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Business model assessments of innovative agricultural value chain technologies in Bangladesh

The case of chimney dryers, floating gardens, and cold storage

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1. Background

1.1 Chimney Dryers

The UC Davis chimney solar dryer was designed to provide efficient drying for vegetables, fruits, seeds, and grains even in hazy or partially cloudy conditions. Constructing the dryer is simple and it can be built from low-cost materials found locally in markets and shops around the world. There are two key and unique characteristics of the solar dryer:

1. The chimney ensures continuous airflow around the product, thus increasing the speed of drying compared to other designs and
2. The dryer's large heat-collection area ensures high temperatures and rapid moisture removal.

Drying can add value to a given product and extend the shelf-life, facilitating producer's access to new markets and ability to supply more regularly and consistently. Additionally, as insufficient drying can lead to the spread of aflatoxin, the solar dryer is promoted as a cost-effective option for improving food safety.

In the effort to promote chimney dryers to smallholder farmers and cooperatives, it is important to understand the economic performance of an archetypical solar dryer over its intended lifespan. Such investigation can illustrate where incentives may be necessary to promote adoption and continued success. In this analysis, we compare the economic performance of one chimney dryer in three separate locations of Bangladesh. Each dryer was constructed identically, but the products being dried vary by location.

1.2 Floating Gardens

Wetland agriculture on various types of floating gardens has been used for centuries in many countries. Bangladesh is a low-lying country that suffers from seasonal floods during the rainy season that render land unsuitable for growing fruits and vegetables for extended periods of time. Widespread small-scale fish farming and large freshwater lakes in rural areas also significantly reduce the land available for cultivation. The Horticulture Innovation Lab at UC Davis has designed an innovative floating garden constructed from locally-available materials that allows small-scale fish farmers to grow horticultural crops on their ponds. The garden comprises a bamboo 'raft' containing a soil-less medium of coconut coir and vermicompost. Flotation is provided by empty second-hand plastic containers attached to the bottom of the raft. A rope and pulley is used to move the floating garden from the bank (where it can be tended) to a sunny location of the pond. In-situ solarization of the growing medium is used to pasteurize the medium. Pest-exclusion nets and Neem extracts can be used to reduce insect infestations. The gardens also provide a location for producing seedlings that can be transplanted into ground beds when the floodwater recedes. This allows farmers to obtain higher prices due to the early-season production. A range of horticultural crops have been successfully grown on the gardens and research is underway to monitor the impact of the gardens on family nutrition. Furthermore, evaluating the economic performance of floating gardens is important in quantifying their impact on farmer income and to encourage increased adoption among smallholders throughout the region.

1.3 CoolBot Cold Room

In many developing countries, a lack of cold storage contributes to the high postharvest loss rate of fruits and vegetables, which can exceed 50%. This is a significant loss to farmers economically, and also decreases local communities' access to nutritious foods. The prohibitively high cost of traditional technologies, like commercial coolers and reefer containers, is why cold storage in developing countries

is virtually nonexistent. It is simply out of reach for smallholder farmer, who are the ones that produce the majority of the food in these countries.

The CoolBot is a simple, yet innovative device developed by Sore It Cold that enables any wall mounted air conditioning unit to be transformed into a refrigeration system. When installed in a properly insulated room, this system provides a much more affordable alternative for small-scale cold storage. By storing products in the cold room, farmers can extend the shelf life of their products and in so doing increase their income in two ways. First, farmers are simply able to sell more product because less is lost to deterioration. Second, storage allows farmers to sell their produce when market prices are the most favorable, rather than having to sell their produce immediately at whatever price offered.

While research has shown that this technology can be implemented in multiple countries and does have positive effects on produce shelf life, this analysis seeks to understand its economic feasibility in a smallholder farmer community setting. It is clear that this system is more affordable, at about a tenth the cost of a commercial cold room, but the question is whether it is affordable enough for smallholder farmers in developing countries, like Bangladesh.

Figure 1. Map of Project Areas

2. Methods

All three technologies were analyzed using a Land Use System (LUS) analysis approach. Using excel to build these models, the LUS is a relatively straight forward cost-benefit analysis that tracks the flow of inputs and outputs over the life of a system or technology. Inputs include all the material and labor that goes into establishment and maintenance, as well as their associated costs. Outputs are either the produce harvested, such as with the floating gardens, the dried products that come out of the chimney dryer, or the stored product from the CoolBot cold room that is then sold.

Field data from various sites around Southern Bangladesh, where these technologies were established, were used to model input and output quantities. In several cases, field data were also used to set associated prices, but historic price data, especially on fruit and vegetable commodities, were also used from various online sources. In particular, commodity prices were obtained from the Bangladesh Department of Agriculture Markets website. Historic price series data were used to predict future prices

using a simple linear regression model[1] and a random normal distribution algorithm. Although, for certain inputs, prices were thought to remain relatively stable over time, and were thus only increased with inflation. The field data that these analyses are based on was collected by local field researchers, Amrita Mukherjee and Mohd. Rezaul Islam. They used data collection sheets tailored to each technology, which were filled out by the farmers involved in this research.

Equation 1. Net Present Value

$$NPV = -Initial\ Investment + \sum_{t=1}^{T} \frac{Net\ Cash\ Flow_t}{(1+r)^t}$$

$$t = Year \qquad r = Discount\ Rate$$

The ultimate product of this analysis for all three technologies is each system's net present value (NPV) (see Equation 1). This value is commonly used to analyze the profitability of a projected investment or project, and is the sum of net cash flows over a given time horizon expressed in today's dollars. Because people often value their present wellbeing more than their future wellbeing to various degrees, future monies are valued less. The discount rate, r, is used to reflect this, and thus the higher the r -value, the less future income is valued. Developed countries, like the United States, have relatively low discount rates, which in many cases is almost zero. Developing countries, however, which often lack stable financial infrastructures, display much higher discount rates since future income is so uncertain. In addition to NPV, returns to land and labor can also be calculated by dividing the NPV calculation by the total quantity of labor or the total area of land.

3. Results

3.1 Chimney dryers

Table 1 presents the annual costs, revenues, and discounted benefits for each of the chimney dryers over the 10-year lifespan. Establishment costs (labor and materials) are the same for each dryer. For Shrirampur and Parhat locations, the revenue generated from dried product surpasses costs starting in the second year, and profit margins continue increasing over the subsequent lifespan of the dryer. In the case of Baghar, the revenue stream never surpasses the costs.

Table 1. Chimney Dryer Costs, Revenue, & Discounted Annual Benefits

	Year									
Shrirampur	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Cost - Establishment	11164	0	0	0	0	0	0	0	0	0
Cost - Maintenance, Operations, Fresh product	12597	15640	10905	11771	13329	13040	13626	15044	15376	16597
Revenue - Outputs (dried product)	21366	21367	22062	23535	25107	26783	28571	30479	32514	34685
Annual Benefits (Revenue - Costs)	-2395	5727	11157	11765	11778	13743	14946	15435	17138	18088
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64

[1] This method is the simplest forecasting approach. However, better methods exist, such as ARMA and ARIMA models, that could give better future price predictions. A significant limitation of this method is that it does not take in to account seasonality when generating future prices.

