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The Cost of Climate Change to Agricultural Industries: Coconuts in Sri Lanka*

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ABSTRACT

Agriculture in low latitude countries such as Sri Lanka is already operating at the maximum temperature limits for crop growth and faces increased production risk from expected climate change. Sri Lanka is a developing country with limited economic and technological capacity to develop adaptation strategies; hence more vulnerable to climate change than developed countries. Coconut (Cocos nucifera L) is a rain fed perennial crop important in Sri Lankan culture, food consumption and the economy. It is the second most important food in the Sri Lankan diet after rice. Several studies have examined the impact of climate change on Sri Lankan agriculture, but none were conducted to simulate the impact of future climate change and future adaptation strategies on coconut production, or to calculate the economic welfare effects for different stakeholders in the coconut value chain. In this paper we report the development of an economic model of the coconut value chain that allows prediction of welfare impacts, and a quantitative representation of coconut yield that allows prediction of the impact of changing climatic conditions. The average outcome of 16 climate models was used to generate future climatic conditions, with two future climatic scenarios for 2020, 2030 and 2050 considered for three production regions. The most important yield estimate was a yield decline of more than 10 percent in the wet climatic zone due to the expected increase of maximum temperature. Without extra adaptation measures this is predicted to result in a loss to the industry of 4,795 Rs. Million annually by 2020, which is nearly 4.7 percent of the total value of the industry at equilibrium prices and quantities. The negative impact of climate change has the potential to be reduced with the implementation of additional adaptation practices. However, the cost effectiveness of these practices needs to be considered. Wider adoption of fertilizer application at specific times and moisture conservation practices are estimated to be economically beneficial.

Keywords: *Climate change; Sri Lanka; coconut; value chain; economic modelling.*

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1 Introduction

Climate change is defined as "any change in climate over time, whether due to natural variability or as a result of human activity" (Houghton et al., 2001:62). Data analyses have confirmed that climate change is consistent with the observations of global warming and other changes in the climate system (Houghton et al., 2001). The agriculture sector is one of the most vulnerable sectors to climate change (Burton et al., 2005; Fischer et al., 2005; Fisher et al., 2012). According to the Intergovernmental Panel on Climate Change (IPCC), negative impacts on crop production will be more common than positive impacts (IPCC, 2014a). Agriculture in low latitude countries is already operating at the maximum temperature limits for crop growth and at a greater production risk than the high latitude countries (IPCC, 2014a). Thus, crop productivity is expected to improve in mid and high latitude countries whereas in low latitude countries it is expected to decrease, with an expected local temperature increase of 1-2 C. Further, an increase in the frequency of droughts and floods is expected in these low latitude regions (IPCC, 2014a). The majority of the countries located in low latitudes are developing countries which have limited economic and technological capacity to develop adaptation strategies; hence they are more vulnerable to climate change than developed countries (Mertz et al., 2009).

Sri Lanka (see Figure 1) is a South Asian tropical island and there is already evidence that its climate has changed. An annual temperature increase of 0.016 C was observed during the period 1960 to 1990 across the country. The day time maximum and night time minimum mean air temperatures have increased by 0.021 C and 0.02 C per year, respectively (Basnayake, 2011). Meanwhile, the number of consecutive dry days has increased in the dry and the intermediate climatic zones. The number of warm days and warm nights has increased while the number of cold days and nights has decreased (Ministry of Environment, 2010a). The average annual rainfall decreased by 144mm, around seven percent, during the same period and the distribution pattern has also changed (Basnayake, 2011). The North East monsoon rainfall has decreased with an increase in rainfall variability, and there are also more single-day heavy rainfall events.

However, studies on future climate projections for Sri Lanka are limited and the available projections show conflicting outcomes especially for rainfall (Eriyagama et al., 2010a). According to Basnayake (2011), monsoon rainfall is predicted to increase by 2025 under the A2 emission scenario. A2 is the medium emission scenario with the HadCM3 model which is based on hypothetical emission scenarios suggested by the IPCC. Mean temperatures are expected to increase by 2.9 C and 2.5 C during the northeast and southwest monsoon periods, respectively, by the end of this century. The occurrence of weather extremes, especially droughts and floods, are expected to be more frequent. Wet areas will get more rain and dry areas will become drier by 2025.

Several recent studies have analysed the potential impact of climate change on the agriculture sector of Sri Lanka. These studies have mainly focussed on paddy rice cultivation which is the staple food of Sri Lanka (De Silva et al., 2007; Kurukulasuriya et al., 2007). They found that the impact on wet season paddy would be negative for many parts of the country except in the extreme south (De Silva et al., 2007). Another study found regional variation in the profitability of smallholder farmers where the farmers in the wet high altitude areas benefited while the farmers in the north western and south eastern lowlands were adversely affected (Kurukulasuriya et al., 2007).

Perennial cropping systems are thought to be more vulnerable to climate change because they are long established (Lobell et al., 2006); however, there are few studies conducted for plantation agriculture. A study of the tea industry found that the impact on mid and lowland grown tea was more negative than that on highland grown tea (Wijeratne et al., 2007).

Coconut (Cocos nucifera L) is a rain fed perennial crop important in Sri Lankan culture, food consumption and the economy. It is the second most important food in the Sri Lankan diet after rice. An analysis of the economic impact of climate variability on the coconut industry conducted using 1971-2001 data showed that 60 percent of the variation in coconut production can be explained by climatic factors. It was estimated that the industry could incur an economic loss of US$32 million to US$73 million in extreme shortages while gaining an income of US$42 million to US$87 million in crop gluts (Fernando et al., 2007). This study emphasized the potential benefits that can be gained through adaptation strategies. Coconut production forecasting studies have shown that annual coconut production is particularly sensitive to rainfall during January to March in the main coconut growing regions (Peiris et al., 2008). Further, maximum ambient temperature and relative humidity in the afternoon are the most significant variables in nut production (Peiris et al., 1997). Coconut production will be lower by 2040 under six climate change scenarios (Peiris et al., 2004).

However, none of the studies cited were conducted to simulate the impact of future climate change and future adaptation strategies on coconut production, or to calculate the economic welfare effects for different stakeholders in the coconut value chain (Winters et al., 1998). That was the objective of this study. Achieving that objective requires an economic model of the value chain that allows prediction of welfare impacts, and a quantitative representation of coconut yield that allows the impact of changing climatic conditions on yield.

The economic structure of coconut production and marketing in Sri Lanka is described first, followed by an outline of the economic industry model and the model of the determinants of coconut yield. Based on two IPCC climate change scenarios (rcp2.6, rcp8.5), coconut yields in Sri Lanka are predicted for three climatic zones (intermediate wet zone, intermediate dry zone, wet zone) in three future time periods (2020, 2030, 2050) for a continuation of current adaptation investments and a range of potential additional adaptation options. The economic cost of the business as usual case is estimated from the economic model, as are the predicted benefits from the range of adaptation investments. A cost effectiveness assessment and an example sensitivity analysis complete the paper.

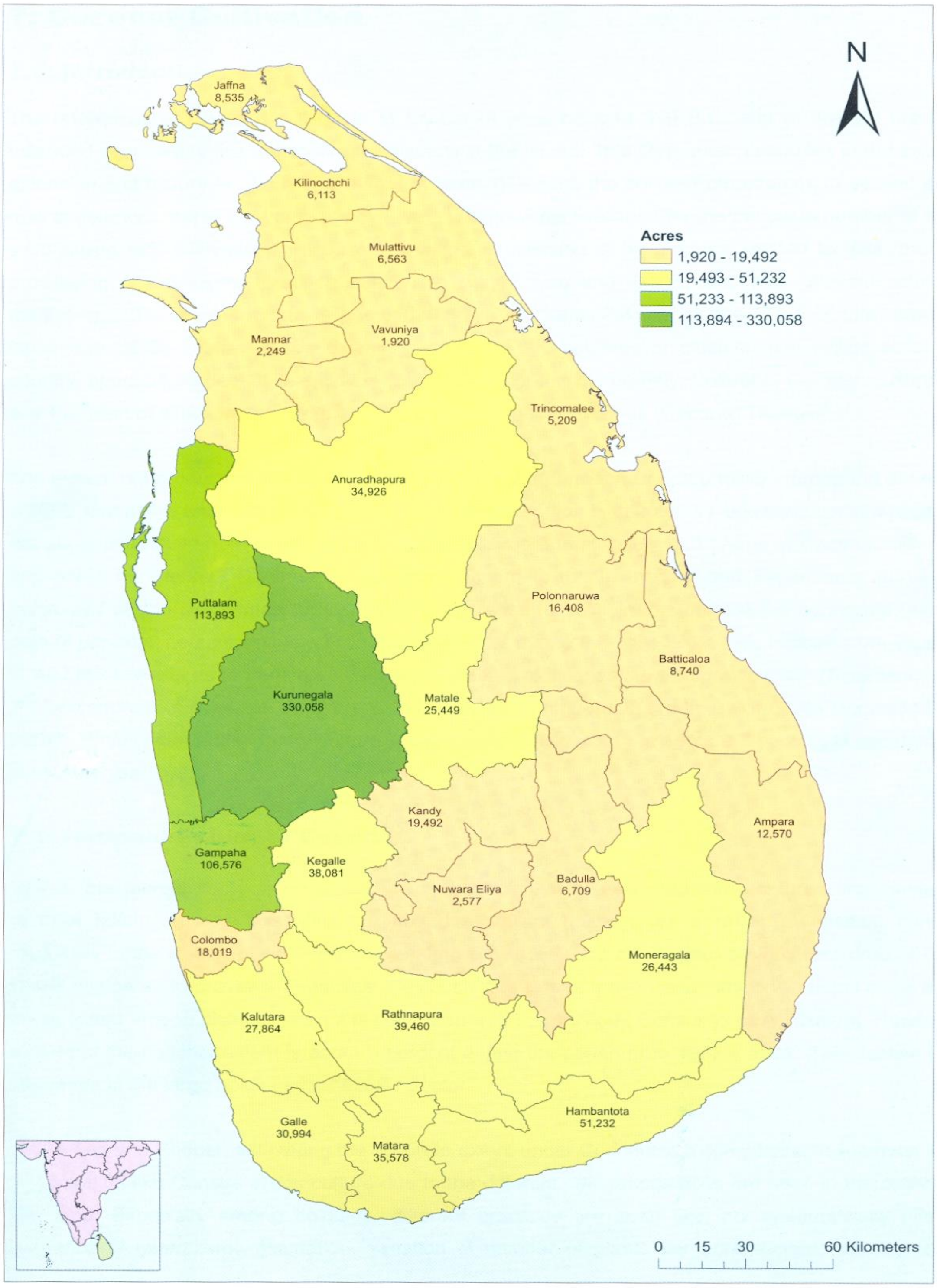

Figure 1. Land under coconut cultivation in Sri Lanka (2002) (Department of Census and Statistics, 2002)

2 Economic structure of the coconut industry in Sri Lanka

The first step is to understand the economic structure of coconut production and marketing in Sri Lanka. Following the land reforms of the early 1970s, the production structure of the industry has shifted dramatically from plantation to small scale. Today, of the 2,175,000 holdings growing coconut, the smallholding sector makes up around 82 per cent of the total. This was around 64 percent in the early 1970s.

