Developing an Equilibrium Displacement Model of the Sri Lankan Tea Industry[1]

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Abstract

The tea industry is an important contributor to the Sri Lankan economy, accounting for around 15 per cent of total exports and around 15 per cent of employment of the Sri Lankan people. However, the performance of the industry has slumped in recent years. The share of Ceylon tea in the world market is gradually decreasing, and its competitiveness is being challenged by emerging tea producing countries such as Kenya. Domestic consumption, while remaining stable, is primarily of low-quality tea as the best quality teas are expensive and are mostly exported to international markets. Production is declining and becoming more unstable because a number of government policies have been introduced which have disrupted the industry and led to unintended consequences. To provide a basis for examining these adverse trends, and some evidence-based data for future policy deliberations, the process of developing an Equilibrium Displacement Model of the tea industry in Sri Lanka is outlined in this paper. The relevant theory is described, input data such as market quantities and prices, and elasticity estimates, that are used in the model, are defined, and some hypothetical external shocks are imposed on different supply and demand functions. The results of those experiments verify that the model outcomes are consistent with the changes in inputs, and that the model would provide a sound basis for evaluating the expected outcomes of actual exogenous shocks or actual policy changes.

Keywords: tea industry, Sri Lanka, equilibrium displacement model, input bans

Introduction

The agribusiness sector is an important contributor to the Sri Lankan economy (Johnsson, 2016) and, within this sector, the tea industry has played a significant role over many decades through generating income, foreign exchange and employment. Sri Lanka is currently the third largest exporter and the fourth largest producer of tea in the world (Tea Exporters Association Sri Lanka, 2020). In 2018, the tea industry accounted for 15 per cent of total exports and it created around 15 per cent of the direct employment for the Sri Lankan people. However, the performance of the Sri Lankan tea industry has slumped in recent years (Hettiachchige and Rathnayake, 2021). Production has declined and become more unstable because of stagnant and/or shrinking areas under production, low land and labour productivity and several other issues as discussed in detail by Rathnayake *et al.* (2021). Furthermore,

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the performance of Ceylon tea in the world market is gradually decreasing and other countries like China, India and Kenya are becoming the leading countries in the global tea industry (Statista, 2019). Domestic consumption, while remaining steady, is primarily of low quality tea due to the high retail price of the best quality tea, and a number of government policies have been introduced such as the 2015-2018 ban on glyphosate use, and a cash voucher system replacing the price subsidy on fertilizer, which have disrupted the industry and led to unintended consequences (Rathnayake *et al.,* 2021). The development of a formal model of the industry would provide a basis for a rigorous examination of these adverse trends and policy decisions, and consequently provide some evidence-based data for future policy deliberations.

The process of developing an Equilibrium Displacement Model (EDM) of the tea industry in Sri Lanka is outlined in this paper. Following a review of the value chain for tea in Sri Lanka, the main market levels of the industry are defined by segmenting the tea production, processing and retailing sectors into markets, both vertically and horizontally. This defines the industry in terms of a system of demand and supply equations in each market sector, using firm production functions and their derivations and representations of consumer demand. These general functions are then translated into equilibrium displacement form. Then input data such as market quantities and prices, and elasticity estimates that are used in the model, are defined, and some hypothetical external shocks on initial supply and demand functions are imposed to verify that the model outcomes are consistent with the changes in inputs. While these shocks are hypothetical, they do reflect real scenarios from government policy decisions which are taken up in later research. For example, Rathnayake *et al.* (2022) present an application of this EDM for assessing the economic impact of the consequences on tea exports from the glyphosate ban.

Industry Review

The structure of the Sri Lankan tea industry is shown in Figure 1. More details on the value chain of the tea industry in Sri Lanka are discussed by Hettiachchige and Rathnayake (2021). This representation of the Sri Lankan tea industry covers most of the forms of final tea products and their flows to market levels along respective channels, expressed as percentages of the total national 'made tea'[2] production.