Discounted annual flow of benefits	-2395	5454	10120	10163	9690	10768	11153	10969	11600	11660
Discounted annual flow of benefits (excluding up-front costs)	8770	5454	10120	10163	9690	10768	11153	10969	11600	11660
Parerhat										
Cost - Establishment	11164	0	0	0	0	0	0	0	0	0
Cost - Maintenance, Operations, Fresh product	16126	20080	20920	21054	21198	21351	21514	21689	21875	22073
Revenue - Outputs (dried product)	15680	20882	21907	23369	24930	26594	28370	30264	32285	34440
Annual Benefits (Revenue - Costs)	-11610	802	987	2315	3732	5243	6855	8575	10410	12367
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64
Discounted annual flow of benefits	-11610	764	895	2000	3070	4108	5116	6094	7046	7972
Discounted annual flow of benefits (excluding up-front costs)	-446	764	895	2000	3070	4108	5116	6094	7046	7972
Baghar										
Cost - Establishment	11164	0	0	0	0	0	0	0	0	0
Cost - Maintenance, Operations, Fresh product	12512	8890	11237	11699	12296	12829	13501	14115	14873	15578
Revenue - Outputs (dried product)	14613	5886	9219	9835	10491	11192	11939	12736	13586	14493
Annual Benefits (Revenue - Costs)	-9064	-3004	-2018	-1865	-1805	-1637	-1562	-1379	-1286	-1084
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64
Discounted annual flow of benefits	-9064	-2861	-1830	-1611	-1485	-1283	-1166	-980	-871	-699
Discounted annual flow of benefits (excluding up-front costs)	2101	-2861	-1830	-1611	-1485	-1283	-1166	-980	-871	-699

Figure 2 is an illustration comparing the annual flow of net benefits for each of the three chimney dryers along the 10-year lifespan. Summing the discounted flow of benefits over the lifespan of each chimney dryer yields the net present value (Table 2). Dividing the NPV by the number of person-days of labor required over the chimney dryer lifespan yields the returns to labor (Table 2). From this figure and tables, we can see the chimney dryers in Shrirampur and Parerhat have generated positive NPV and returns to labor, and are therefore examples of positive economic activities.

Figure 2. Discounted Annual Flow of Benefits - Chimney Dryer

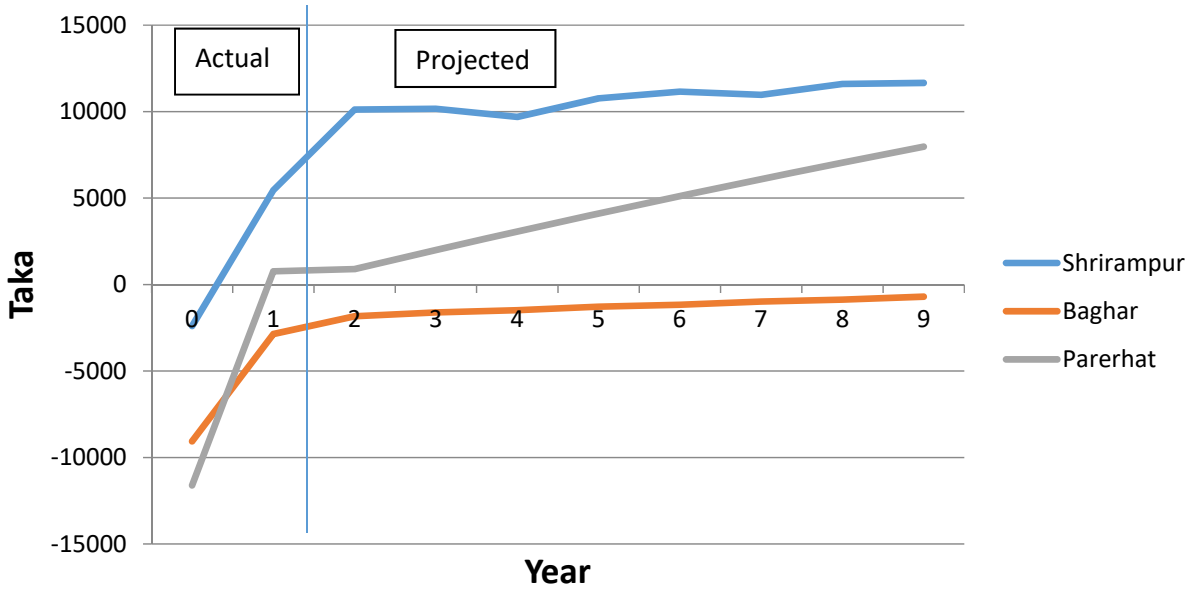


Table 2. Summary of economic feasibility measures for chimney dryers

	Shrirampur		Parerhat		Baghar	
	Taka	USD	Taka	USD	Taka	USD
Net Present Value	89,181.00	1,116.00	25,456.00	319.00	-21,848.95	-273.49
Returns to Labor (person-day)	1,328.00	17.00	533.10	7.00	-226.79	-2.84
Net Present Value (excluding up-front costs)	100,0345.00	1,256.00	36,620.00	458.00	-10,685.00	-134.00
Returns to Labor (excluding up-front costs)	1,495.00	19.00	766.90	10.00	-110.90	-1.00

In Table 1, the final row for each chimney dryer includes the annual discounted benefits under the scenario in which the establishment (up-front) costs are not included. The effect on overall NPV and returns to labor of such scenario are illustrated in Table 2. We see that subsidizing the establishment costs results in a marginal increase in NPV for each chimney dryer, but isn't quite enough to generate a positive NPV for the Baghar location.

Through this analysis, we found that the economic performance of the chimney dryers varies significantly depending on the products being dried. In Shrirampur, three products are dried: pulses, groundnuts, and chili (Table 3). In Parerhat, the only product is fish (Table 4). These products all have

large gains in value due to drying (Tables 3, 4). The large gain in value for dried product drives the profitability of these two scenarios.

Table 3. Products dried in Shrirampur

2016 Avg Price (tk/kg)	Pulses	Groundnuts	Chili
Fresh	32	38	70
Dried	48	80	163
% Difference	50	111	133

Table 4. Products dried in Parerhat

2016 Avg Price (tk/kg)	Phasa (fish)
Fresh	116
Dried	303
% Difference	161

In contrast, the Baghar chimney dryer is used to dry several products and is the only scenario to generate a negative NPV and returns to labor (Table 1). It appears that there are some products that are not cost effective to dry because the value added to the dried product is not sufficient to offset the loss in weight from drying. Examples of these products include puti (fish), bitter gourd, nigella seed, and jackfruit (Table 5). From these preliminary results, we see that focusing on drying products with high dried product unit price, as well as products with a large difference between fresh and dried unit prices, helps to promote a positive net present value.

Table 5. Products dried in Baghar

Products	2016 Avg Price (tk/kg)		
	Fresh	Dried	% Difference
Mango Leather	83	267	222
Arometic Rice	50	106	112
Chili	48	120	150
Puti (fish)	120	200	67
Mango	45	98	118
Bitter Gourd	29	39	34
Potato	19	40	111
Cabbage	20	50	150
Rice Cake	30	50	67
Green Olives	20	60	200
Mola (fish)	300	400	33
Nigella Seed	50	60	20
Jackfruit	60	70	17

A hypothetical situation for the Baghar chimney dryer in which lower added-value products (Jackfruit, Nigella Seed, Mola, Bitter Gourd, Puti) are excluded while doubling the input and output of highest added value products (Mango leather and Chili) generates a positive NPV (Table 6 & 7).