The main coconut growing area consists of three administrative districts called the "Coconut Triangle": Kurunegala, Puttalam and Gampaha (as shown in Figure 1). This region contains 57 percent of the total coconut lands. The Southern Province is identified as the "Mini-Coconut Triangle" and comprises the Galle, Matara and Hambantota administrative districts. It contains around 12 percent of the coconut cultivated lands. The remaining coconut land is distributed throughout the country except for the central upcountry where coconut is not grown due to low temperatures.

The coconut processing sector comprises two distinct sub-sectors: kernel and non-kernel products. The major kernel products are coconut oil, desiccated coconut, copra, coconut cream and coconut milk powder. Up until the mid-1970s coconut oil was the major export commodity and it utilized some 28 percent of annual output processed for export (or 683 million nuts), followed by desiccated coconut (15 percent or 380 million nuts) and copra (180 million nuts annually).

The value chain map of the coconut kernel products sector is shown in Figure 2. Fresh coconut production requires input supplies such as seedlings, fertilizer and agrochemicals, extension services, management and labour (Pathiraja et al., 2013b). Direct sales to the processors are not very common. Estate level plantations and contract based cooperative societies are examples of chain actors that deal directly with processors. Generally the longest chain is through village level primary collectors, secondary collectors, wholesalers and brokers to the processors (Samarajeewa et al., 2004). Fresh coconuts are sold through a broker to the exporters in the fresh nut export market. However, the fresh nut export market is comparatively small and only comprises one to two percent of the total coconut production. Fresh nuts are sold to domestic retailers through any of these collectors and local fresh nut consumers are the ultimate market.

The desiccated coconut industry is the main coconut processing industry and 99 percent of its production is exported through brokers. Copra is an intermediary product sold directly to the coconut oil processors or through village level collectors to the copra dealers. Coconut oil reaches the local consumers through a wholesaler and retailer. Around 4 percent of coconut oil production is exported and brokers are involved in sales. Other kernel products are coconut milk powder, coconut milk and cream, sold in both local and export markets. The local consumer market is approached through a distributor or wholesaler, whereas the export market is through direct sales to the buyers.

The non-kernel sector products are based on the husk and the shell of the coconut. Husk products include bristle fibre, mattress fibre, coir pith and other value added products, for example coir yarn, coir twine, Tawashi brushes, coir brooms, brushes, rubberized coir pads, mattress for bedding, coir mats, rugs, fibre pith, husk chips, geo textiles and moulded coir products used in horticulture. The greater part of these value added products are exported.

These value chains are described in detail in Pathiraja et al. (2015).

3 Economic model of the coconut market in Sri Lanka

The next step is to translate this information on the value chains into an economic model that can be used for simulation purposes. Previous literature on the coconut industry was also examined but none of the previous studies focused on both vertical and horizontal disaggregation and all are quite dated. De Silva (1985) hypothesised the impacts of different domestic and export policies but these were illustrated graphically due to a lack of coefficients in estimating the actual impact. A coconut market model was estimated (Samarajeewa, 2002a; Samarajeewa et al., 2002), which considered three major products: culinary coconut, coconut oil and desiccated coconut. The supply and demand functions were linked using the equilibrium price and those functions were econometrically estimated. Producer surplus for growers was analysed in terms of trade liberalisation, cultivation subsidies and an export levy on desiccated coconut. However, the economic surpluses were not estimated for all the horizontal markets and vertical disaggregation was not considered.

A carefully designed market structure to represent an industry is vital in accurately estimating the impacts of exogenous shocks to the market and its segments (Mounter et al., 2008; Zhao et al., 2000b). Further, disaggregation of the industry in both vertical and horizontal directions allows a sound analysis of the impacts across different sectors and, where relevant, regions (Mounter et al., 2008; Zhao et al., 2000b).

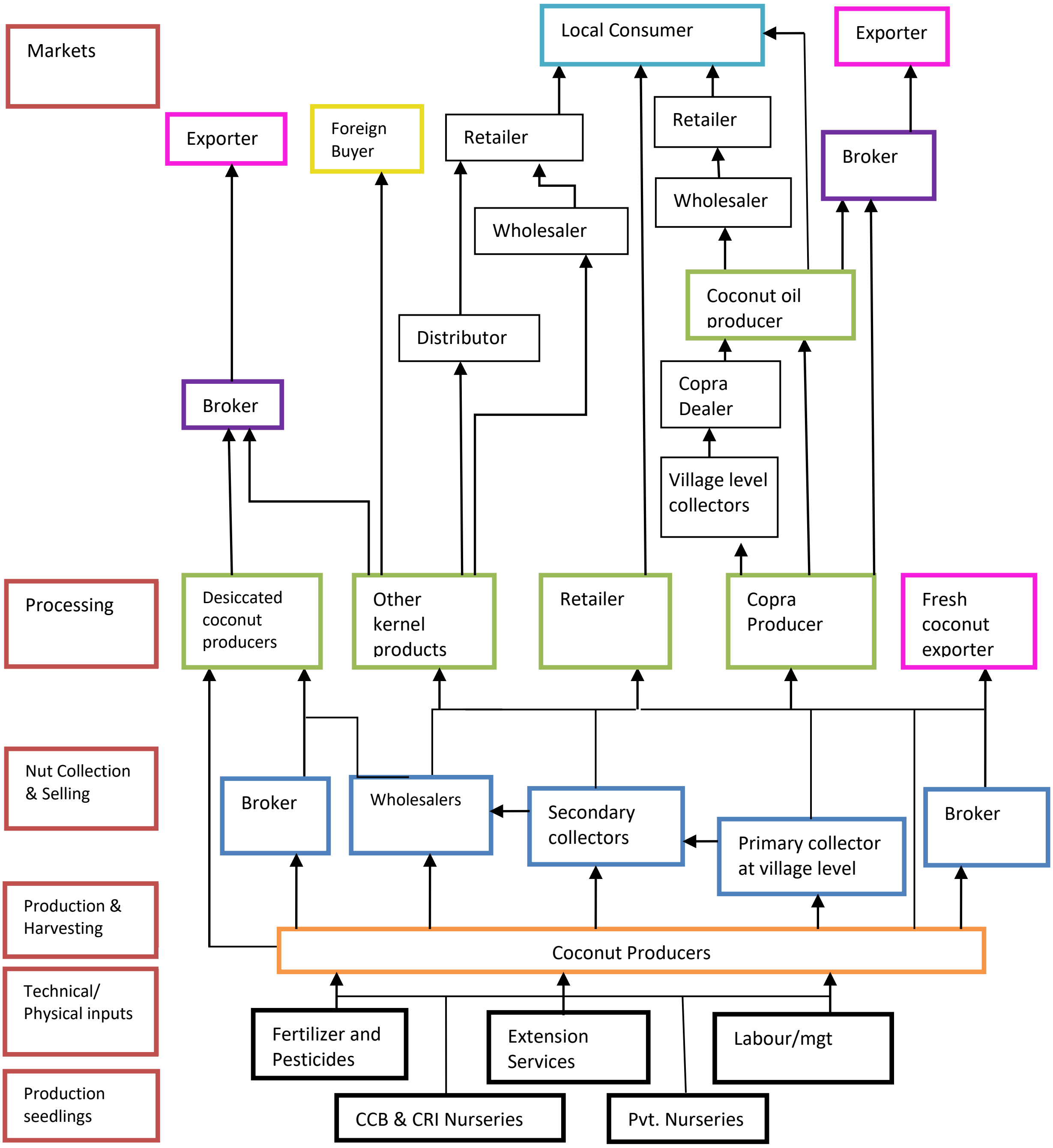

Figure 2. Value chain map of the Sri Lanka coconut kernel product sector (Pathiraja et al., 2013b)

The economic structure of the coconut industry in Sri Lanka in equilibrium displacement model (EDM) form is shown in Appendix Figure 1. A summary is shown in Figure 3a and 3b. This framework is based on the detailed mapping of the various sector value chains reported in (Pathiraja et al., 2015). Following previous EDM studies (Mounter et al., 2007; Mounter et al., 2008; Zhao, 1999; Zhao et al., 2003), each rectangle represents a production function. The arrows represent demand and supply relationships where an arrow head represents a product demand while the arrow shaft indicates the supply of a product. The ovals represent factor supplies and product demands where an exogenous shift would occur.

The industry is vertically disaggregated into coconut production, processing, marketing and consumption. Horizontally it is segmented into four major product groups. Thus, there are eight industry sectors in the model: fresh nut retailing, desiccated coconut processing, export marketing of desiccated coconut, copra processing, coconut oil processing, export marketing of coconut oil, domestic marketing of coconut oil, and “other products” processing. This is similar to the model of Henderson et al. (2006).

