaster, and plotted them in Figure 4. The plotted survival figures suggest that it usually takes longer for wp20 users to become defaulters compared to higher capacity SHS users. For overall default users, the higher price of the IDCOL SHS increased the probability of risk of default, followed by financial constraint, disaster, and poor after-sales service. For default group 1 who were willing to pay back, financial constraint was the primary cause, followed by disaster, higher price, and poor after-sales service. For default group 2 who were not willing to pay back, the main cause was higher price, followed by poor service, financial constraint, and natural disaster.

Thus, there is clear evidence of adverse selection in default group 2 that might be linked to a moral hazard problem. For example, the households that became defaulters due to higher prices of IDCOL SHS (compared to the private market) are sheer cases of adverse selections from the part of POs as they are not supposed to raise this issue after paying back some installments. Again, those who reported that they don't need SHS now because they got REB electricity also represent the adversely selected cases because POs perhaps aggressively convinced them to buy SHS knowing that REB grid expansion would take place in a short period of time. This means that POs aggressive selling of SHSs to adversely selected customers in order to gain from IDCOL's refinancing schemes (subsidies) in the face of weaker conditions might be linked to a moral hazard problem, which is consistent with relevant literature (Jeanne and Zettelmeyer 2005; Castillo, Mora-Valencia, and Perote 2018).[4] Note that adverse selection of customers was also highlighted in the survey of POs (Hossain et al., 2018) that claimed over 77% of customers selected were politically/socially influential and it is now difficult to recover the amounts due from them.[5] On the other hand, there are some factors for default that are associated with POs inefficiency in providing committed after-sales service. Those who claimed to become defaulters due to "higher price of IDCOL's SHS" compared to, perhaps, the private market (as seen in Table 1) is related to market structure. Therefore, there are combinations of factors that have affected the government-sponsored SHS program in Bangladesh.

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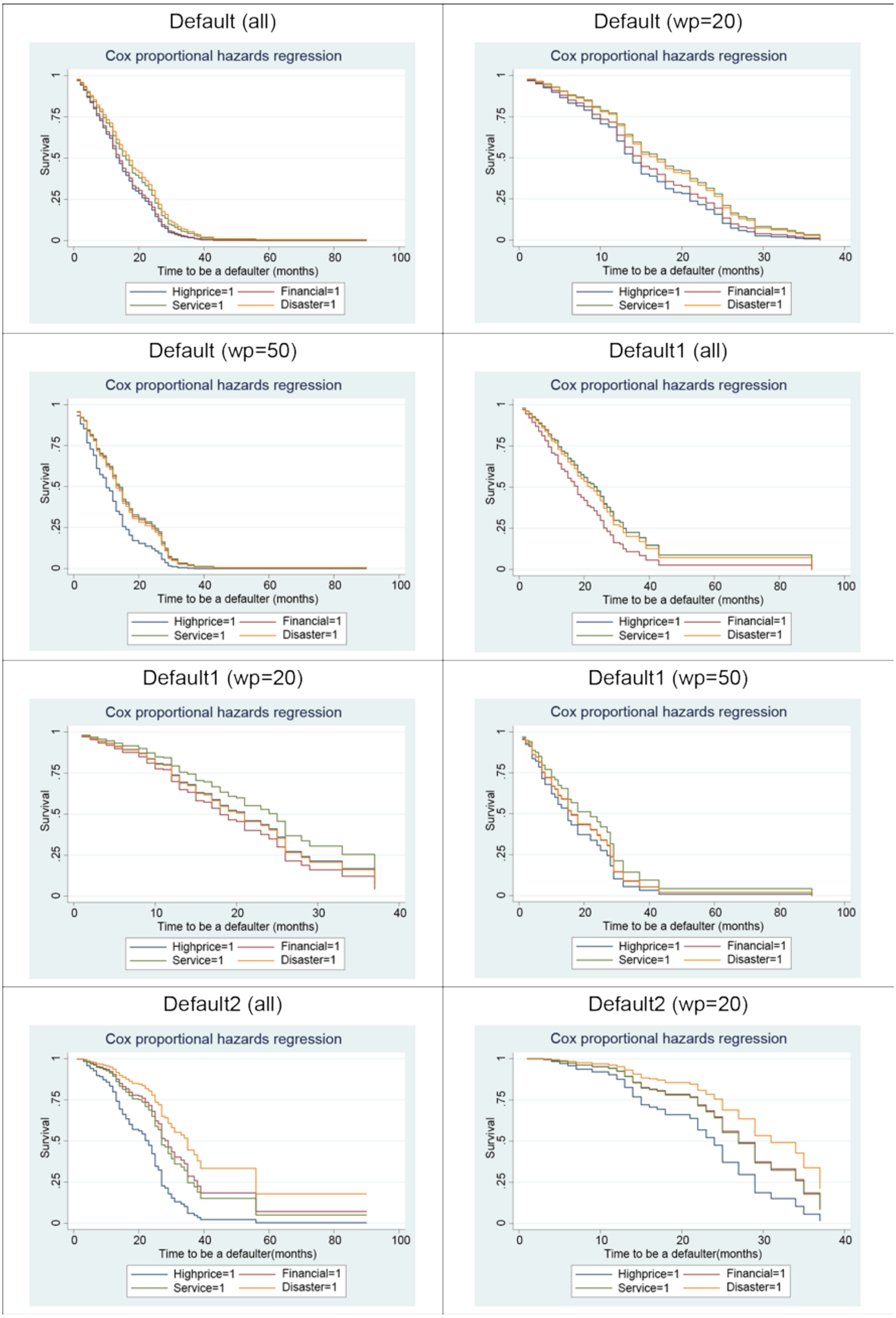
[4] Jeanne and Zettelmeyer (2005) argued that there is no straightforward way to identify moral hazard problems, and, therefore, it may be judged from the real situation of the program.