Table 6. Chimney dryer costs, revenue, & discounted annual benefits (in Taka) under modified product mix

	Baghar									
Cost - Establishment	11,164.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost - Maintenance, Operations, Fresh product	14,138.00	8,285.00	10,728.00	11,156.00	11,717.00	12,211.00	12,842.00	13,411.00	14,122.00	14,777.00
Revenue - Outputs (dried product)	24,174.00	5,99.002	10,760.00	11,479.00	12,24.005	13,063.00	13,935.00	14,865.00	15,858.00	16,917.00
Annual Benefits (Revenue - Costs)	-1,128.00	-2,293.00	32.00	322.00	529.00	852.00	1,093.00	1,454.00	1,736.00	2,13.009
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64
Discounted Annual Flow of Benefits	-1,127.50	-2,183.62	29.41	278.57	434.85	667.36	815.73	1,033.35	1,174.77	1,379.10

Table 7. Economic feasibility measures for chimney dryer under modified product mix

Baghar	Taka	$ USD
Net Present Value (NPV)	2,502.01	31.32
Returns to Labor (taka/day)	25.97	0.33

Alternatively, subsidizing the costs of establishment as well as the maintenance and operations costs for the first two years of production (highlighted in yellow) creates a scenario with a positive NPV (Tables 8 & 9).

Table 8. Chimney dryer costs, revenue, & discounted annual benefits (in Taka) under cost subsidized scenario

	Year									
Baghar	0	1	2	3	4	5	6	7	8	9
Cost: Establishment	11164.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost: Maintenance and Operations	7679.50	3325.50	3562.98	3512.98	3562.98	3512.98	3562.98	3512.98	3562.98	3512.98
Cost: Inputs (fresh product)	4832.50	5564.50	7674.09	8186.47	8733.05	9316.13	9938.14	10601.68	11309.52	12064.63
Total costs subsidized: Establishment + Maintenance & Operations	18843.50	3325.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Revenue: Outputs (dried product)	14612.50	5885.70	9219.03	9834.55	10491.18	11191.64	11938.87	12735.99	13586.34	14493.46

Annual Benefits: (Revenue - non-subsidized costs (fresh product))	9780.00	321.20	-2018.05	-1864.90	-1804.86	-1637.47	-1562.25	-1378.67	-1286.17	-1084.15
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64
Discounted annual flow of benefits	9780.00	305.90	-1830.43	-1610.97	-1484.86	-1283.00	-1165.78	-979.79	-870.53	-698.85

Table 9. Economic feasibility measures of chimney dryer under cost subsidized scenario

Baghar	Taka	$ USD
Net Present Value (NPV)	161.69	2.02
Returns to Labor (taka/day)	1.68	0.02

3.2 Floating Gardens

Vegetable production on nine floating gardens was monitored over 15 months (April 2016 to June 2017). In total, 22 vegetable species were produced across all nine locations, with each garden producing between 5 and 15 species (Table 10). These vegetables were chosen based on a number of factors, including farmers' preference and practice based on their food choices, suitability of growing such vegetables in a floating garden, and nutrient content of the vegetables. Cucumber, Indian spinach and Chinese spinach were grown with the most frequency. Market values for harvested produce are presented in Table 11.

Table 10. Inventory of vegetables produced in 9 different floating gardens in Bangladesh

	Babul	**Polash**	**Rofik**	**Sonjoy**	**Sukanto**	**Delowar**	**Hamida**	**Morzina**	**Nasima**
Carrot	x	x	x						
Chili	x				x	x		x	
Okra	x	x							
Cucumber	x	x	x	x	x		x	x	x
Bitter gourd	x			x				x	
Indian spinach	x	x	x		x	x	x	x	x
wax gourd	x								
Chinese spinach	x	x	x	x	x	x	x	x	x
Mint	x	x	x				x		
ridge gourd	x						x		
Chinese cabbage	x						x		
Bottle gourd leaf	x	x			x				
Beans	x			x			x		x
Tomato	x	x							
Eggplant	x	x	x	x					x
Coriander	x	x	x			x	x	x	
Radish		x	x						
Spinach		x							
Snake gourd				x	x		x		
Bottle gourd				x	x				
Red amaranth		x	x	x		x		x	
Cauliflower					x	x			
TOTAL SPECIES	15	13	9	8	8	6	9	7	5

Market prices for each vegetable were monitored monthly and multiplied by monthly production levels to calculate monthly revenue. Monthly labor and material maintenance costs were recorded to calculate a discounted cost-benefit analysis. Figure 3 illustrates the annual flow of net benefits for each of the floating gardens over 15 months. Summing the discounted flow of benefits of each floating garden yields the net present value (Table 12). Dividing the NPV by the number of person-days of labor required, or by the area of size occupied by each floating garden (0.0004 ha) yields the returns to labor and returns to land (Table 12).

From this figure and table, we can see that all floating gardens have negative net present values. Generally, revenue generated through production is not sufficient to offset the costs of building and maintaining the floating gardens. A recommendation would be to produce higher-value crops, or to increase production if possible.

Table 11. Avg. market prices for vegetables produced in floating gardens

Product	Average market price (tk/kg)
Mint	267
Coriander	135
Chili	55
Cucumber	39
Indian spinach	33
bean	33
Tomato	31
turnip	30
bottle gourd leaf	30
Chinese cabbage	30
ridge gourd	30
wax gourd	30
bitter gourd	30
carrot	30
red amaranth	30
cabbage	30
Bottle gourd	30
cauliflower	30
spinach	30
okra	28
eggplant	27
snake gourd	25
Chinese spinach	20