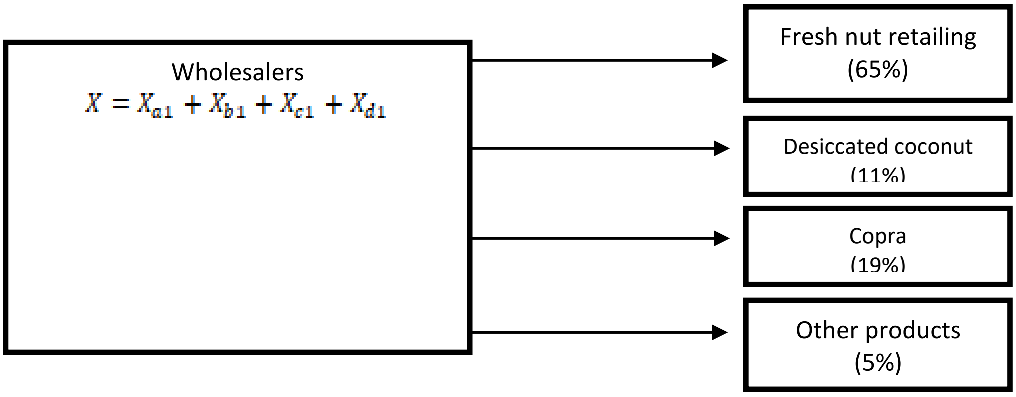

Figure 3a. Horizontal disaggregation of the Sri Lankan coconut industry

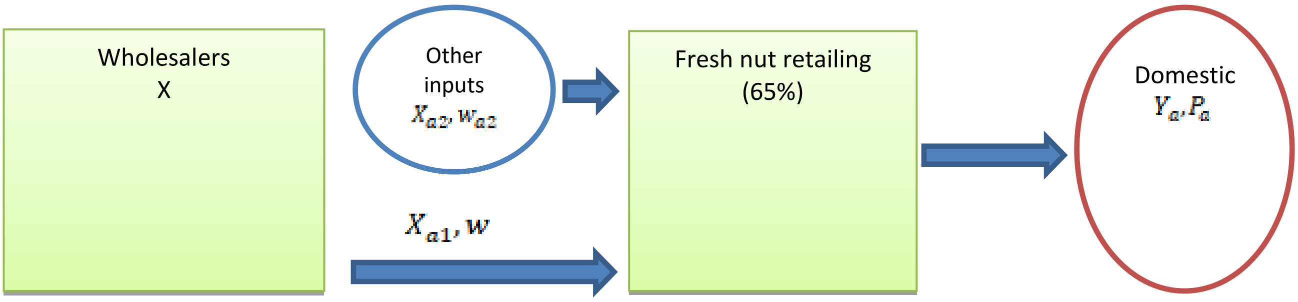

Figure 3b. Economic framework for fresh coconut retailing

Total production indicates the annual national production of the country in the equilibrium year. Thus, the model cannot differentiate between the range of types of producers (and other value chain participants). In this structure output is not represented as a production function considering the complexity of modelling production of a perennial crop. Generally, farmers provide their harvest directly or through collectors to the wholesaler which involves a marketing cost, however there is little data on these transactions (although anecdotally there is thought to be an average price mark up of about 30 percent between farm gate and wholesale price which could be an approximation for the benefit share of this segment). The distribution link from farmers to wholesalers is contracted to just wholesalers in this model (which also consists of farmers and collectors at different levels below the wholesalers), and it is assumed that wholesalers then distribute the raw coconuts to different production sectors.

Distribution of coconuts to the processors and retailers involves transportation, handling, initial processing (removing husk), storage and marketing costs. Therefore, in this model, the wholesale price is considered as the farm gate price (supply price) and it is common for all the horizontal markets.

Nearly 65 percent of the produce is retailed and freshly consumed (this figure includes the farm consumption of fresh nuts due to the unavailability of disaggregated data). Coconut retailers purchase from wholesalers and it involves transportation, storage and marketing inputs in reaching the ultimate consumers.

The remaining 35 percent is used in the processing industries. The desiccated coconut industry uses nearly 11 percent of the raw nuts and nearly 99 percent of this output is exported. Copra is an intermediary product used in coconut oil production which utilises about 20 percent of raw coconuts. Nearly 97 percent of copra production is used for coconut oil production while the rest is exported. Approximately 96 percent of coconut oil is domestically consumed while the rest is exported. Desiccated coconut is processed and packed at the factory and sold by auction to the exporters. The major part of this output is exported. Copra is processed and sold through dealers to a coconut oil miller. The millers process and sell coconut oil to wholesalers or retailers and exporters.

Other products include a variety of export products (instant coconut milk powder, coconut milk, coconut cream, seed nuts). All of these products are aggregated into one category named ‘other products’ that altogether utilises approximately five percent of the raw coconuts.

The above structure can be described in terms of demand and supply equations. The industry is assumed to be in equilibrium and together with assumptions of normal profit and constant returns to scale technologies this ensures that all the markets clear. The relationship among the industries is represented by general functional forms. Exogenous shift variables are incorporated in product demand and factor supply equations. These exogenous and endogenous variables are defined in Appendix Table 1.

The details of the theoretical development of the equations in the model, and the transformation of these equations into the displacement form used in the simulations, are provided in Pathiraja et al. (2017a). Also described are the choices for equilibrium prices and quantities (Coconut Development Authority, 1970-2013), and parameter values. Finally, that study describes some hypothetical simulations of external shocks which provide some validation of the plausibility of the results that are generated.

4 Modelling of coconut yield determinants - Analytic Hierarchy Process

Estimating the welfare impacts of climate change on coconut production, and the potential benefits of investing in adaptation options, requires a process whereby future climate scenarios can be explicitly related to coconut yield.

Previous yield estimation and prediction studies for coconut in Sri Lanka which attempted to develop statistical relationships between annual yield and climatic factors were not conclusive due to the complex nature of coconut yield (Abeywardena, 1966, 1968; Brintha et al., 2012; Peiris et al., 2008; Peiris et al., 2000; Peiris et al., 1997; Peiris et al., 1995; Peiris, 1998; Peiris, 1991-1993). Process based models such as InfoCrop are considered more illustrative and there is one developed for India (Kumar et al., 2008). However, applicability of these models to the Sri Lankan context is limited due to data availability.

In this study, an Analytic Hierarchy Process (AHP) (Saaty, 1987) was used. AHP is an Expert Systems Modelling approach and provides a means of modelling in a situation where data from conventional sources may be partially lacking (Sposito et al., 2013). The problem or the goal is first decomposed into its determinants or decision variables (Bantayan et al., 1998). For a yield estimation study, mean annual yield is the objective and determinant variables are found to be climate, soil and topography. In deciding the contribution of these factors to mean annual yield, previous literature can be used. In the absence of a reliable source, expert opinion can be incorporated and the contribution is measured in terms of a weight. Those are obtained through a pairwise comparison of determinant variables by the experts. The hierarchy structure of the AHP differs from the traditional decision tree approach since each level shows a different aspect of the problem which runs down from an overall objective to criteria, sub criteria and alternatives (Saaty, 1990).

AHP has been used in climate change and climate change adaptation studies as a decision support tool (Bharwani, 2013; Jayathilaka et al., 2012; Jorge et al., 2015; Kazemi et al., 2016; Li et al., 2014; Sposito et al., 2013). A main advantage of this method over other biophysical methods is that it can take into account both factors that can be quantified and that cannot be quantified (Bharwani, 2013; Saaty, 1988). For this reason, it has the advantage of incorporating expert opinion over empirical methods which are entirely based on correlations among factors (Sposito et al., 2013).

The way that AHP was implemented in this study is described in Pathiraja et al. (2019). The objective was to explain variation in annual yield of coconut using a set of criteria known to influence yield taken from past research results. Monthly historical climate data, a range of soil quality data and current crop management practices were collected for research sites within each of the three major coconut production zones to initially calibrate the model. The views of four expert researchers in the biophysical aspects of coconut production were obtained to form the weights for the various criteria at the different levels of the model. For example, Table 1 shows how expert opinion is used to develop the higher level weightings for the influence of the three key biophysical factors (climate, soil and topography), and the second level weights for the climate components.

Table 1.
Expert view on main climatic factors affecting coconut yield (%)

Factor	Expert 1	Expert 2	Expert 3	Expert 4	Average
Level 1					
Climate	48	77	75	49	48.7
Soil	44	17	18	44	43.5
Topography	8	5	6	8	7.8
Level 2					
Temperature	45	77	69	47	45.5
Rainfall	45	17	23	47	45.5
Solar Radiation	9	5	8	7	9

The weights show that the most influential factor is climate, closely followed by soil and then topography. The assigned values are 0.487, 0.435 and 0.078. Sub criteria for climatic factors were selected based on the literature and weighed with expert views. Maximum temperature and rainfall were weighed equally important with a weight of 0.455 and solar radiation (sunshine hours) was given 0.090. Similar types of weightings were developed for the level 2 soil and topography criteria, and all of the sub components for climate and soil. Topography has no lower level classifications. Figure 4 summarises the overall structure of the land suitability model, while the full model structure is shown in Appendix Figure 2 (a and b).

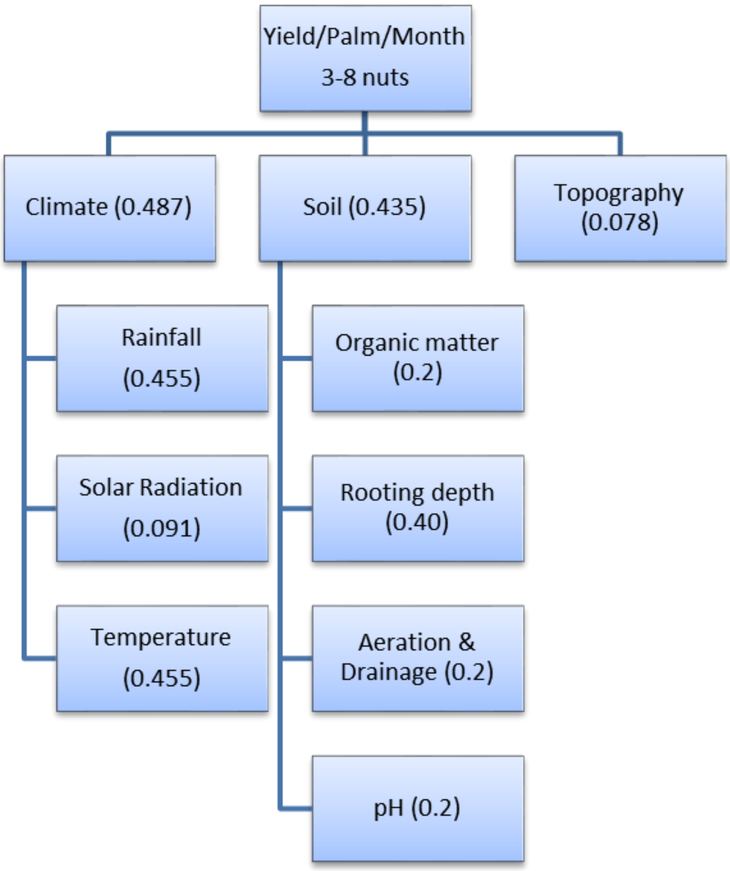

Figure 4. Overall structure of Land Suitability Model

The AHP model was then calibrated to research sites within each of the three major coconut production zones (Figure 1), using a range of climate models[1]. Predictability of each of the 16 climate models was compared with the base year 2010 to find the best suitable model. However, with the disparities of the predicted climatic conditions, the average outcome of the 16 models was used to generate the future climatic conditions and 99 replicates for each site were obtained for smoothing the data. Two future climatic scenarios (from the IPCC) for 2020, 2030 and 2050 were considered (rpc2.6 and rpc8.5).

The estimated yield estimates under the two designated climate scenarios for the three production zones are shown in Appendix Table 2. Based on these results, a yield decline is expected in the wet zone with the expected increase of maximum temperature; yield is expected to increase in the intermediate dry zone with the expected precipitation increase (rainfall is a limiting factor in the intermediate dry zone compared to the wet zone); and yield in the intermediate wet zone is not expected to be influenced by the expected climate.

5 Adaptation options and yield change

Adaptation at the plantation level is already occurring. Producers are trialling mulching to reduce weed growth and soil water loss, incorporating organic matter, using cover crops, and harvesting rainwater. However, given the predicted changing climatic conditions, considerable additional effort will be required to enable the industry to adapt. And given the dominant influence of the wet zone shown in Appendix Table 2, the adaptation practices required in the expected future climate should be focussed on mitigating the impact of increased maximum temperature.