### Vertical structure of tea production and marketing

This Sri Lankan tea industry can be vertically segmented into sectors that are engaged in tea cultivation, primary processing, secondary processing, and marketing.

Tea cultivation and green leaf production

In Sri Lanka, tea is commercially cultivated by two entities: the private tea grower sector; and the estate sector. Private tea growers are referred to as those with no processing facilities and who sell their harvest to private processors. This sector comprises smallholder tea growers in addition to medium scale growers without their own tea factories. All other entities are aggregated and considered as the estate/plantation sector. The largest proportion of this group is 23 Regional Plantation Companies (RCPs). It is considered that this sector is representative of plantation companies and contributes to 29 per cent of the total national made tea production. The production systems of these two sectors differ in major ways (Shyamalie, 2015). The differences can be observed in scale of operation, management structure, input use, labor allocation, shares of fixed and variable

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[2] While the word 'tea' can be used generally, 'made tea' refers to the product obtained after primary processing of harvested tea buds. That is, black tea or green tea that is suitable for drinking.

Figure 1. Structure of the tea industry in Sri Lanka
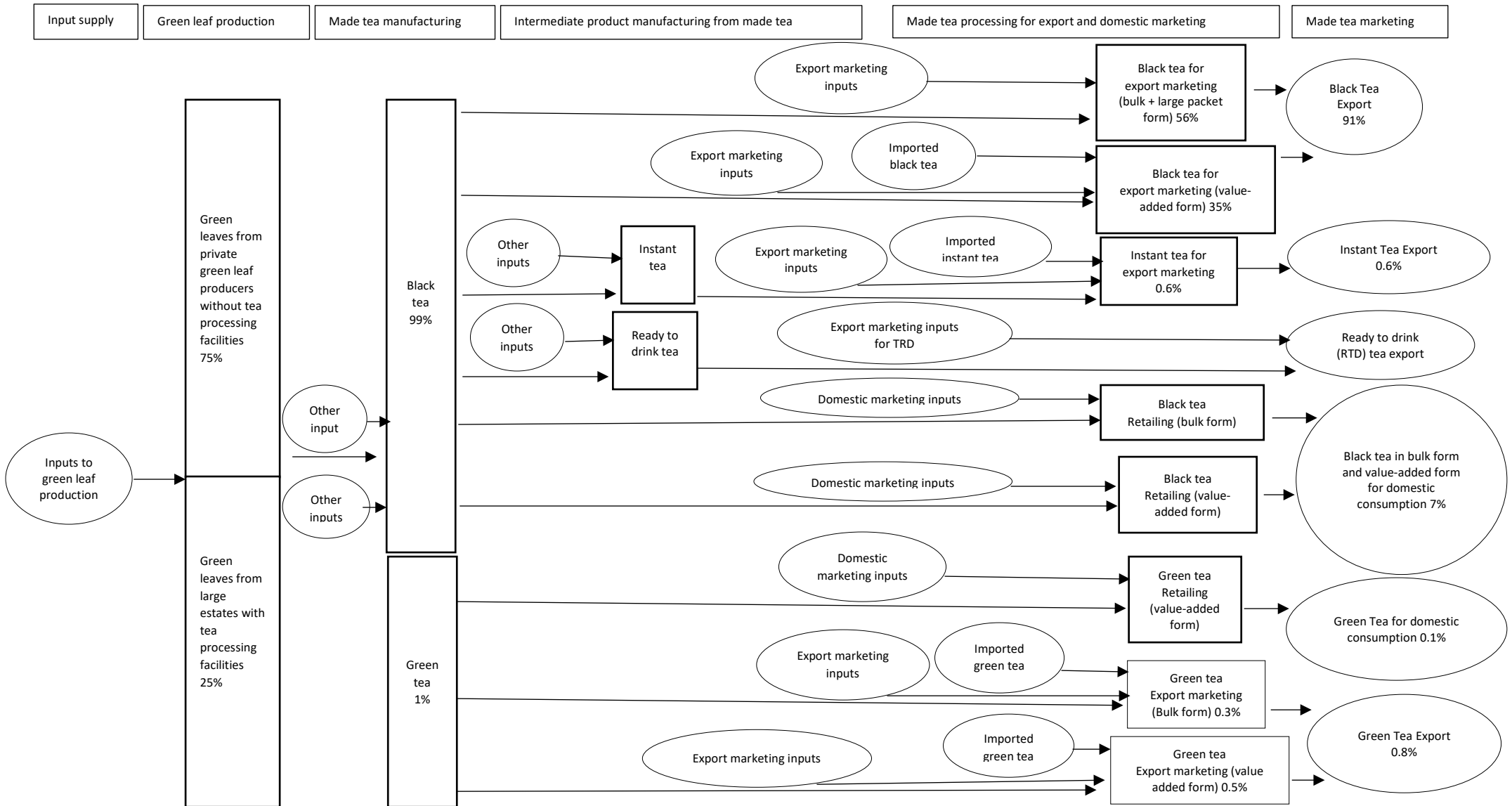
costs, input purchasing prices (in bulk form in the estate sector) and so on. Therefore, the cost of production of green leaves across these two sectors is different. Further information about the farm sector of the tea industry in Sri Lanka is discussed by Rathnayake *et al.* (2021).