Figure 3. Discounted Annual Flow of Benefits - Floating Gardens

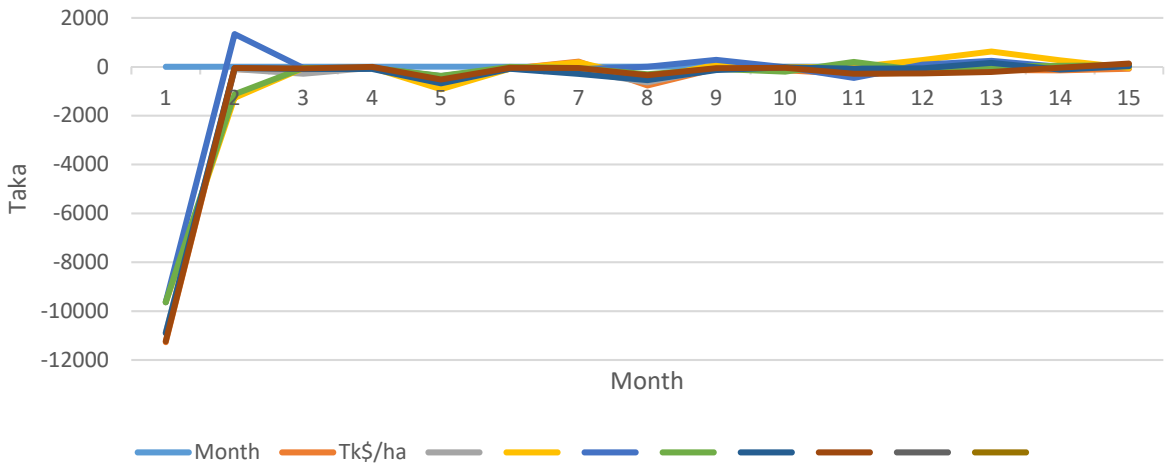


Table 12. Summary of economic feasibility measures for floating gardens

		Baseline Scenario				Subsidized up-front cost scenario			
Location	Currency	Net Present Value	Returns to Land (ha)	Returns to Labor (person-day)	Average Returns per hectare equivalent (ha/months)	Net Present Value	Returns to Land (ha)	Returns to Labor (person-day)	Average Returns per hectare equivalent (ha/months)
Babul	Taka	-13,762.86	-3,4407,160.71	-1,203.31	-2,293,810.71	-4,128.00	-10,320,000.00	-1,203.31	-688,000.00
	USD$	-172.27	-430,681.70	-15.06	-28,712.11	-52.00	-130,000.00	-15.06	-8,666.67
Polash	Taka	-13,329.11	-33,322,784.20	-1,306.78	-2,221,518.95	-3,694.00	-9,235,000.00	-46.00	-615,666.67
	USD$	-166.84	-417,108.33	-16.36	-27,807.22	-362.00	-905,000.00	-11.00	-60,333.33
Rofik	Taka	-11,118.50	-27,796,252.08	-1,245.42	-1,853,083.47	-1,484.00	-3,710,000.00	-166.00	-247,333.33
	USD$	-139.17	-347,931.56	-15.59	-23,195.44	-19.00	-47,500.00	-2.00	-3,166.67
Sonjoy	Taka	-8,696.56	-21,741,407.42	-870.00	-905,892.00	-1,676.00	-4,190,000.00	-168.00	-279,333.33
	USD$	-108.86	-272,141.79	-11.00	-11,339.00	-21.00	-52,500.00	-2.00	-3,500.00
Sukanto	Taka	-11,690.58	-29,226,453.39	-1,508.46	-1,217,768.89	-1,867.00	-4,667,500.00	-241.00	-311,166.67
	USD$	-146.33	-365,833.69	-18.88	-15,243.07	-23.00	-57,500.00	-3.00	-3,833.33
Delowar	Taka	-12,963.34	-32,408,339.49	-1,355.64	-1,350,347.48	-3,328.00	-8,320,000.00	-348.00	-554,666.67
	USD$	-162.26	-405,662.03	-16.97	-16,902.58	-42.00	-105,000.00	-4.00	-7,000.00
Hamida	Taka	-1,3071.38	-32,678,446.19	-1,584.41	-2,178,563.08	-3,336.00	-8,340,000.00	-404.00	-556,000.00
	USD$	-163.62	-409,043.01	-19.83	-27,269.53	-42.00	-105,000.00	-5.00	-7,000.00
Morzina	Taka	-13,377.14	-33,442,857.94	-1,465.99	-2,229,523.86	-3,642.00	-9,105,000.00	-399.00	-607,000.00
	USD$	-167.44	-418,611.31	-18.35	-27,907.42	-46.00	-115,000.00	-5.00	-7,666.67
Nasima	Taka	-11,651.08	-29,127,689.48	-1,467.85	-1,941,845.97	-1,916.00	-4,790,000.00	-241.00	-319,333.33
	USD$	-145.84	-364,597.44	-18.37	-24,306.50	-24	-60,000.00	-3.00	-4,000.00

Table 13 provides more detail into how costs were distributed within floating garden production at all nine locations as well as a monthly account of discounted net benefits. The impact of subsidizing up-front costs on NPV and returns to labor is outlined in tables 12 & 13. One important trend is that harvest does not occur until the 5th month of production, and remains irregular throughout the lifecycle.

Table 13. Floating garden costs, revenue, & discounted annual benefits

	2016									2017					
	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Babul															
Costs: Establishment	9635.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs: Seed	385.00	0.00	95.00	0.00	64.00	0.00	40.00	519.00	70.00	0.00	385.00	185.00	15.00	100.00	25.00
Costs: Labor	650.00	100.00	100.00	50.00	150.00	100.00	325.00	350.00	150.00	200.00	300.00	300.00	300.00	175.00	75.00
Costs: Maintenance materials	600.00	0.00	0.00	0.00	550.00	0.00	200.00	300.00	0.00	180.00	0.00	105.00	230.00	75.00	300.00
Total Costs	11270.00	100.00	195.00	50.00	764.00	100.00	565.00	1169.00	220.00	380.00	685.00	590.00	545.00	350.00	400.00
Revenue: Vegetable production	0.00	0.00	0.00	0.00	222.50	0.00	847.50	93.00	122.50	164.00	187.50	199.00	302.25	74.50	243.00
Monthly Benefits: Revenue - Costs	-11270.00	-100.00	-195.00	-50.00	-541.50	-100.00	282.50	-1076.00	-97.50	-216.00	-497.50	-391.00	-242.75	-275.50	-157.00
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64	0.61	0.58	0.56	0.53	0.51
Discounted monthly flow of benefits	**-11270.00**	**-95.24**	**-176.87**	**-43.19**	**-445.49**	**-78.35**	**210.81**	**-764.69**	**-65.99**	**-139.24**	**-305.42**	**-228.61**	**-135.17**	**-146.10**	**-79.30**
Costs: excluding establishment	1635.00	100.00	195.00	50.00	764.00	100.00	565.00	1169.00	220.00	380.00	685.00	590.00	545.00	350.00	400.00
Monthly Benefits: Revenue - costs (excluding establishment)	-1635.00	-100.00	-195.00	-50.00	-541.50	-100.00	282.50	-1076.00	-97.50	-216.00	-497.50	-391.00	-242.75	-275.50	-157.00
Discounted monthly flow of benefits	**-1635.00**	**-95.24**	**-176.87**	**-43.19**	**-445.49**	**-78.35**	**210.81**	**-764.69**	**-65.99**	**-139.24**	**-305.42**	**-228.61**	**-135.17**	**-146.10**	**-79.30**
Polash															
Costs: Establishment	9635.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs: Seed	96.00	0.00	165.00	0.00	59.00	0.00	0.00	280.00	49.00	0.00	110.00	15.00	100.00	85.00	0.00
Costs: Labor	550.00	100.00	150.00	50.00	200.00	100.00	300.00	350.00	75.00	150.00	230.00	200.00	100.00	100.00	25.00
Costs: Maintenance materials	600.00	0.00	0.00	0.00	550.00	0.00	200.00	300.00	0.00	105.00	330.00	30.00	30.00	0.00	0.00
Total Costs	10881.00	100.00	315.00	50.00	809.00	100.00	500.00	930.00	124.00	255.00	670.00	245.00	230.00	185.00	25.00
Revenue: Vegetable production	0.00	0.00	0.00	0.00	102.50	0.00	265.00	30.00	29.00	225.00	99.00	84.00	89.00	139.00	187.00
Monthly Benefits: Revenue - Costs	-10881.00	-100.00	-315.00	-50.00	-706.50	-100.00	-235.00	-900.00	-95.00	-30.00	-571.00	-161.00	-141.00	-46.00	162.00
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64	0.61	0.58	0.56	0.53	0.51
Discounted monthly flow of benefits	**-10881.00**	**-95.24**	**-285.71**	**-43.19**	**-581.24**	**-78.35**	**-175.36**	**-639.61**	**-64.30**	**-19.34**	**-350.54**	**-94.13**	**-78.51**	**-24.39**	**81.82**
Costs: excluding establishment	1246.00	100.00	315.00	50.00	809.00	100.00	500.00	930.00	124.00	255.00	670.00	245.00	230.00	185.00	25.00