Some of the adaptation strategies identified by researchers as being effective for coconut are summer or drought irrigation, targeted application of high doses of fertilizer to capture the positive effect of climate change (increase in rainfall and CO_2), innovative soil moisture conservation (coconut husk or dust pits), growing short term pulses and growing drought tolerant varieties (Hebbar et al., 2013; Naresh Kumar et al., 2013).

Shifting of cultivation to more suitable areas can be considered as another strategy to overcome the total yield loss. In a previous study, the increase in rainfall in the intermediate zone has suggested an increase in moderately suitable areas for coconut towards the north and south-west part of the zone (Jayathilaka et al., 2012). This shows productivity improvements in the existing coconut lands due to favourable rainfall.

The predicted climatic conditions for these three sites show that an increase in the maximum temperature would be the main yield limiting factor despite an increasing rainfall trend. This temperature increase is already clear in historical data for the wet zone, where favourable temperature conditions for coconut are starting to change and become less favourable. Generally, rainfall increase is offsetting the temperature effect to some extent (IPCC, 2014b). Moisture conservation practices are recommended for regions where rainfall is low and dry periods are prominent (intermediate and dry zone). However, since the temperature peak during the February/March period is prominent with a slight rainfall increase, the transpiration rate will be high. Adapting these practices (moisture conservation, suitable intercropping to change the micro climate and diversify the income, weed management, fertilizer application and organic matter improvement) will help to improve plant vigour and to sustain the current productivity level or to gain the optimum benefit of climate change under future climatic conditions. These can be considered as good agricultural practices that will improve the productivity and income of the farmers. A higher level of adoption of these practices can be considered as a way of adapting to productivity changes due to climate change.

The other option for adapting to climate change is through the adoption of new technologies. More efficient irrigation systems and heat tolerant cultivars would come under this category. A heat tolerant cultivar or a variety that can withstand the temperature increase to perform well under increased temperature conditions would be the long-term solution, although it may take many years to develop for coconut. Cultivars with drought tolerant traits are important for moisture stress which is observed in each climatic zone.

In all, ten potential adaptation option scenarios were considered, in addition to current practice. These scenarios are shown in Table 2.

If we assume the need for a high level of adaptation measures (from among the above practices), each adaptation practice will somewhat reduce the total yield loss. These options, under different adaptation levels and relative yield changes in terms of total industry, are represented in Table 3.

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[1] The models considered were BCC-CSM1-1, BCC-CSM1-1-M, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC5, MIROC-ESM, MIROC-ESM-CHEM, MRI-CGCM3 and NorESM1-M.

6 Likely economic impact of climate change on the coconut industry

The yield changes due to each adaptation practice described under scenarios 2 to 11 were estimated with respect to the predicted yield under current adaptation measures (or scenario 1). Therefore, these yield estimates are net yield changes that offset the yield loss due to climate change and add some extra yi eld. However, yield changes per se are not the inputs required by the economic model (the K shift). A shift in supply is equivalent to a productivity change which affects the cost of production of coconut. Therefore, the supply price of coconut changes depending on the size and direction of the supply shift, and depends on the relative magnitudes of the supply and demand elasticities. Figure 5 shows the expected direction of the supply shifts under each scenario.

The equilibrium supply is denoted by S_0 and the other notations are related to some of the scenarios specified in Table 3. For example, S_1 shows the expected decrease in yield due to climate change if no additional adaptation in undertaken; S_8 shows the expected increase in yield due to expanded use of moisture conservation (husk pits) in the wet zone. The K shifts equivalent to the various yield changes are shown in Table 4. The K-shifts are much larger than the underlying yield changes due to the assumed very inelastic nature of coconut supply and demand in Sri Lanka (Pathiraja et al., 2015, 2017a).

Table 2.

Different scenarios describing possible adaptation options at different scales

Scenario 1 describes the yield change predicted under climate change conditions in 2020 compared to the base equilibrium condition, with current adaptation investments. It is the base for the other scenarios.
Scenario 2 describes increased fertilizer application in the wet zone. It is expected that there will be a 22 percent yield increase for irregular fertilizer users in the wet zone when they shift from irregular to regular fertilizer application. Nearly 35 percent of the lands currently have irregular fertilizer applied.
Scenario 3 and scenario 4 show increases in fertilizer application from irregular to regular in the intermediate zone (intermediate wet and intermediate dry zones) and both wet and intermediate zones. A 22 percent yield increase is expected for irregular fertilizer users. It is estimated there are 26 percent and 18 percent irregular fertilizer users from intermediate wet and intermediate dry zones.
Scenarios 5, 6 and 7 show the possible yield changes with irrigation during drought periods. Yield changes in the wet zone, intermediate zone and in both intermediate and wet zones are represented by the scenarios 5, 6 and 7 respectively. Only 50 percent of the lands are assumed to be irrigated and a yield increase of 30 percent is assumed with irrigation for those lands based on previous studies.
Scenarios 8, 9 and 10 show the yield increase due to husk pits as a moisture conservation practice in the wet zone, intermediate zone and in both zones. Nearly 41 percent of the farmers practice husk pits and we assumed here a further 25 percent of the farmers will practice this moisture conservation practice. It has the potential to increase yield by 20 percent from those lands.
Scenario 11 shows the impact of a heat tolerant cultivar that can sustain the existing productivity in the wet zone under future climate change conditions especially the increase in temperature.

Table 3.
Yield change estimates under different levels of potential adaptation practices

	Potential agronomic practices (scenarios)	Wet zone	Intermediate zone	Industry
1	Current adaptation	-3.09	1.8	-1.3
2	Fertilizer application wet zone	-0.8	1.8	1.0
3	Fertilizer application intermediate zone	-3.09	4.22	1.1
4	Fertilizer application in both wet and intermediate zones	-0.8	4.22	3.4
5	Irrigation in wet zone	1.41	1.8	3.2
6	Irrigation in intermediate zone	-3.09	9.3	6.2
7	Irrigation in both wet and intermediate zones	1.41	9.3	10.7
8	Moisture conservation in wet zone	-1.59	1.8	0.2
9	Moisture conservation in intermediate zone	-3.09	4.3	1.2
10	Moisture conservation in both wet and intermediate zones	-1.59	4.3	2.7
11	Heat tolerant cultivar in wet zone	0	1.8	1.8

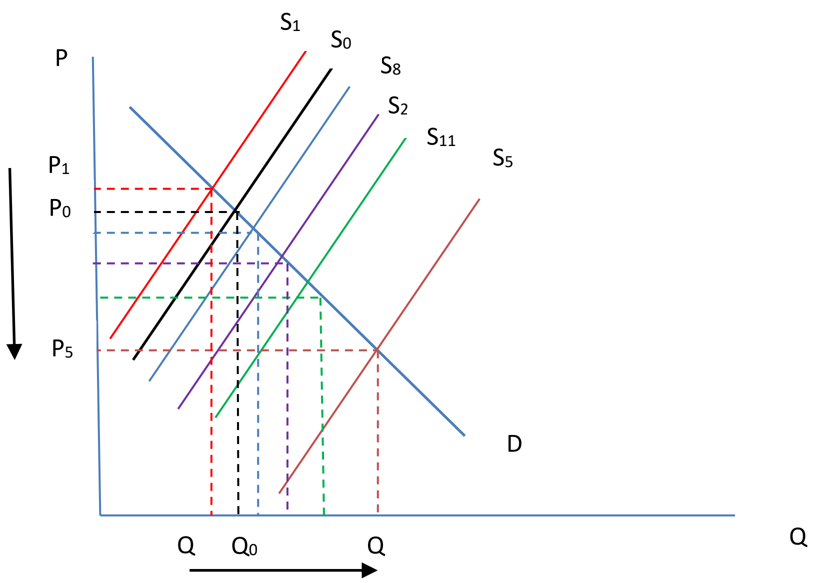

Figure 5. Shift in aggregate supply due to adaptation practices

Given these 11 K shifts, the quantity and price changes under climate change with respect to the base equilibrium, and then under the five sets of adaptation practices (scenarios 2 to 11), were estimated with the previously described EDM. The impact of these price changes on the coconut industry and its stakeholders were quantified in economic surplus terms. These economic surplus changes were estimated for each scenario with respect to the base equilibrium condition. The detailed results are shown in Appendix Table 3 (a, b, c), and are summarised in Table 5.

One issue to note here is that the underlying assumption of local linearity, and therefore the strict validity of the EDM results, only holds when the changes around the equilibrium are "small". Small is not defined but less than ten percent would be a reasonable assumption. When the K shift is greater than ten percent, the economic surplus changes are very uncertain and the functional form of the demand and supply curves matter (Zhao et al., 1997). Therefore, the precision of EDM outcome for the scenarios 4 to 7 and 10 (shaded orange in Tables 4, 5 and 6) are highly uncertain.

Table 4.
Yield changes and K shifts under different adaptation practices

Scenario		Yield change	K-shift (change in w – supply price)
1	Climate change without extra adaptation (base)	-1.3%	+6.7%
2	Fertilizer application in wet zone	+1.0%	-5.1%
3	Fertilizer application in intermediate zone	+1.1%	-5.6%
4	Fertilizer application in both intermediate and wet zones	+3.4%	-17.3%
5	Drought irrigation in wet zone	+3.2%	-16.5%
6	Drought irrigation in intermediate zone	+6.2%	-31.9%
7	Drought irrigation in both intermediate and wet zones	+10.7%	-54.9%
8	Husk pits in wet zone	+0.2%	-1.0%
9	Husk pits in intermediate zone	+1.2%	-6.2%
10	Husk pits in both intermediate and wet zone	+2.7%	-13.9%
11	A heat tolerant cultivar in wet zone	+1.8%	-9.2%

Table 5.
Summary of the results in terms of economic surplus

Scenario	Change in producer surplus		Change in consumer surplus		Change in total surplus	
	Rs. Million	% of total change	Rs. Million	% of total change	Rs. Million	% of total industry value at equilibrium
Scenario 1	-3246	68%	-1549	32%	-4795	-5%
Scenario 2	2520	68%	1201	32%	3721	4%
Scenario 3	2772	68%	1320	32%	4092	4%
Scenario 4	8559	68%	4070	32%	12628	12%
Scenario 5	8148	68%	3875	32%	12023	12%
Scenario 6	15928	68%	7557	32%	23485	23%
Scenario 7	27874	68%	13178	32%	41052	40%
Scenario 8	505	68%	241	32%	745	1%
Scenario 9	3023	68%	1440	32%	4464	4%
Scenario 10	6844	68%	3256	32%	10100	10%
Scenario 11	4547	68%	2165	32%	6712	7%

6.1 With current adaptation

Scenario 1 describes the predicted economic impact of climate change under current adaptation measures. The total change in surplus due to climate change is 4,795 Rs. Million[2] which is nearly 4.7 percent of the total value of the industry at equilibrium (Appendix Table 3a, scenario 1). This is an annual loss to the industry since the yield is reduced by 1.3 percent under climate change.