Primary processing to produce bulk tea

Harvested green leaves from the tea grower sector are delivered to manufacturing factories located in tea tea growing areas for primary processing of green leaves to produce made tea (black tea and/or green tea). The output in the primary manufacturing process that converts fresh green leaves to black tea is in the bulk form. This bulk black tea output is graded based on the particle size and categorized into several types, as explained by Hettiachchige and Rathnayake (2021). Therefore, it is the same set of inputs that are used to produce these intermediate products of final black tea products in different grades.

There are two groups engaged in green leaf processing: private processors operating with bought leaves mostly from tea smallholders, and estate sector processors with their own processing factories. In Figure 1 both these groups are considered as one sector since the made tea production processes are similar.

Annual reports of the Tea Small Holdings Authority provide the percentage contribution of different tea growing sectors to the national made tea production, while the Sri Lanka Tea Board gives proportions of total national made tea produced based on the processing method. The breakdown of the total national made tea production by processing method includes black tea produced by the orthodox and cut and curl (CTC) methods and green tea. Hence, the summation of black tea produced by these two methods are defined as the total national black tea production. It is assumed that the quality of black tea produced by either method is the same to avoid complexity of the model. Black tea covers almost 99 per cent of the total national production, confirming that Sri Lanka is a major global black tea producer. Of the total national made tea production, on average 75 per cent and 25 per cent were contributed by the smallholder/ private and estate/plantation sector respectively within the five years under consideration. These details are used in deriving the average annual contribution to the total national black tea production by the two grower sectors.

Made tea in different grades in bulk form end up in the secondary processing for either export or domestic marketing, in bulk or value-added form. Before being sent for secondary processing, made tea manufactured at tea factories is transported to warehouses in the capital city to be sold to traders. The Colombo tea auction is a platform for the sale of made tea, while the selling process is facilitated by brokers by linking manufacturers with traders who engage in secondary processing.

Secondary processing of tea for marketing

Tea in the bulk form after primary processing is the main input for the secondary processing of tea into packets in many sizes and bags. The amounts of bulk tea that are absorbed into each category of final products, bulk tea or value added tea (VAT), are not decided at primary processing level, but at the auction and secondary processing stage. There are no published statistics on quantities of these intermediate stage of final tea products sold from manufacturing factories to traders in the auction for secondary processing. Instead, statistics are available in the aggregated form as the total volume of made tea marketed in the Colombo tea auction on a monthly and annual basis.