[5] Various factors are associated with default situations. The BIDS survey of POs (2017) revealed that the main factors of default include politically/socially influential customers (73.3%), customers in a low-income group (55.5%), customers in natural-disaster areas (28.9%), and customers with grid connections in their households (26.7%). The first two factors refer to adverse selection of customers, which has occurred in the face of weaker financial contracts between IDCOL and POs that created a potential moral hazard problem.

Figure 4: Survival Curves of Defaults against Various Factors



Source: Authors' compilation.

6. MARKET-BASED SOLUTION FOR RE PROGRAM: A POLICY OPTION

Considering the theoretical framework in Section 3 and empirical analysis in Section 4, there is a strong likelihood of moral hazard problems in a government sponsored RE program, given the trade-off between commercialization and welfare concerns. In light of our findings in the previous sections, particularly the piling up of a huge default risk accrued under an SHS program in Bangladesh due to moral hazards, lack of coordination between agencies, and inefficiencies of implementing agencies, a market-based solution is warranted. From that concern, we here show theoretically that by using the spill-over revenue of a solar electricity program, the government can design a program that can solve the problems highlighted in this paper.

Household:

Assuming individual HH production function Y, which is a function of private capital (K_t) as household members can even work at night with electricity, L is the human capital because electricity improves the hours of children's education and E represents renewable energy. Our assumption is based on some empirical studies that showed SHS adoption improves a child's study time at night, increases per capita consumption and income, and saves kerosene consumption, thereby reducing indoor air pollution (Hossain et al. 2018; Khandker et al. 2014). Over time, the function would look like the following: (Eqs. 16, 16-1 and 16-2)

$$Y_t = F(K_t, L_t, E_t) \quad (16)$$

$$Y_{t+1} = F(K_{t+1}, L_{t+1}, E_t) \quad (16\text{-}1)$$

…

$$Y_{t+n} = F(K_{t+n}, L_{t+n}, E_t) \quad (16\text{-}2)$$

Changes in Y with respect to changes in green energy supply (E) over time *t* will be as follows:

$$\frac{dY_{t+n}}{dE_t} = \frac{\partial F}{\partial K_t}.\frac{\partial K_{t+n}}{\partial E_t} + \frac{\partial F}{\partial L_{t+n}}.\frac{\partial L_{t+n}}{\partial E_t} + \frac{\partial F}{\partial E_t} \quad (17)$$

where $\frac{\partial F}{\partial K_t}.\frac{\partial K_{t+n}}{\partial E_t} + \frac{\partial F}{\partial L_{t+n}}.\frac{\partial L_{t+n}}{\partial E_t}$ represents the spillover effects of solar electricity access.