[2] At recent exchange rates of around $US1=LKR150, this annual loss is around $US32 million. Alternatively, the annual loss is around Euro30 million.

The distribution of benefits or losses from climate change is useful in identifying the most affected stakeholders. Broadly defined, nearly 68 percent of the loss is shared by input suppliers into the coconut industry while the remaining 32 percent is shared by coconut product consumers.

Nearly 66 percent of the losses are shared by coconut "wholesalers". Recall that this group involves coconut growers, intermediary collectors and wholesalers. Domestic coconut consumers share around 22 percent of the economic surplus while six percent is shared by domestic coconut oil consumers and some three percent by export desiccated coconut consumers. Other export product processors and consumers share nearly one percent each.

6.2 With additional adaptation

Scenario 2 to Scenario 11 describe possible additional adaptation practices at different levels under which yield changes due to climate change are expected to be minimised or improved through good agricultural practices and specific climate change adaptation practices (Appendix Table 3).

The largest total impact to the industry is shown under scenarios 5, 6 and 7 which show increased irrigation during drought periods. Scenario 5 shows a benefit gain (Rs. Million 12,023) to the industry which is equivalent to 12 percent of the total value of the industry at equilibrium. Irrigation during dry periods by 50 percent of the farmers in the wet zone is assumed in scenario 5. Scenarios 6 and 7 show gains of 23 and 40 percent to the total value of the industry with irrigation in intermediate zone and in both wet and intermediate zones respectively. However, as noted above, given the large yield changes and even larger K-shifts in these scenarios, these results are highly uncertain.

The next rewarding adaptation practice is scenario 11 which assumes adoption of a new heat-tolerant cultivar that would sustain the existing productivity level under wet zone climatic conditions. This benefit change is equivalent to Rs. Million 6,712 which is nearly seven percent of the total value of the industry at equilibrium.

The third rewarding crop management practice is greater fertilizer application in the wet zone (scenario 2). A benefit gain of Rs. Million 3,721 is observed to the industry which is nearly four percent of the value of the industry at equilibrium. Scenario 3 shows nearly the same amount of gain which shows fertilizer application improvements in intermediate zone. This is a net gain to the industry which offset the yield reduction in wet zone. If fertilizer application can be improved in both the wet and intermediate zones, the benefit gain is nearly Rs. Million 12,628 which is around 12 percent of the value of the industry at equilibrium (Scenario 4). This is important for the intermediate zone since the expected rainfall gain will improve the land suitability for coconut.

Scenarios 8, 9 and 10 show the benefit change due greater use of moisture conservation practices such as coconut husk pits. It shows a net gain to the industry at equilibrium with the percentages of one, four and ten respectively.

The distribution pattern of economic surplus change is exactly the same as the distribution of the losses from no additional adaptation - nearly 66 percent of the benefits from investments in adaptation practices go to coconut "wholesalers" (coconut growers, intermediary collectors and wholesalers); domestic coconut consumers share around 22 percent of the economic surplus; six percent is shared by domestic coconut oil consumers; some three percent by export desiccated coconut consumers; and other export product processors and consumers share nearly one percent each.

6.3 Cost effectiveness

Thus, the expected negative impact of climate change on the Sri Lankan coconut industry has the potential to be reduced with the implementation of additional adaptation practices. However, the cost effectiveness of these practices needs to be considered in comparing the practices. Generally, there are previous studies that analysed the yield gains and cost effectiveness of those practices which are site specific especially to the intermediate and dry zones (Abeygunawardena et al., 1995; Appuhamy, 2005; Dias, 1993; Liyanage, 1987; Liyanage, 1988). Investment potential in financial and practical terms (availability of a water source for irrigation during drought periods, time taken to develop a drought tolerant variety, labour availability, site specific factors that affect responsiveness to agronomic practices and availability of coconut husk) can be limited. Table 6 shows the estimated investment costs for each scenario from previous studies converted to current prices. Fertilizer application and moisture conservation are estimated to be economically beneficial.

Irrigation is economical under option 'a' which is developed as a low cost drip irrigation method for small scale application (Liyanage et al., 2008). Option 'b' is large scale drip irrigation systems and is not economical. This shows the potential for agronomic practices to offset the expected yield declines in the wet zone.

Table 6.
Estimated cost of each agronomic practice

Scenario		Cost/Ha (Rs.)	Estimated total area (Ha)	Total cost	
				Rs. Million	%
Scenario 2		23940	40273	964	1%
Scenario 3		23940	43432	1040	1%
Scenario 4		23940	83705	2004	2%
Scenario 5	a	96615	59225	5722	6%
	b	398766	59225	23617	23%
Scenario 6	a	96616	98709	9537	9%
	b	398766	98709	39362	38%
Scenario 7	a	96617	157934	15259	15%
	b	398766	157934	62979	62%
Scenario 8		27330	29613	809	0.8%
Scenario 9		27330	49355	1349	1.3%
Scenario 10		27330	78967	2158	2.1%
Scenario 11		n.a			

6.4 Sensitivity analysis: probability distributions of economic surplus changes

The results of the base case EDM depend on the selected parameters for the model that were chosen based on previous empirical estimates, economic theory and subjective judgements. Empirical estimates were available from only a few studies and some parameter values were not available. Assumptions were made especially for input substitution and product transformation elasticities based on the assumptions of previous literature. To overcome these uncertainties in the estimates, these parameters were assigned probability distributions. Then a Monte Carlo simulation was performed to generate the probability distribution of the results. All of the relevant assumptions and the full set of results are reported in Pathiraja (2016). The distributions for the parameters that were varied are shown in Appendix Table 4.

Figure 6 provides an example of the style of the results of the sensitivity analysis - the probability distribution for the losses accruing to coconut wholesalers from Scenario 1. It shows that the benefits are between -5790 and -1388 Rs. Million for 95 percent of the time, with the mean value being -3,470 Rs. Million and the mode being -3,152 Rs. Million. The latter figure is very close to the -3,169 Rs. Million loss calculated from the point estimates of the parameter values (Appendix Table 3a, row 2 column 2). Regression analysis of the determinants of the variation in economic surplus for coconut wholesalers with the climate change show that the K shift is the most important factor followed by the supply elasticity of coconut and the export demand elasticity of desiccated coconut. Other factors such as the domestic demand elasticity of coconut oil, the domestic demand elasticity for fresh coconut, the supply elasticity of desiccated coconut and the export demand elasticity of other products only contribute two per cent of the explained variance.

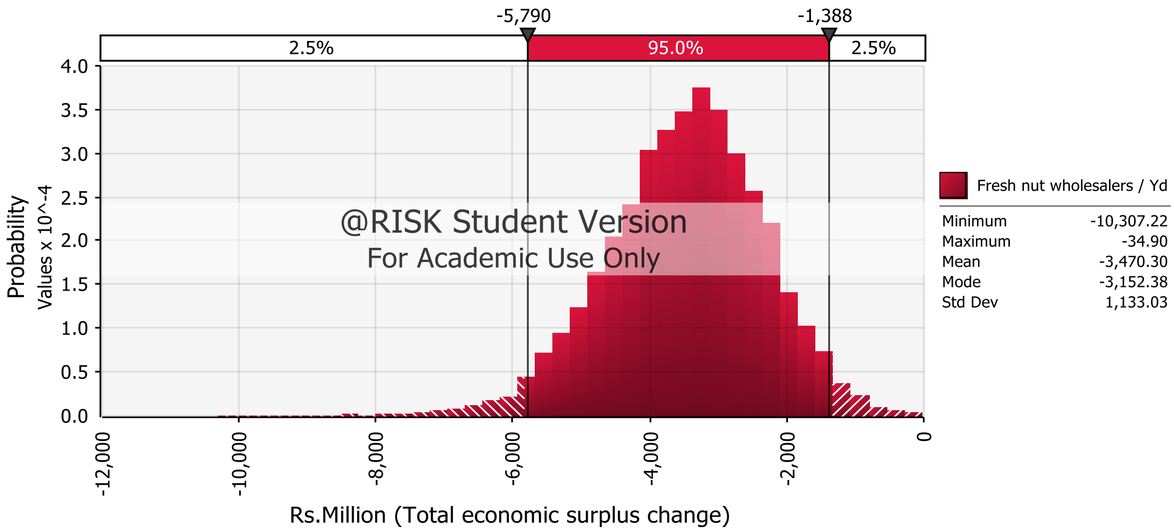

Figure 6. Probability distribution of benefits among coconut wholesalers

7 Discussion and conclusions

The analysis reported here shows that estimated future climate change scenarios have a large potential negative economic impact on the Sri Lankan coconut value chain. The mean value of this loss is Rs. Million 4,781 per year which is nearly five percent of the total value of the industry at equilibrium. This loss is mainly borne by coconut wholesalers (growers, collectors and wholesalers) which account for two-thirds of the total impact, followed by domestic coconut and coconut oil consumers. The impact on other input suppliers is comparatively low - nearly 33 Rs. Million for other product exporters; 31 Rs. Million for the desiccated coconut industry (including export marketing and processing); and 11 Rs. Million for the coconut oil industry including processing and marketing. Thus, coconut farmers and domestic consumers should be the main beneficiaries from any assistance schemes.

A range of agronomic adaptation practices which are currently being used or which are under consideration were tested for their economic feasibility. All the agronomic practices considered showed potential for further improvements in yield which can offset the negative impact due to climate change in the wet zone. All the economic surplus changes showed positive gains.

The most rewarding management practice was irrigation (scenarios 5, 6 and 7). It has a potential to improve the yield in each climatic zone. However, these K shifts are greater than 10 percent which shows that the results can be highly variable. The expected economic benefit change is 12,034 Rs. Million when adapted in the wet zone only and 41,198 Rs. Million when adapted in both the wet and intermediate zones. This was assuming that 50 percent of the lands would practice irrigation in both zones considering the practical limitations (soil type, shallow depth ground water table). However, the cost estimates show that this is not economically feasible given the cost of drip irrigation systems estimated in a previous study (Mahindapala et al., 1991) and converted to current prices. This cost is nearly 23,617 Rs. Million for the wet zone and 62,979 Rs. Million for both wet and intermediate zones which are far beyond the expected gain in benefits. A low cost irrigation system developed for small scale lands has been shown to be economically feasible (Liyanage et al., 2008). However, this estimate has omitted operational cost and some machinery cost. It shows the cost is around 5,722 and 15,259 Rs. Million for wet zone and in adapting in both zones. However, even if the economic benefits are reduced with the inclusion of other costs, it still shows net benefits from low cost irrigation systems. A study has found that irrigation is mainly limited due to the high cost of establishing irrigation systems followed by the lack of a water source (Somasiri et al., 1993). Therefore, this has become a rarely practiced adaptation except for seedling irrigation which is mainly hand irrigated. To address the issue of unavailability of a water source for irrigation during drought periods, a farmer support scheme was introduced to establish deep ground water wells (50 percent of the cost) in drought prone areas (Dias, 1993). However, the effectiveness of this scheme in addressing the issue has not been reported.