Monthly Benefits: Revenue - costs (excluding establishment)	-1246.00	-100.00	-315.00	-50.00	-706.50	-100.00	-235.00	-900.00	-95.00	-30.00	-571.00	-161.00	-141.00	-46.00	162.00
Discounted monthly flow of benefits	**-1246.00**	**-95.24**	**-285.71**	**-43.19**	**-581.24**	**-78.35**	**-175.36**	**-639.61**	**-64.30**	**-19.34**	**-350.54**	**-94.13**	**-78.51**	**-24.39**	**81.82**
Rofik															
Costs: Establishment	9635.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs: Seed	0.00	183.00	0.00	0.00	115.00	0.00	0.00	58.00	32.00	33.00	25.00	0.00	5.00	0.00	30.00
Costs: Labor	0.00	550.00	50.00	50.00	200.00	100.00	300.00	200.00	75.00	50.00	50.00	74.00	74.00	74.00	174.00
Costs: Maintenance materials	0.00	600.00	0.00	0.00	880.00	0.00	100.00	600.00	0.00	60.00	0.00	150.00	30.00	30.00	30.00
Total Costs	9635.00	1333.00	50.00	50.00	1195.00	100.00	400.00	858.00	107.00	143.00	75.00	224.00	109.00	104.00	234.00
Revenue: Vegetable production	0.00	0.00	0.00	0.00	80.00	0.00	640.00	180.00	225.00	125.00	45.00	700.00	1230.00	600.00	150.00
Monthly Benefits: Revenue - Costs	-9635.00	-1333.00	-50.00	-50.00	-1115.00	-100.00	240.00	-678.00	118.00	-18.00	-30.00	476.00	1121.00	496.00	-84.00
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64	0.61	0.58	0.56	0.53	0.51
Discounted monthly flow of benefits	**-9635.00**	**-1269.52**	**-45.35**	**-43.19**	**-917.31**	**-78.35**	**179.09**	**-481.84**	**79.87**	**-11.60**	**-18.42**	**278.31**	**624.21**	**263.04**	**-42.43**
Costs: excluding establishment	0.00	1333.00	50.00	50.00	1195.00	100.00	400.00	858.00	107.00	143.00	75.00	224.00	109.00	104.00	234.00
Monthly Benefits: Revenue - costs (excluding establishment)	0.00	-1333.00	-50.00	-50.00	-1115.00	-100.00	240.00	-678.00	118.00	-18.00	-30.00	476.00	1121.00	496.00	-84.00
Discounted monthly flow of benefits	**0.00**	**-1269.52**	**-45.35**	**-43.19**	**-917.31**	**-78.35**	**179.09**	**-481.84**	**79.87**	**-11.60**	**-18.42**	**278.31**	**624.21**	**263.04**	**-42.43**
Sonjoy															
Costs: Establishment	9635.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs: Seed	0.00	239.00	0.00	0.00	40.00	0.00	105.00	0.00	0.00	0.00	45.00	0.00	0.00	0.00	0.00
Costs: Labor	0.00	500.00	50.00	50.00	200.00	50.00	350.00	100.00	50.00	25.00	150.00	50.00	50.00	75.00	25.00
Costs: Maintenance materials	0.00	600.00	0.00	0.00	850.00	0.00	0.00	0.00	0.00	0.00	550.00	30.00	30.00	30.00	0.00
Total Costs	9635.00	1339.00	50.00	50.00	1090.00	50.00	455.00	100.00	50.00	25.00	745.00	80.00	80.00	105.00	25.00
Revenue: Vegetable production	0.00	0.00	0.00	0.00	625.00	0.00	330.00	110.00	476.50	0.00	0.00	234.00	528.00	96.00	116.00
Monthly Benefits: Revenue - Costs	-9635.00	-1339.00	-50.00	-50.00	-465.00	-50.00	-125.00	10.00	426.50	-25.00	-745.00	154.00	448.00	-9.00	91.00
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64	0.61	0.58	0.56	0.53	0.51
Discounted monthly flow of benefits	**-9635.00**	**-1275.24**	**-45.35**	**-43.19**	**-382.56**	**-39.18**	**-93.28**	**7.11**	**288.67**	**-16.12**	**-457.37**	**90.04**	**249.46**	**-4.77**	**45.96**

Costs: excluding establishment	0.00	1339.00	50.00	50.00	1090.00	50.00	455.00	100.00	50.00	25.00	745.00	80.00	80.00	105.00	25.00
Monthly Benefits: Revenue - costs (excluding establishment)	0.00	-1339.00	-50.00	-50.00	-465.00	-50.00	-125.00	10.00	426.50	-25.00	-745.00	154.00	448.00	-9.00	91.00
Discounted monthly flow of benefits	**0.00**	**-1275.24**	**-45.35**	**-43.19**	**-382.56**	**-39.18**	**-93.28**	**7.11**	**288.67**	**-16.12**	**-457.37**	**90.04**	**249.46**	**-4.77**	**45.96**
Sukanto															
Costs: Establishment	9635.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs: Seed	0.00	100.00	0.00	0.00	0.00	0.00	160.00	0.00	175.00	205.00	60.00	124.00	0.00	0.00	0.00
Costs: Labor	0.00	475.00	50.00	50.00	50.00	0.00	150.00	100.00	100.00	150.00	150.00	200.00	75.00	25.00	25.00
Costs: Maintenance materials	0.00	600.00	0.00	0.00	850.00	0.00	0.00	330.00	0.00	30.00	30.00	180.00	30.00	0.00	0.00
Total Costs	9635.00	1175.00	50.00	50.00	900.00	0.00	310.00	430.00	275.00	385.00	240.00	504.00	105.00	25.00	25.00
Revenue: Vegetable production	0.00	0.00	0.00	0.00	475.00	0.00	270.00	0.00	194.00	102.00	616.00	283.00	158.40	133.50	172.25
Monthly Benefits: Revenue - Costs	-9635.00	-1175.00	-50.00	-50.00	-425.00	0.00	-40.00	-430.00	-81.00	-283.00	376.00	-221.00	53.40	108.50	147.25
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64	0.61	0.58	0.56	0.53	0.51
Discounted monthly flow of benefits	**-9635.00**	**-1119.05**	**-45.35**	**-43.19**	**-349.65**	**0.00**	**-29.85**	**-305.59**	**-54.82**	**-182.42**	**230.83**	**-129.21**	**29.74**	**57.54**	**74.37**
Costs: excluding establishment	0.00	1175.00	50.00	50.00	900.00	0.00	310.00	430.00	275.00	385.00	240.00	504.00	105.00	25.00	25.00
Monthly Benefits: Revenue - costs (excluding establishment)	0.00	-1175.00	-50.00	-50.00	-425.00	0.00	-40.00	-430.00	-81.00	-283.00	376.00	-221.00	53.40	108.50	147.25
Discounted monthly flow of benefits	**0.00**	**-1119.05**	**-45.35**	**-43.19**	**-349.65**	**0.00**	**-29.85**	**-305.59**	**-54.82**	**-182.42**	**230.83**	**-129.21**	**29.74**	**57.54**	**74.37**
Delowar															
Costs: Establishment	9635.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs: Seed	120.00	0.00	0.00	55.00	0.00	0.00	0.00	230.00	172.00	10.00	163.00	25.00	0.00	90.00	0.00
Costs: Labor	550.00	50.00	100.00	50.00	150.00	100.00	300.00	250.00	25.00	125.00	150.00	200.00	100.00	100.00	75.00
Costs: Maintenance materials	600.00	0.00	4.00	0.00	850.00	0.00	200.00	300.00	0.00	30.00	0.00	180.00	30.00	30.00	0.00
Total Costs	10905.00	50.00	104.00	105.00	1000.00	100.00	500.00	780.00	197.00	165.00	313.00	405.00	130.00	220.00	75.00
Revenue: Vegetable production	0.00	0.00	0.00	0.00	175.00	0.00	109.00	12.00	0.00	126.00	189.00	295.00	417.00	0.00	124.00
Monthly Benefits: Revenue - Costs	-10905.00	-50.00	-104.00	-105.00	-825.00	-100.00	-391.00	-768.00	-197.00	-39.00	-124.00	-110.00	-287.00	-220.00	-49.00
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64	0.61	0.58	0.56	0.53	0.51