Similarly, for the *n*th period, the changes in household production function with respect to E will be as in Eq.18:

$$dY_{t+n} = \left(\frac{\partial F}{\partial K_t}.\frac{\partial K_{t+n}}{\partial E_t} + \frac{\partial F}{\partial L_{t+n}}.\frac{\partial L_{t+n}}{\partial E_t} + \frac{\partial F}{\partial E_t}\right).dE_t \quad (18)$$

Eq. 18 shows the change in household income due to use of solar energy, which will increase gradually after an initial period as it takes some time for household members to make better use of electricity in education and generation of income. This pattern of spillover return is evident from some infrastructure projects in Japan and the Philippines (Yoshino and Abidhadjaev 2017; Yoshino, Nakahigashi, and Pontines 2017; Yoshino and Pontines 2015).

Government and RE Sector:

It is expected that with an increase in income of households through electricity use, higher taxes will be paid to the government, which will ultimately increase government's tax revenue in those off-grid regions. With access to electricity, new businesses might also emerge, which will generate spillover benefits to the region. Performing a cost-benefit analysis, Hossain (2019) estimated that the financial rate of return from adopting an SHS is about 20% for a household, which is about 5% higher than the economic rate of return. The estimated benefit−cost ratios are greater than 1 for both 20 Wp and 30 Wp cases, implying its beneficial role for the households. Moreover, new businesses and infrastructure based on electricity will emerge that will enhance government's tax revenue.

Against this backdrop, assuming T is tax revenue after the adoption of SHS at t+1, the tax revenue will increase at a proportionate rate of individual income $t.dY_{t+1}$.

$$\Delta T_{t+1} = t.\Delta Y_{t+1} = t.dY_{t+1} \tag{19}$$

$$\Delta T_{t+n} = t.\Delta Y_{t+n} = t.dY_{t+1}$$

Finally, assuming that the solar homes market comprises both local and foreign producers (for imported items), the accumulated tax revenue will be as follows:

$$\sum_{i=1}^{n} \Delta T_{t+i} = \sum_{i=1}^{n} t.\Delta Y_{t+i} \tag{20}$$

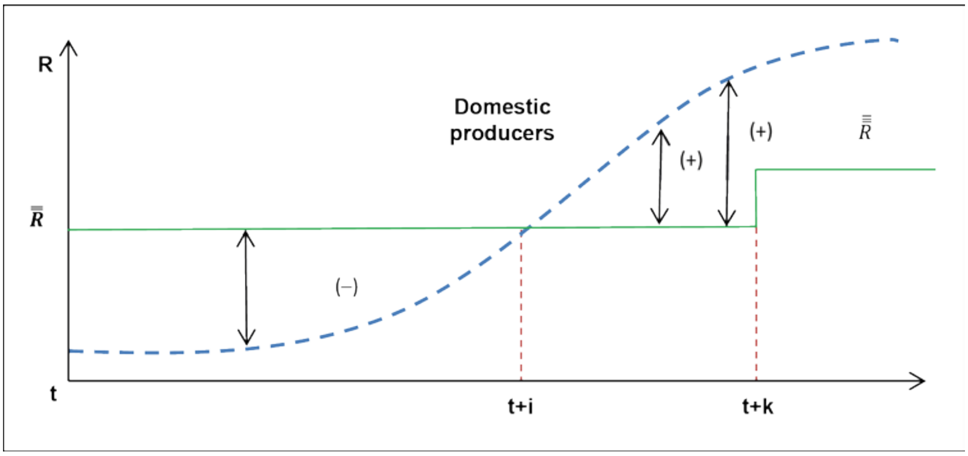
The dotted lines in Figure 5 represent government tax returns $(t.dY_t)$ from the intervention areas. The lower line on Figure 6a shows that the fixed return ($\bar{R}$) green bond is issued at a higher rate than the rate of spillover tax revenues from RE investments. Empirical evidence from infrastructure investments in Japan (railway) and the Philippines suggest that after a certain period *t+j*, the spillover tax revenue will be larger than the fixed return ($\bar{R}$) rate of the issued green bonds. Different types of green bonds with varying rates can be issued to support domestic producers and foreign producers. The rate of return of the bonds targeting the domestic producers can be set at a somewhat higher level than that for foreign producers to support domestic RE investments.