The next most effective agronomic practice is fertilizer application. It shows a benefit gain of 3,723 Rs. Million with fertilizer application in the wet zone alone. Under current management practices, nearly 26 percent of the growers are regular fertilizer users while nearly 34 percent are irregular users. It is assumed that those 34 percent of the growers can be converted to regular fertilizer users which may result in a yield increase of 27 percent from those lands (from eight percent to 35 percent compared to unfertilized land). Cost is estimated to be 1,040 Rs. Million for the wet zone. This shows that fertilizer application is an economically feasible practice. However, the response to fertilizer depends on several factors including soil type, variety and split application which may incur additional labour charges. Empirically the response rate is low compared to the experimental results (13 nuts /palm is observed while 25 nuts/palm is expected). As a result, site specific fertilizer recommendations are provided for the farmers.

Rainfall increase in the intermediate zone is expected to result in a productivity improvement (1.8 percent annual yield). A previous study has shown a shift in productivity of coconut lands in these areas with favourable climate (Jayathilaka et al., 2012). Fertilizer application will be an option for capturing the positive effect of climate change and to offset the negative impact to the industry. Therefore, the grower subsidies can be directed for the farmers in these areas with further favourable future climate improvements. However, the wet zone has better climatic conditions compared to other regions despite its temperature increase.

The third rewarding adaptation option is a heat tolerant cultivar that would sustain the current productivity level under temperature increase in the wet zone. This is expected to result in 6,715 Rs. Million gain for the industry offsetting the 4,781 Rs. Million loss. However, the cost involved in developing a heat tolerant cultivar is not available. It will be important to have a variety with traits of heat and drought tolerance under future climatic conditions.

Moisture conservation with husk or coir dust pits is already practiced by 41 percent of the growers. Adoption of this practice by a further 25 percent of growers is assumed since the rest of the growers had concerns on cost (50 percent) and availability of husks. It is not essential for some areas with shallow water table. It is specially recommended for gravelly soils in the wet and intermediate zones. The benefit change due to moisture conservation in the wet zone is nearly 745 Rs. Million and the cost is estimated to be 809 Rs. Million. However, this gain is after offsetting the loss of 4,795 Rs. Million due to climate change. Therefore, moisture conservation can be considered as a potential adaptation measure.

The uncertainty of the model parameters was addressed with a stochastic sensitivity analysis. It shows the probability distribution of benefits incurred in each scenario. The magnitude of these impacts mainly depends on the K shift which represents the yield shock in terms of price change, followed by the supply elasticity of coconut, the domestic coconut oil demand elasticity and the desiccated coconut export demand elasticity. More accurate estimation of these parameters will improve the accuracy of the results, and further work is required on the specification of the appropriate distributions for the various parameter values. Also, the model has limitations in selecting the parameters for input substitution and output transformation which was assumed based on previous literature. The economic surplus estimated for scenarios 4 to 7 and 10 are highly uncertain since the K shift for these scenarios are not small.

Given the long production cycles and the length of the time horizons being considered, further work is also required on introducing dynamics into this type of static analysis**.** An implication is that the price elasticities of supply and demand in the EDM can no longer be treated as constants and will change over the adjustment process. Piggott (1992) highlighted that this could be remedied to some extent by repeated applications of EDM using elasticities corresponding to different lengths of run. Just, Hueth and Schmitz (1982) presented an approach to measuring the welfare impacts for the years after the initial exogenous shock and before reaching the new equilibrium, using different supply curves of different lengths of run. In many other cases, a dynamic problem is simply treated as a comparative static problem, with the uncertainty of research benefits associated with dynamics being managed by carrying out stochastic sensitivity analysis on the market parameters.

Finally, given that investment in a range of adaptation options appears to be profitable, there is the issue of who should pay for these investments. As noted above, given the assumed very small supply and demand own-price elasticity values, coconut farmers and domestic consumers are the main losers from climate change and conversely the main beneficiaries from any assistance schemes. Those two groups represent the largest number of individuals. Also, when coconut output expands at the farm level, all the sector stakeholders benefit. Therefore, investments on coconut cultivation would be an effective way of transferring a positive impact to the whole industry. In the presence of direct and indirect government interference which is prominent in controlling the grower's price in favour of other stakeholders, it is quite reasonable to pay for the adaptation options through the income generated from the industry.

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Appendix

Appendix Table 1.
Definition of variables and parameters in the model

Variables/ Parameters	Definitions
X	Quantity of total coconut supply
X_{a1}	Quantity of coconut supply for retailing
X_{b1}	Quantity of coconut supply for desiccated coconut
X_{c1}	Quantity of coconut supply for copra
X_{d1}	Quantity of coconut supply for other processed products
Z_{b1}	Quantity of desiccated coconut supply for export marketing
Z_{c1}	Quantity of copra supply for coconut oil production
Q_{e1}	Quantity of coconut oil supply for export marketing
Q_{d1}	Quantity of coconut oil supply for domestic retail marketing
Y_a	Quantity of coconut demanded by domestic consumers
Y_b	Quantity of export desiccated coconut demand
Y_{ce}	Quantity of export coconut oil demand
Y_{cd}	Quantity of domestic consumer coconut oil demand
Y_d	Quantity of other product export demand
X_{a2}	Quantity of other coconut retailing input supply
X_{b2}	Quantity of other desiccated coconut processing input supply
X_{c2}	Quantity of other copra processing input supply
X_{d2}	Quantity of other inputs supply for other export products processing
Z_{b2}	Quantity of desiccated coconut export marketing inputs supply
Z_{c2}	Quantity of other coconut oil processing inputs supply
Q_{e2}	Quantity of coconut oil export marketing inputs supply
Q_{d2}	Quantity of coconut oil domestic marketing input supply
W	Supply price of coconuts
P_{b1}	Price of desiccated coconut supplied for export marketing
P_{c1}	Price of copra supplied for coconut oil processing
P_{e1}	Price of coconut oil supplied for export marketing
P_{d1}	Price of coconut oil supplied for domestic marketing
P_a	Price of domestic retail coconuts
P_b	Price of export desiccated coconut
P_{ce}	Price of export coconut oil
P_{cd}	Price of domestic retail coconut oil
P_d	Price of other export products
W_{a2}	Price of other coconut retailing input supply

Variables/ Parameters	Definitions
Endogenous variables	
W_{b2}	Price of other desiccated coconut processing input supply
W_{c2}	Price of other copra processing input supply
W_{d2}	Price of other inputs supply for other export products processing
P_{b2}	Price of desiccated coconut export marketing inputs supply
P_{c2}	Price of other coconut oil processing inputs supply
P_{e2}	Price of coconut oil export marketing inputs supply
P_{d2}	Price of coconut oil domestic marketing input supply
Z_c	Aggregated input index of coconut oil processing
Q	Aggregated output index of coconut oil processing
Exogenous variables	
T_x	Supply shifters
t_x	Amount of shift T_x as a percentage of supply price
N_x	Demand shifters
n_x	Amount of N_x as a percentage of demand price
Parameters	
$\varepsilon_{x,w}$	Supply elasticity of variable 'x' with respect to change in price 'w'
$\rho_{X_{a1}}, \rho_{X_{b1}}, \rho_{X_{c1}}, \rho_{X_{d1}}$	Quantity shares of X_{a1}, X_{b1}, X_{c1}, X_{d1}
k_x	Cost share of input 'x'
γ_{Y_i}	Revenue shares of output
$\sigma_{(X_i,X_j)}$	Allen's elasticity of input substitution between input 'X_i' and input 'Xj'
τ_{Y_i,Y_j}	Allen's elasticity of product transformation between outputs Y_i and Y_j
$\eta_{(Y,P)}$	Demand elasticity of variable 'Y' with respect to change in price 'P'
$\bar{\varepsilon}_{x,w}$	Constant-input output supply elasticity of output 'X', with respect to change in input price 'w'
$\bar{\eta}_{(Y,P)}$	Constant-output input demand elasticity of input 'X' with respect to change in input price 'P'

Appendix Table 2.
Yield estimates under the two climate scenarios in the selected sites

Climatic Zone	Factor	Base History	Value of factor						%Yield change in each scenario					
			2020		2030		2050		2020		2030		2050	
			rcp2.6	rcp8.5	rcp2.6	rcp8.5	rcp2.6	rcp8.5	rcp2.6	rcp8.5	rcp2.6	rcp8.5	rcp2.6	rcp8.5
Intermediate Wet Zone	Climate	0.363	0.363	0.3628	0.363	0.363	0.363	0.363						
	Soil	0.351	0.351	0.351	0.351	0.351	0.351	0.351						
	Topography	0.0702	0.0702	0.0702	0.0702	0.0702	0.0702	0.0702						
	Yield factor	0.7842	0.7847	0.7840	0.7842	0.7842	0.7842	0.7842						
	Observed yield	2.13-6.27												
	Mean	4.2												
	Expected Yield	2.35-6.27	2.35-6.27	2.35-6.27	2.35-6.27	2.35-6.27	2.35-6.27	2.35-6.27						
	Mean	4.31	4.31	4.31	4.31	4.31	4.31	4.31	0	0	0	0	0	0
Intermediate Dry Zone	Climate	0.336	0.363	0.362815	0.363	0.363	0.363	0.336						
	Soil	0.324	0.324	0.324	0.324	0.324	0.324	0.324						
	Topography	0.0702	0.0702	0.0702	0.0702	0.0702	0.0702	0.0702						
	Yield factor	0.7302	0.7572	0.757015	0.7572	0.7572	0.7572	0.7302						
	Observed yield	3-6.25												
	Mean	4.625												
	Expected Yield	2.19-5.84	2.27-6.05	2.27-6.05	2.27-6.05	2.27-6.05	2.27-6.05	2.19-5.84						
	Mean	4.015	4.16	4.16	4.16	4.16	4.16	4.02	3.6	3.6	3.6	3.6	3.6	0.0
Wet Zone	Climate	0.4649	0.376	0.3759	0.376	0.376	0.376	0.376						
	Soil	0.34	0.34	0.34	0.34	0.34	0.34	0.34						
	Topography	0.0702	0.0702	0.0702	0.0702	0.0702	0.0702	0.0702						
	Yield factor	0.8751	0.7862	0.7861	0.7862	0.7862	0.7862	0.7862						
	Observed yield	3.15-8.05												
	Mean	5.6												
	Expected Yield	2.62-7.0	2.35-6.28	2.35-6.29	2.35-6.28	2.35-6.28	2.35-6.28	2.35-6.28						
	Mean	4.81	4.315	4.32	4.32	4.32	4.32	4.32	-10.3	-10.3	-10.3	-10.3	-10.3	-10.3

Appendix Table 3a.