Discounted monthly flow of benefits	**-10905.00**	**-47.62**	**-94.33**	**-90.70**	**-678.73**	**-78.35**	**-291.77**	**-545.80**	**-133.34**	**-25.14**	**-76.13**	**-64.31**	**159.81**	**-116.67**	**24.75**
Costs: excluding establishment	1270.00	50.00	104.00	105.00	1000.00	100.00	500.00	780.00	197.00	165.00	313.00	405.00	130.00	220.00	75.00
Monthly Benefits: Revenue - costs (excluding establishment)	-1270.00	-50.00	-104.00	-105.00	-825.00	-100.00	-391.00	-768.00	-197.00	-39.00	-124.00	-110.00	287.00	-220.00	49.00
Discounted monthly flow of benefits	**-1270.00**	**-47.62**	**-94.33**	**-90.70**	**-678.73**	**-78.35**	**-291.77**	**-545.80**	**-133.34**	**-25.14**	**-76.13**	**-64.31**	**159.81**	**-116.67**	**24.75**
Hamida															
Costs: Establishment	9735.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs: Seed	350.00	0.00	75.00	0.00	40.00	0.00	0.00	5.00	85.00	25.00	110.00	0.00	0.00	15.00	0.00
Costs: Labor	550.00	50.00	0.00	0.00	225.00	50.00	325.00	175.00	0.00	100.00	350.00	75.00	50.00	125.00	25.00
Costs: Maintenance materials	600.00	0.00	0.00	0.00	434.00	0.00	130.00	330.00	0.00	30.00	0.00	480.00	430.00	30.00	0.00
Total Costs	11235.00	50.00	75.00	0.00	699.00	50.00	455.00	510.00	85.00	155.00	460.00	555.00	480.00	170.00	25.00
Revenue: Vegetable production	0.00	0.00	0.00	0.00	70.00	0.00	390.00	30.00	0.00	87.00	0.00	95.00	95.00	99.00	283.00
Monthly Benefits: Revenue - Costs	-11235.00	-50.00	-75.00	0.00	-629.00	-50.00	-65.00	-480.00	-85.00	-68.00	-460.00	-460.00	-385.00	-71.00	258.00
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64	0.61	0.58	0.56	0.53	0.51
Discounted monthly flow of benefits	**-11235.00**	**-47.62**	**-68.03**	**0.00**	**-517.48**	**-39.18**	**-48.50**	**-341.13**	**-57.53**	**-43.83**	**-282.40**	**-268.95**	**-214.38**	**-37.65**	**130.31**
Costs: excluding establishment	1500.00	50.00	75.00	0.00	699.00	50.00	455.00	510.00	85.00	155.00	460.00	555.00	480.00	170.00	25.00
Monthly Benefits: Revenue - costs (excluding establishment)	-1500.00	-50.00	-75.00	0.00	-629.00	-50.00	-65.00	-480.00	-85.00	-68.00	-460.00	-460.00	-385.00	-71.00	258.00
Discounted monthly flow of benefits	**-1500.00**	**-47.62**	**-68.03**	**0.00**	**-517.48**	**-39.18**	**-48.50**	**-341.13**	**-57.53**	**-43.83**	**-282.40**	**-268.95**	**-214.38**	**-37.65**	**130.31**
Morzina															
Costs: Establishment	8235.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs: Seed	170.00	0.00	53.00	0.00	0.00	76.00	0.00	66.00	0.00	0.00	45.00	10.00	0.00	75.00	0.00
Costs: Labor	550.00	100.00	75.00	50.00	100.00	100.00	50.00	350.00	300.00	100.00	175.00	125.00	75.00	75.00	25.00
Costs: Maintenance materials	600.00	30.00	0.00	0.00	925.00	0.00	100.00	300.00	30.00	300.00	180.00	30.00	30.00	0.00	0.00
Total Costs	9555.00	130.00	128.00	50.00	1025.00	176.00	150.00	716.00	330.00	400.00	400.00	165.00	105.00	150.00	25.00
Revenue: Vegetable production	0.00	0.00	0.00	0.00	90.00	0.00	306.00	60.00	0.00	30.00	20.00	21.00	48.00	57.00	180.00
Monthly Benefits: Revenue - Costs	-9555.00	-130.00	-128.00	-50.00	-935.00	-176.00	156.00	-656.00	-330.00	-370.00	-380.00	-144.00	-57.00	-93.00	155.00

Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64	0.61	0.58	0.56	0.53	0.51
Discounted monthly flow of benefits	**-9555.00**	**-123.81**	**-116.10**	**-43.19**	**-769.23**	**-137.90**	**116.41**	**-466.21**	**-223.36**	**-238.51**	**-233.29**	**-84.19**	**-31.74**	**-49.32**	**78.29**
Costs: excluding establishment	1320.00	130.00	128.00	50.00	1025.00	176.00	150.00	716.00	330.00	400.00	400.00	165.00	105.00	150.00	25.00
Monthly Benefits: Revenue - costs (excluding establishment)	-1320.00	-130.00	-128.00	-50.00	-935.00	-176.00	156.00	-656.00	330.00	370.00	380.00	144.00	-57.00	-93.00	155.00
Discounted monthly flow of benefits	**-1320.00**	**-123.81**	**-116.10**	**-43.19**	**-769.23**	**-137.90**	**116.41**	**-466.21**	**223.36**	**238.51**	**233.29**	**-84.19**	**-31.74**	**-49.32**	**78.29**
Nasima															
Costs: Establishment	9735.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs: Seed	145.00	0.00	80.00	0.00	0.00	5.00	0.00	60.00	75.00	0.00	110.00	0.00	0.00	15.00	0.00
Costs: Labor	500.00	50.00	100.00	50.00	100.00	0.00	275.00	250.00	125.00	100.00	100.00	100.00	75.00	100.00	50.00
Costs: Maintenance materials	100.00	50.00	50.00	50.00	0.00	0.00	25.00	100.00	75.00	0.00	25.00	25.00	25.00	50.00	0.00
Total Costs	10480.00	100.00	230.00	100.00	100.00	5.00	300.00	410.00	275.00	100.00	235.00	125.00	100.00	165.00	50.00
Revenue: Vegetable production	0.00	0.00	0.00	0.00	100.00	0.00	45.00	75.00	33.00	51.50	45.00	25.00	117.50	75.00	168.00
Monthly Benefits: Revenue - Costs	-10480.00	-100.00	-230.00	-100.00	0.00	-5.00	255.00	-335.00	242.00	-48.50	190.00	100.00	17.50	-90.00	118.00
Discount factor	1.00	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.64	0.61	0.58	0.56	0.53	0.51
Discounted monthly flow of benefits	**-10480.00**	**-95.24**	**-208.62**	**-86.38**	**0.00**	**-3.92**	**190.28**	**-238.08**	**163.80**	**-31.26**	**116.64**	**-58.47**	**9.74**	**-47.73**	**59.60**
Costs: excluding establishment	745.00	100.00	230.00	100.00	100.00	5.00	300.00	410.00	275.00	100.00	235.00	125.00	100.00	165.00	50.00
Monthly Benefits: Revenue - costs (excluding establishment)	-745.00	-100.00	-230.00	-100.00	0.00	-5.00	255.00	-335.00	242.00	-48.50	190.00	100.00	17.50	-90.00	118.00
Discounted monthly flow of benefits	**-745.00**	**-95.24**	**-208.62**	**-86.38**	**0.00**	**-3.92**	**190.28**	**-238.08**	**163.80**	**-31.26**	**116.64**	**-58.47**	**9.74**	**-47.73**	**59.60**