Instead of a fixed-return bond, the government can also issue a floating-rate bond so that RE investors can receive more benefit and thus be attracted to invest in RE technologies (Figure 6). In that case, the government can increase the rate of return from $\bar{\bar{R}}$ to $\bar{\bar{\bar{R}}}$ at *t+k* in order to encourage further domestic production. The return of a producer over the period *t, t+1,…, t+n* can be expressed as:

$$R_t = \frac{dY_t}{dE_t} \ldots\ldots\ldots. R_{t+n} = \frac{dY_{t+n}}{dE_t} \tag{21}$$

Therefore, for the period *t* to *t+i*, the government will receive lower tax revenue, but after *t+I,* the loss will be compensated by higher tax revenues. Between *t* and *t+i*, the government will compensate future tax revenues after *t+i*, which will create a win-win situation for both the government and RE investors. As a solution, pension funds or insurance funds can be used to finance green bonds.

Figure 5: A Model of Commercial SHS/RE Market (with Floating Rate)



Source: Authors.

The amount of loss due to a fixed-rate of return bond and tax revenue accrued can be estimated from Eqs. 21, 22, and 23.

$$\int_{t}^{t+i}(\frac{dY_t}{dE_t} - \bar{R})\,dt < \int_{t+i+1}^{t+n}(\frac{dY_t}{dE_t} - \bar{R})\,dt \quad (21)$$

And $$\int_{t}^{t+i}(\frac{dY_t}{dE_t} - \bar{\bar{R}})\,dt < \int_{t+i+1}^{t+n}(\frac{dY_t}{dE_t} - \bar{\bar{R}})\,dt \quad (22)$$

Or $$\int_{t}^{t+i}(\frac{dY_t}{dE_t} - \bar{\bar{\bar{R}}})\,dt < \int_{t+i+1}^{t+n}(\frac{dY_t}{dE_t} - \bar{\bar{\bar{R}}})\,dt \quad (23)$$

The above equations suggest that spillover benefit during *t+i+1* to *t+n* will be higher after the initial period *t* to *t+i*, which means that the government can compensate current rate of return from future spillover revenues. In that case, governments might use green bond or a green credit guarantee scheme to finance private investors to invest in RE programs.

7. CONCLUSIONS AND POLICY RECOMMENDATIONS

This paper analyzes the default credit situation of the largest SHS program in Bangladesh implemented by IDCOL. Once termed as a very successful SHS program, it is now on the brink of abandonment mainly due to piling up of default loans. The dwindling situation is linked to the adverse selection of customers associated with a moral hazard problem, which is further aggravated with uncoordinated REB grid electricity expansion and emergence of an unregulated private RE market. Under weak financial contracts between IDCOL and POs, the behavior of both IDCOL and POs represent a classic principal-agent problem of moral hazard. With a subsidized structure, the POs went for aggressive marketing of SHSs to a big portion of customers. Our analysis suggests that about 35% of the defaulters were adversely selected and are not willing to pay back the amount due because of some non-monetary reasons, such as higher price, poor after-sales service, etc. A portion of the default also happened due to financial constraints of the customers. In line with our theoretical framework, our empirical analysis using *probit* and Cox's proportional hazard model support this.

The default credit and associated moral hazard in a SHS program is a unique case and the analysis in this paper contributes toward the literature with a possible market-based solution for RE programs. The problem of the simultaneous objectives of commercialization and welfarism is highlighted in the paper. In order to achieve a market-based solution, a RE program should comply with the following conditions: (i) Set a standard regulation for quality specifications for all types of marketing and production of PV panels or other RE products; (ii) Provide cheaper financing opportunities to RE/SHS traders/producers through generating funds from issuing green bonds with a fixed rate/floating rate for a certain period of maturity. In the case of an underdeveloped bond market, the establishment of a public green credit guarantee scheme is possible to reduce the risk of financing, thereby reducing the interest rate; (iii) A regulatory oversight body should be in place to oversee the RE market, particularly financing and pricing aspects; and (iv) A proper subsidy/incentive mechanism also needs to be devised for the households to address distributional concerns.