Economic surplus changes (in Rs. Million) and percentage shares of total surplus changes to various industry groups under climate change: with and without different adaptation strategies

	Scenario 1 t_X=-6.7%		Scenario 2 t_X= -5.1 %		Scenario 3 t_X=-5.6%		Scenario 4 t_X-17.3%	
	Rs. Million	%	Rs. Million	%	Rs. Million	%	Rs. Million	%
ΔPSX (Fresh nut wholesalers)	-3168.81	66%	2459.46	66%	2704.86	66%	8349.15	66%
ΔPSXa2 (Fresh nut retailers)	-1.60	0%	1.23	0%	1.35	0%	4.14	0%
ΔPSXb2 (Desiccated coconut processors)	-6.10	0%	4.83	0%	5.32	0%	16.71	0%
ΔPSXc2 (Copra other input suppliers)	-0.63	0%	0.49	0%	0.54	0%	1.66	0%
ΔPSXd2 (other export products processors)	-40.68	1%	32.18	1%	35.42	1%	111.33	1%
ΔPSZb2 (Desiccated coconut export marketing)	-15.62	0%	12.36	0%	13.60	0%	42.75	0%
ΔPSZc2 (Coconut oil other processing)	-2.60	0%	2.01	0%	2.21	0%	6.82	0%
ΔPSQe2 (Coconut oil export marketing)	-1.81	0%	1.40	0%	1.54	0%	4.75	0%
ΔPSQd2 (Coconut oil retailing)	-8.14	0%	6.31	0%	6.93	0%	21.36	0%
Subtotal producer surplus	**-3245.99**	68%	**2520.27**	**68%**	**2771.77**	**68%**	**8558.68**	**68%**
ΔCSYa (Domestic coconut consumers)	-1065.04	22%	821.6	22%	903.34	22%	2771.80	22%
ΔCSYb (Export desiccated coconut consumers)	-150.73	3%	119.6	3%	131.63	3%	414.82	3%
ΔCSYcd (Domestic coconut oil consumers)	-288.80	6%	224.1	6%	246.47	6%	760.64	6%
ΔCSYce (Export coconut oil consumers)	-4.18	0%	3.2	0%	3.56	0%	10.98	0%
ΔCSYd (Export other products consumers)	-40.53	1%	32.1	1%	35.36	1%	111.33	1%
Subtotal consumer surplus	**-1549.28**	32%	**1200.65**	**32%**	**1320.36**	**32%**	**4069.57**	**32%**
Total surplus	**-4795.28**	100%	**3720.92**	**100%**	**4092.13**	**100%**	**12628.25**	**100%**
As a % to the industry value at equilibrium	**-5%**		**4%**		**4%**		**12%**	

Appendix Table 3b.

Economic surplus changes (in Rs. Million) and percentage shares of total surplus changes to various industry groups under climate change: with and without different adaptation strategies

	Scenario 5 t_X=-16.5%		Scenario 6 t_X=-31.9%		Scenario 7 t_X=-54.9%		Scenario 8 t_X=-1%	
	Rs. Million	%	Rs. Million	%	Rs. Million	%	Rs. Million	%
ΔPSX (Fresh nut wholesalers)	7948.8	66%	15531.81	66%	27161.92	66%	492.5099	7%
ΔPSXa2 (Fresh nut retailers)	3.94	0%	7.63	0%	13.16	0%	0.25	0%
ΔPSXb2 (Desiccated coconut processors)	15.89	0%	31.77	0%	57.42	0%	0.96	0%
ΔPSXc2 (Copra other input suppliers)	1.58	0%	3.08	0%	5.36	0%	0.10	0%
ΔPSXd2 (other export products processors)	105.86	1%	211.69	1%	382.57	1%	6.40	0%
ΔPSZb2 (Desiccated coconut export marketing)	40.65	0%	81.30	0%	146.93	0%	2.46	0%
ΔPSZc2 (Coconut oil other processing)	6.49	0%	12.66	0%	22.05	0%	0.403372	0%
ΔPSQe2 (Coconut oil export marketing)	4.52	0%	8.82	0%	15.36	0%	0.281073	0%
ΔPSQd2 (Coconut oil retailing)	20.34	0%	39.64	0%	69.06	0%	1.263477	0%
Subtotal producer surplus	**8148.08**	**68%**	**15928.39**	**68%**	**27873.83**	**68%**	**504.62**	**8%**
ΔCSYa (Domestic coconut consumers)	2639.99	22%	5118.39	22%	8848.44	22%	164.8752	2%
ΔCSYb (Export desiccated coconut consumers)	394.36	3%	791.20	3%	1436.40	3%	23.76562	0%
ΔCSYcd (Domestic coconut oil consumers)	724.18	6%	1414.69	6%	2473.11	6%	44.88138	1%
ΔCSYce (Export coconut oil consumers)	10.46	0%	20.40	0%	35.58	0%	0.649174	0%
ΔCSYd (Export other products consumers)	105.85	1%	212.13	1%	384.54	1%	6.386104	0%
Subtotal consumer surplus	**3874.83**	**32%**	**7556.80**	**32%**	**13178.07**	**32%**	**240.56**	**4%**
Total surplus	**12022.91**	**100%**	**23485.19**	**100%**	**41051.90**	**100%**	**745.18**	**11%**
As a % to the industry value at equilibrium	**12%**		**23%**		**40%**		**1%**	

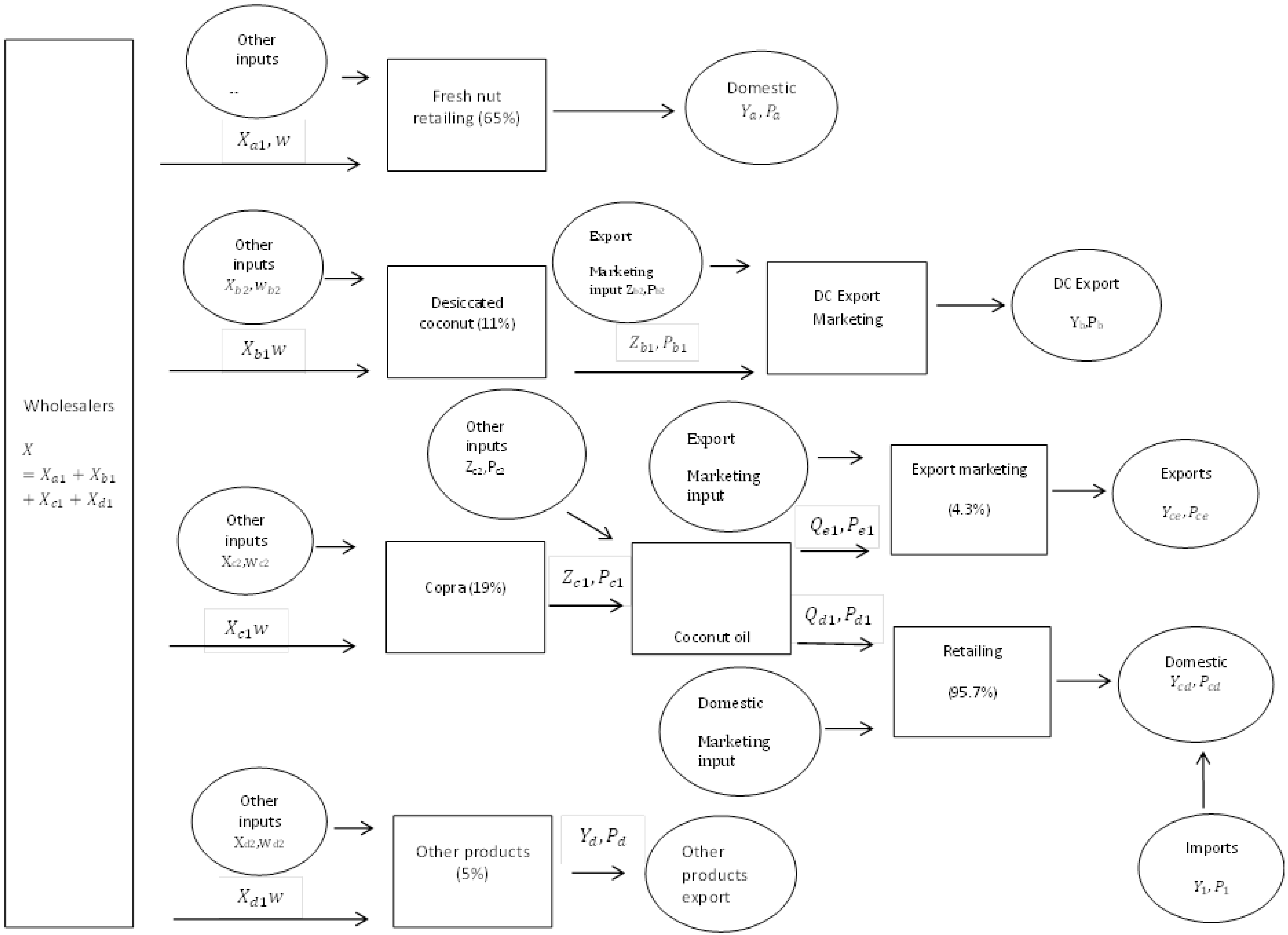
Appendix Table 3c.