3.3 Cold Storage

Storage of vegetables and the market price at input and output was tracked on a weekly time step for the CoolBot cold room in Lebukhali[2] from May 2016 to July 2017. In total, 28 different commodities, chosen by the farmer participants, were stored over this time period. All the commodities showed some benefit from storage in that there were reduced losses from having been cold stored. This could be due to receiving a higher price, as a result of waiting for the market price to increase, or simply being able to sell more because less food was lost to deterioration. It is likely that it is a combination of these, however it is difficult to distinguish between these two factors using this model.

Table 14. CoolBot Cold Room in Lebukhali costs, revenue, & discounted benefits (in USD)

	YEAR										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Cost: Establishment	$12,808.20	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Cost: Maintenance, operation, & input produce (stored)	n/a	$1,193.11	$2,257.67	$1,757.39	$1,842.18	$1,945.84	$1,972.73	$1,986.58	$2,056.26	$2,086.79	$2,118.66
Revenue: Output produce (sold)	n/a	$1,380.37	$2,879.95	$2,369.99	$3,095.51	$3,105.86	$3,090.27	$3,094.02	$3,062.21	$3,071.29	$3,058.95
Annual Benefits (revenue - total cost)	-$12,808.20	$187.26	$622.28	$612.60	$1,253.33	$1,160.02	$1,117.54	$1,107.44	$1,005.95	$984.50	$940.28
Discounted annual flow of benefits @ r = 0.05	-$12,808.20	$178.34	$564.43	$529.19	$1,031.12	$908.91	$833.92	$787.04	$680.87	$634.62	$577.25
Discounted annual flow of benefits @ r = 0.08	-$12,808.20	$173.39	$533.51	$486.30	$921.23	$789.49	$704.24	$646.18	$543.49	$492.49	$435.53
Discounted annual flow of benefits @ r = 0.10	-$12,808.20	$170.23	$514.28	$460.26	$856.04	$720.28	$630.82	$568.29	$469.29	$417.52	$362.52

[2] Two additional cold rooms have also been constructed, but to date, the one is Lebukhali has been running the longest and therefore has the most complete data. Those seeking to apply the results and recommendations based on this data should keep in mind that this analysis only reflects a single cold room, and further analysis is needed once the other rooms are fully functional.

Table 15. Summary of economic feasibility measures for the CoolBot Cold Room in Lebukhali, Bangladesh

	r = 0.05		r = 0.08		r = 0.1	
	5 Years	**10 Years**	**5 Years**	**10 Years**	**5 Years**	**10 Years**
Net Present Value (Taka)	-767,505.98	-486,480.40	-792,144.57	-566,446.50	-767,505.98	-610,940.66
Net Present Value (USD)	- $9,596.22	- $6,082.53	- $9,904.28	- $7,082.35	- $9,596.22	- $7,638.67
Returns to Family Labor per person-day (USD)	- $19.66	- $12.46	- $20.29	- $14.51	- $19.66	- $15.65

Table 14 shows the flow of costs and benefits at various discount rates (r) over a 10-year time span, and Table 15 displays the net present value (NPV) in Takas and USD for both 5 and 10 years, and at 3 different discount rates (r) to test the sensitivity of these estimates. Often, the discount rate is the same as the interest rate set by a country's central bank. The Bangladesh Bank has set an interest rate of 5% (r=0.05)[3]. However, this might not be reflective of the true social discount rate, which is people's relative valuation of today's wellbeing versus future wellbeing. A 2010 study found[4] the social discount rate in Bangladesh to be between 9-11%. Furthermore, in many developing countries, a discount rate of 10% (r=0.1) is commonly used in NPV calculations. Thus, this analysis uses the three different r-values of 0.05, 0.08, and 0.10 displayed in Tables 14, 15, and 16. In addition to 3 different discount rates, two different time spans, 5 and 10 years, were also used to calculate various NPV values. These two values were chosen because it is estimated that a cold room has a lifespan of about 10 years, but since discount rates in developing countries tend to be high, it also made sense to estimate a shorter timeframe.

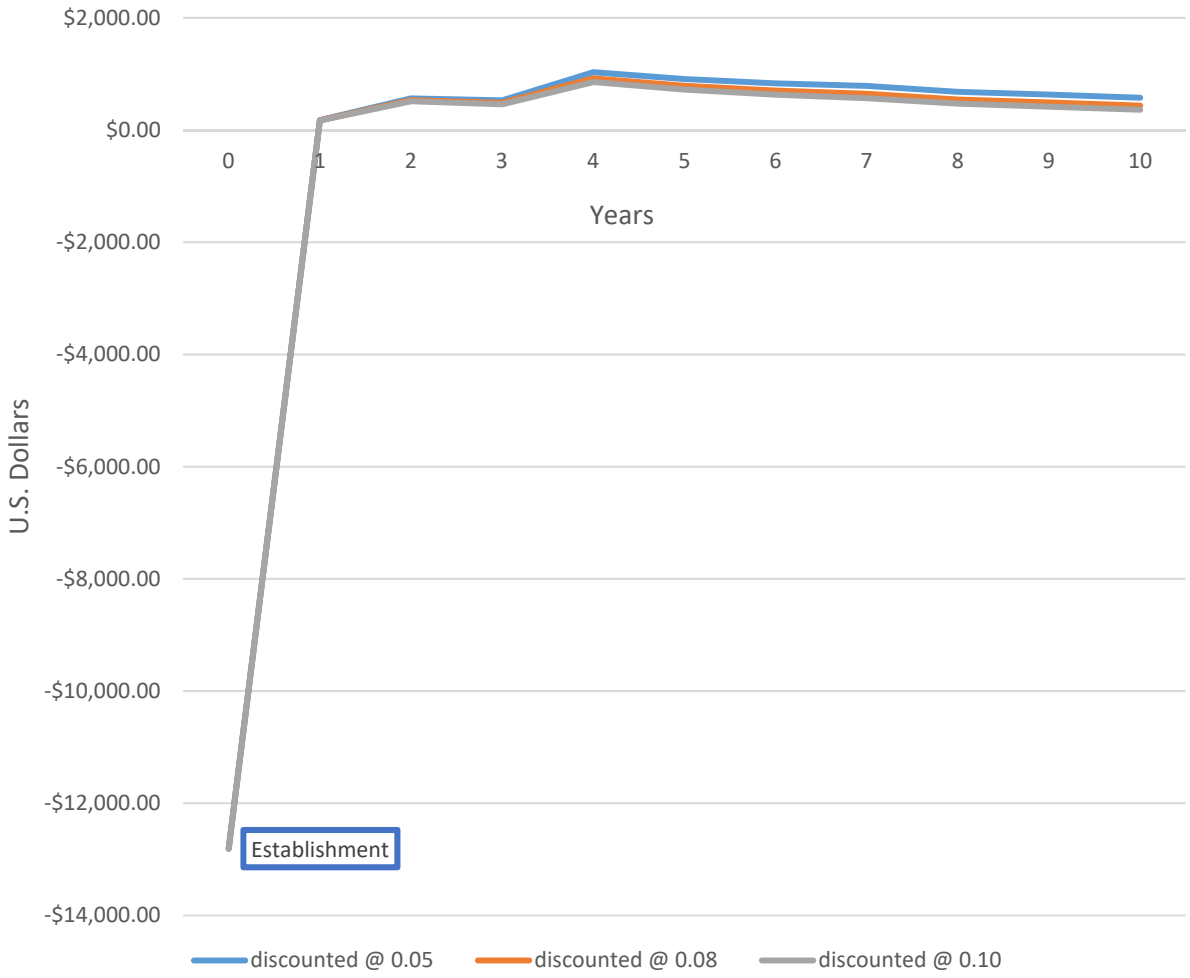
The NPV at each discount rate and timespan is decidedly negative, as Table 15 shows. Figure 4 highlights how the high establishment cost of around $12,800 USD is driving this negative NPV and the negative returns to labor[5]. A critical thing to note with these estimates, however, is that the model currently assumes that usage would stay exactly the same in the future as it has over the past year, but the cold room is not being used anywhere near its full capacity.