To arrange the market-based financing backed by spill-over revenues, a competent regulatory body should be in place. In this regard, institutional development, such as the establishment of the credit guarantee scheme and the development of the capital market—particularly the bond market with improved capacities of the government's revenue collection—are necessary to make RE projects viable and sustainable.

REFERENCES

Barnes, Douglas F., and Halpern, Jonathan. (2000). The role of energy subsidies. In ESMAP (Ed.), *Energy services for the world's poor* (pp. 60–66). Washington, D.C.: World Bank.

Castillo, J. A., Mora-Valencia, A., and Perote, J. (2018). Moral hazard and default risk of SMEs with collateralized loans. *Finance Research Letters*, *26*, 95–99.

Cox, D. R. (1972). Regression models and life-tables. *Journal of the Royal Statistical Society: Series B (Methodological)*, *34*(2), 187–202.

Gupta, J., and Gregoriou, A. (2018). Impact of market-based finance on SMEs failure. *Economic Modelling*, *69*, 13–25.

Hossain, M. (2019). Green finance in Bangladesh: Barriers and solutions. In J. D. Sachs, W. T. Woo, N. Yoshino, and F. Taghizadeh-Hesary (Eds.), *Handbook of green finance: Energy security and sustainable development.* Singapore: Springer.

Hossain, M., Asaduzzaman, M., Yunus, M., Jamaluddin, A., Alam, K. E., Iqbal Z., and Roy, P. K. (2018). Assessing the current situation of Solar Home System (SHS) program of IDCOL and recommending action plan: Executive summary. *Bangladesh Institute of Development Studies.* Unpublished.

IEA. (2017). Key world energy statistics. Retrieved 23 February 2019 from www.iea.org/publications/freepublications/publication/KeyWorld2017.pdf.

Jeanne, O., and Zettelmeyer, J. (2005). The Mussa Theorem (and other results on IMF-induced moral hazard). *IMF Staff Papers*, *52*(1), 64–84.

Khandker, S. R., Samad, H. A., Sadeque, Z. K., Asaduzzaman, M., Yunus, M., and Haque, A. E. (2014). *Surge in solar-powered homes: Experience in off-grid rural Bangladesh*. Washington, D.C.: World Bank.

Nelson, D., and Shrimali, G. (2014). Finance mechanisms for lowering the cost of renewable energy in rapidly developing countries. *Climate Policy Initiative*. https://climatepolicyinitiative.org/wp-content/uploads/2014/01/Finance-Mechanisms-for-Renewable-Energy-in-Emerging-Economies-Slide-Deck.pdf.

Taghizadeh-Hesary, F., and Yoshino, N. (2019). The way to induce private participation in green finance and investment. *Finance Research Letters, 31*, 98–103. doi:org/10.1016/j.frl.2019.04.016.

Taghizadeh-Hesary, F., Yoshino, N., and Inagaki, Y. (2019). Empirical analysis of factors influencing the price of solar modules. *International Journal of Energy Sector Management*, *13*(1), 77–97. doi:org/10.1108/IJESM-05-2018-0005.

Yoshino, N., and Abidhadjaev, U. (2017). Impact of infrastructure on tax revenue: Case study of high-speed train in Japan. *Journal of Infrastructure, Policy and Development*, *1*(2), 129–148.

Yoshino, N., Nakahigashi, M., and Pontines, V. (2017). Attract private financing to infrastructure investment by injecting spillover tax revenues. *Nomura Journal of Asian Capital Market*, *1*(2), 4–9.

Yoshino, N., and Pontines, V. (2015). *The 'Highway Effect' on public finance: Case of the Star highway in the Philippines* (ADBI Working Paper No. 549). Tokyo: Asian Development Bank Institute.

Yoshino, N., and Taghizadeh-Hesary, F. (2018). Alternatives to private finance: Role of fiscal policy reforms and energy taxation in development of renewable energy projects. In *Financing for low-carbon energy transition* (pp. 335–357). Singapore: Springer.