Economic surplus changes (in Rs. Million) and percentage shares of total surplus changes to various industry groups under climate change: with and without different adaptation strategies

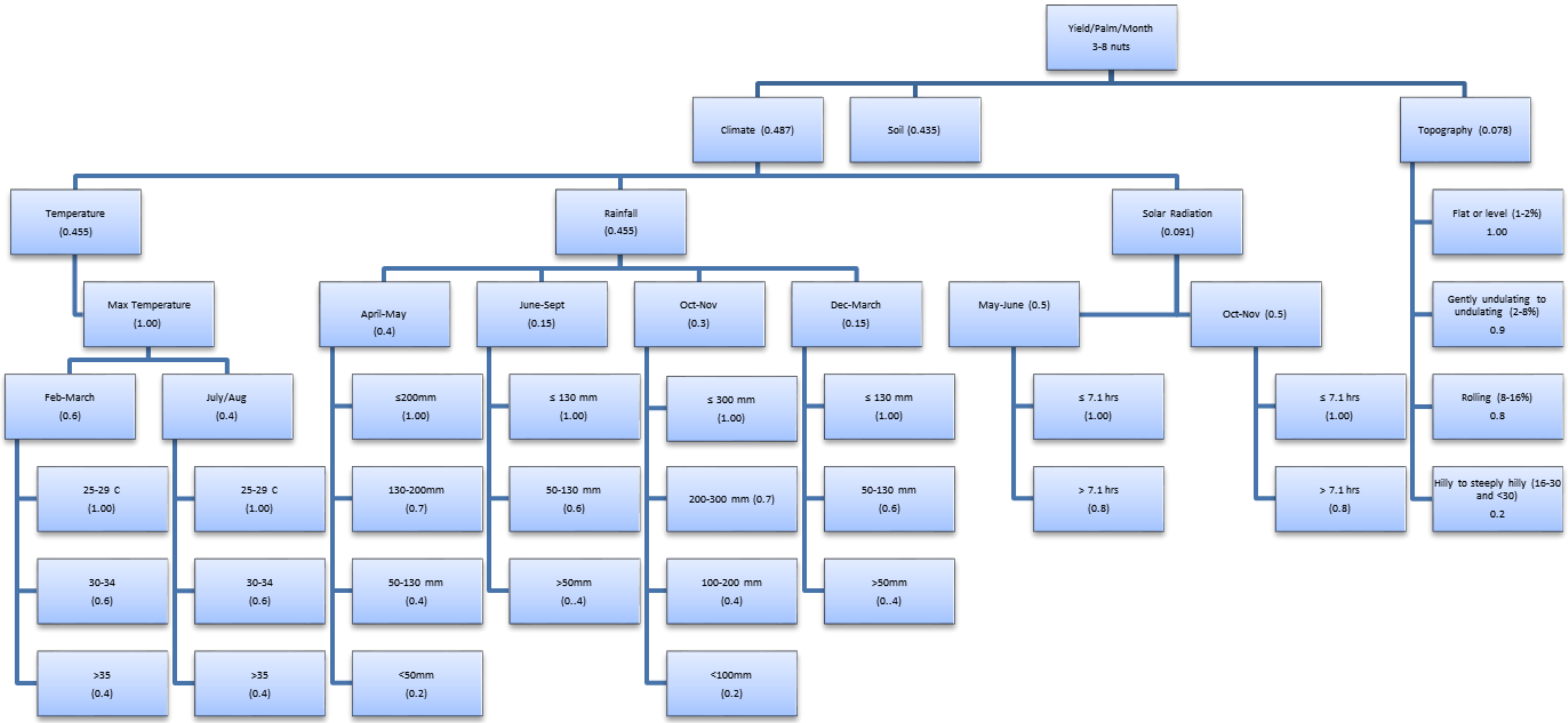
	Scenario 9 t_X=-6.2%		Scenario 10 t_X=-13.9%		Scenario 11 t_X=-9.2 %	
	Rs. Million	%	Rs. Million	%	Rs. Million	%
ΔPSX (Fresh nut wholesalers)	2950.41	44%	6677.26	99%	4436.77	66%
ΔPSXa2 (Fresh nut retailers)	1.47	0%	3.32	0%	2.21	0%
ΔPSXb2 (Desiccated coconut processors)	5.80	0%	13.29	0%	8.77	0%
ΔPSXc2 (Copra other input suppliers)	0.59	0%	1.33	0%	0.88	0%
ΔPSXd2 (other export products processors)	38.67	1%	88.57	1%	58.43	1%
ΔPSZb2 (Desiccated coconut export marketing)	14.85	0%	34.01	1%	22.44	0%
ΔPSZc2 (Coconut oil other processing)	2.414316	0%	5.46	0%	3.63	0%
ΔPSQe2 (Coconut oil export marketing)	1.682314	0%	3.80	0%	2.53	0%
ΔPSQd2 (Coconut oil retailing)	7.562336	0%	17.09	0%	11.37	0%
Subtotal producer surplus	**3023.45**	**45%**	**6844.13**	**102%**	**4547.02**	**68%**
ΔCSYa (Domestic coconut consumers)	985.0926	15%	2220.64	33%	1479.02	22%
ΔCSYb (Export desiccated coconut consumers)	143.708	2%	329.7533	5%	217.31	3%
ΔCSYcd (Domestic coconut oil consumers)	268.8423	4%	608.3585	9%	404.26	6%
ΔCSYce (Export coconut oil consumers)	3.88651	0%	8.787691	0%	5.84	0%
ΔCSYd (Export other products consumers)	38.60071	1%	88.52215	1%	58.36	1%
Subtotal consumer surplus	**1440.13**	**21%**	**3256.06**	**49%**	**2164.79**	**32%**
Total surplus	**4463.58**	**67%**	**10100.19**	**150%**	**6711.81**	**100%**
As a % to the industry value at equilibrium	**4%**		**10%**		**7%**	

Appendix Table 4.
Distributions of parameters selected for the sensitivity analysis

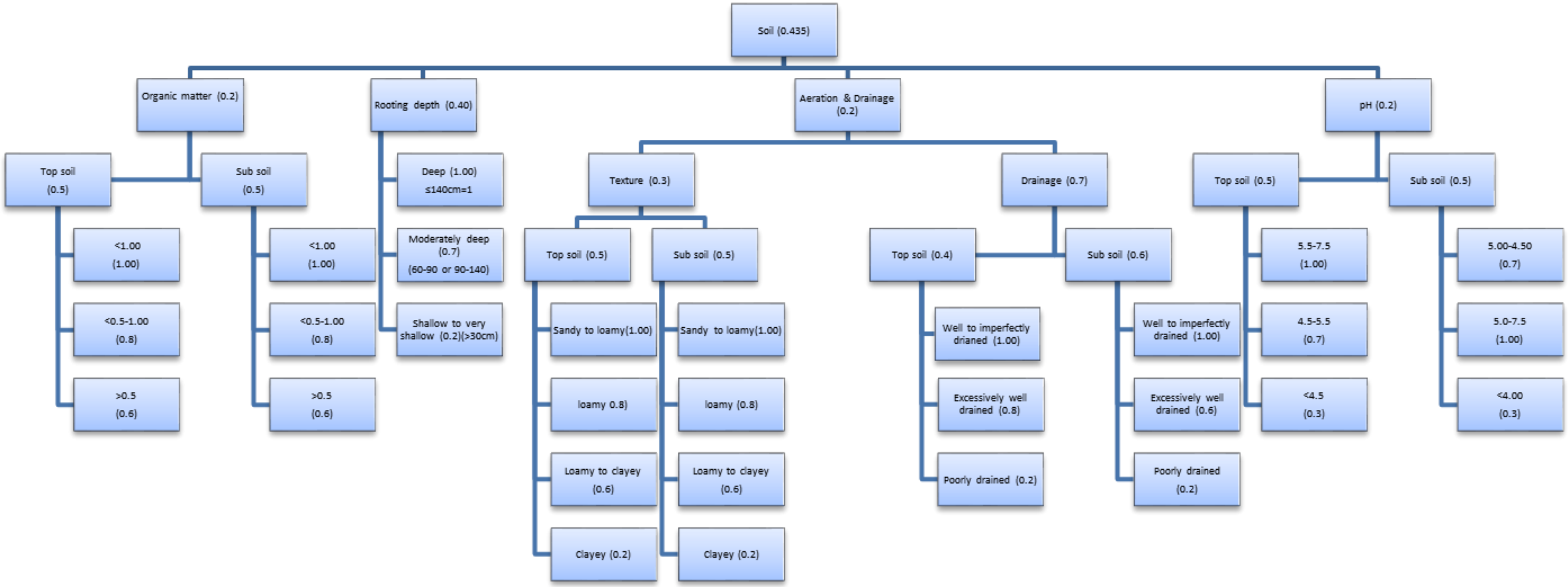
Parameter	**Probability distribution**	**Summary statistics**		
		Mean	**SD**	**95% PI**
Supply elasticity of fresh nuts	$\varepsilon_{x,w} = 0.195$ N(0.191,0.074^2|$\varepsilon_{x,w} \geq 0$) RiskExtvalueMinAlt	0.191	0.074	(0.05,0.3)
Other factor supply elasticities	$\varepsilon_{x_{a2},w_{a2}}$=2, $\varepsilon_{x_{b2},w_{b2}}$=2, $\varepsilon_{x_{c2},w_{c2}}$=2, $\varepsilon_{x_{d2},w_{d2}} = 2$, $\varepsilon_{z_{b2},P_{b2}} = 2$, $\varepsilon_{z_{c2},P_{c2}} = 2$, $\varepsilon_{Q_{e2},P_{e2}} = 2$, $\varepsilon_{Q_{d2},P_{d2}} = 2$, N(2.0,0.5^2|Ɛ≥0)	2.0	0.5	(1.17,2.8)
Input substitution elasticities (Allen-Uzawa)	$\sigma_{(X_{a1},X_{a2})} = 0.1$, $\sigma_{(Z_{b1},Z_{b2})} = 0.1$, $\sigma_{(X_{d1},X_{d2})} = 0.1$, $\sigma_{(X_{c1},X_{c2})} = 0.1$ $\sigma_{(X_{b1},X_{b2})} = 0.1$, $\sigma_{(Z_{c1},Z_{c2})} = 0.1$ $\sigma_{(Q_{d1},Q_{d2})} = 0.1$, $\sigma_{(Q_{e1},Q_{e2})} = 0.1$ N (0.1,0.04^2|σ≥0)	0.1	0.04	(0.036,0.165)
Product transformation elasticities	$\tau_{Q_{e1},Q_{d1}} = 0.1$ N(0.1,0.04^2|τ≤0)	0.1	0.039	(0.036,0.165)
Domestic fresh coconut retail demand elasticity	$\eta_{(Y_a,P_a)} = -0.11$ N(-0.11,0.02| $\eta \leq 0$)	-0.11	-0.02	(-0.14,-0.077)
Desiccated coconut export demand elasticity	$\eta_{(Y_b,P_b)} = -4$ N(-3.7,0.9 | $\eta \leq 0$)	-3.7	0.91	(-5,-2.05)
Coconut oil export demand elasticity	$\eta_{(Y_{ce},P_{ce})} = -2.00$ N(-2.64,1.2| η ≤0) RiskExtvalueMinAlt	-2.64	1.2	(-5,-1))
Coconut oil retail demand elasticity	$\eta_{(Y_{cd},P_{cd})} = -0.479$ N(-0.479,0.1|0)	-0.479	0.1	(-0.643,-0.315)
Other products export demand elasticity	$\eta_{(Y_d,P_d)} = -5.00$ N(-5,1.2 |0)	-5	1.2	(-6.97,-3.03)
K shift	0.066 N(0.0666,0.02|≥0)	0.066	0.02	(0.033,0.099)



Appendix Figure 1. Structure of the model



Appendix Figure 2a. Coconut land suitability model: overall structure, climate and topography hierarchy



Appendix Figure 2b. Coconut land suitability model: soil hierarchy