[3] https://www.bb.org.bd/econdata/intrate.php; http://mecometer.com/whats/bangladesh/central-bank-discount-rate/

[4] Jalil, Mohammad Muaz, Approaches to Measuring Social Discount Rate: A Bangladesh Perspective (November 11, 2010). Available at SSRN: https://ssrn.com/abstract=1921987 or http://dx.doi.org/10.2139/ssrn.1921987

[5] Returns to land are not calculated because this is not a relevant measure for this cold room technology.

Figure 4. Discounted Annual Flow of Benefits - Cold Room Lebukhali



It is estimated that a cold room, which is 4 x 3 x 3 meters, can hold 340 crates (measuring 54 x 35 x 25 cm). If a crate can hold on average about 14 Kg, then an estimated maximum weight of produce is 4,760 Kg. To be conservative, let us assume that the maximum weight that can be stored in this cold room is 4,500 kg/day. That means that over a week, if the cold room is kept constantly full, the total weight of produce kept in the cold room should be 31,500 Kg. Given this estimate, the cold room is used a maximum of 5.6% of its full capacity, and only on average 0.94%. Thus, there is lots of room for improvement in this system.

One reason for this underutilization is the current management system. The cold room is kept locked and only one farmer has the key. Thus, in order for other farmers to store their product in the cold room, they need to schedule it with this primary farmer who has the key. This management system was put in place to ensure accurate data collection on the products that go in and out of the cold room and their prices at that time, as the primary farmer was also trained on how to collect this information. However, this management system could create barriers to storage for other farmers, since their harvest schedules might not align well with the availability of the key-holder and in many cases, time to

cool is a critical factor in ensuring farmers realize the benefits of cold storage. Future analysis will work towards estimating what the optimal mix of products should be stored and at what times of year.

It is conceivable that establishment costs could be covered by another entity, such as the government or an NGO, meaning that a smallholder farming community would only be responsible for the ongoing operational and maintenance costs. Table 16 displays the NPV calculations without taking into account the high establishment costs, estimated be around $12,800 USD (see Table 14 for exact value).

Table 16. Summary of economic feasibility measures for the CoolBot Cold Room in Lebukhali, Bangladesh without Establishment Costs

	r = 0.05		r = 0.08		r = 0.10	
	5 Years	**10 Years**	**5 Years**	**10 Years**	**5 Years**	**10 Years**
Net Present Value (Taka)	256,894.02	537,919.60	232,255.43	457,953.50	256,894.02	413,459.34
Net Present Value (USD)	$3,211.98	$6,725.68	$2,903.92	$5,725.85	$2,721.09	$5,169.53
Returns to Family Labor per person-day (USD)	$6.58	$13.78	$5.95	$11.73	$5.57	$10.59

Confirming that the high establishment costs are driving the initially negative NPV values, without factoring in the establishments cost the NPV and returns to labor become positive. This shows that even at low use rates, farmers are experience positive returns from cold storage. The primary takeaway is that establishment costs would need to come down between $9,500-$10,000 USD over a 5-year lifespan and about $6,000-$8,000 USD for 10 years. These cost reductions would mean that the NPV would be about zero. To display a positive NPV there would need to be both a reduction in establishment costs and an increase in the amount of produce stored.

4. Preliminary Conclusions

4.1 Chimney Dryers

- Some products that are not cost effective to dry because the value added to the dried product is not sufficient to offset the loss in weight from drying.
- Drying products with high dried product unit price, as well as products with a large difference between fresh and dried unit prices, helps to promote a positive net present value.

4.2 Floating Gardens

- Across all 9 floating garden locations, current revenue generated through production is not sufficient to offset establishment and operating costs.
- Revenue is not generated until the 5th month of production. Incorporating quick-maturing crops could help smooth revenue.

4.3 CoolBot Cold Room

- High establishment costs combined with low usage rates make the NPV and returns to labor significantly negative for the CoolBot cold room in Lebukhali. However, if establishment costs were not considered, even low use rates show positive returns.
- An improved management system, as well as further educational outreach and training is needed to encourage increased use of the cold room.
- More research is necessary in order to properly advise farmers on what produce to store, when, and in what quantities.
- Reducing establishment costs, such as retrofitting an existing building or using less expensive building materials, would also help to improve the economic feasibility of this technology.

General Considerations

It should be noted that all three technologies are still in a relatively early research and implementation stage. This means that the economic calculations made above, based on actual field data collected to date, reflect establishment and usage rates that are still in flux. For example, the floating gardens are a novel technology and the first year of data demonstrates that there was a lot of learning, both by farmers and researchers, as to what would be the best products to grow and at what times. Many gardens were built just before the rainy season, which delayed planting and harvesting. Currently in the second year of production, gardens show much more consistent planting and harvesting schedules. Thus, this analysis should be done again once more data has been collected, as this new data will be more representative of regular usage going forward. Similarly, with the chimney dryers and cold room, this analysis highlighted a number of areas that can be improved upon (see above), and once these changes have been made it would be good to re-evaluate the cost-benefit of these technologies as has been done here. This is especially true, since the chimney dryer and cold room forecasted future use to be the same as what users have demonstrated to date. However, improvements in product mix, use rate, or management system could significantly affect these estimates.

Furthermore, limitations in access to historic price data hampered precise price forecasting, and the simple linear regression model combined with a random normal distribution algorithm did not take into account seasonality when predicting prices. Seasonality is especially important for technologies like the cold room and the chimney dryer, so future research should focus on getting access to accurate historic price data that can be used with more sophisticated time series models, such as ARMA or ARIMA[6]. This, in conjunction with longer-term field data, will improve the economic analysis of these three technologies. Yet overall, despite these limitations, the finding presented here remain informative for future analysis and in guiding research and adaptation of these technologies in Bangladesh.

[6] Autoregressive moving average (ARMA) and autoregressive integrated moving average (ARIMA)