Secondary processing and packaging of made tea is performed by tea traders to transform the undifferentiated, bulk commodity into a differentiated and consumable form. Secondary processing involves value addition by blending, flavouring, and packing into consumer packets, small bags, gift

packs and other types of packaging with branding (Ariyawardana, 2001). Bulk tea undergoes some value adding by blending and marketing in large packets with volumes more than 10 kg as defined by the Sri Lanka Tea Board (2017).

Subsequently, tea products are marketed internationally and domestically. Some factories have their own branded tea products in retail sizes sold in their factory or sales outlets as direct sales in small quantities. However, the government policy on tea trading is that all primary processed tea should be sold via the Colombo tea auction to secondary processors. Companies whose tea cultivation, primary and secondary processing are vertically integrated have their own brands that might not necessarily contain tea only from their own estates and factories.

Horizontal market segments and product specifications

The final products of black tea and green tea can be segmented horizontally into two differentiated products as bulk tea and value-added tea produced by secondary processing to be marketed internationally and domestically.

Export market

Sri Lankan tea production is heavily export-oriented, and the country is best known as a black tea exporter. Around 90 per cent of the total national production of made tea is exported annually. The main types of tea marketed internationally are black and green tea, instant tea, and ready-to-drink (RTD) tea that account for nearly 93 per cent of the national made tea production as shown in Figure 1. The latter two products are secondary processed products of black tea targeting export markets. Both black tea and green tea are exported in bulk form and value-added form in different packaging sizes as tea bags and packets with loose tea.

In recent years Turkey, Russia, Iraq, and Iran have been the top Sri Lankan tea importers. The United Kingdom was the largest importer of Sri Lankan tea for many years; however, Sri Lanka now faces strong competition from emerging producers such as Kenya, Indonesia, and India in that market (Kasturiratne, 2008). Black tea accounts for around 98 per cent of total exports, while green tea and instant tea exports are less than one per cent.

More than 50 per cent of black tea exports are in the value-added form, while more than 40 per cent of exports are in bulk form. Bulk black tea is also known as "commodity tea" and is processed into value-added forms (tea bags and packets) in processing plants of the importing country to be sold domestically or re-exported. Russia is the number one bulk importer of Sri Lankan tea, followed by Iran (Sri Lanka Tea Board, 2017). This is because of the discriminative tea import tariff structure in Russia that imposes a tax of 12.5 per cent on prepacked teas but zero per cent on bulk teas. In addition, there have been improvements in tea packaging industries recently in Russia that has led to more bulk tea imports (Sri Lanka Tea Board, 2017). Iran imports bulk tea and packs it for consumption, meeting their specific quality standards (Hilal and Mubarak, 2016). There is an increasing trend of exports of Sri Lankan bulk tea to the Middle Eastern region as using tea bags there has grown in popularity.

As described by the Sri Lanka Tea Board, international exports of black tea and green tea in value-added forms are marketed as tea bags and tea packets ranging from 1kg – 3kg, as well as RTDs and instant tea. As shown in Figure 1, all other forms of tea products exported in large packets with volumes ranging from 3kg up to 10kg and bulk tea lots of more than 10kg volumes are collectively considered to be bulk tea.

At the same time, Sri Lanka imports black tea, green tea, and instant tea from other producer countries to supplement value added processes by blending teas. Sri Lanka exports tea bags mainly to Russia, Syria, and Jordan from the value-added tea export sector (Hilal and Mubarak, 2016). The main value-added tea importers in the world tea market are the United Kingdom, United States of America, and the United Arab Emirates, but Sri Lanka does not sell to them in significant quantities.

Domestic market

Domestic consumption of tea in Sri Lanka is a low share of total production, hence the industry is very export oriented. The per capita consumption of tea in Sri Lanka has been steady over recent decades; 1.29kg/year in 1998 (Ariyawardana, 2001) and nearly 1.4kg/year in 2016 (Food and Agriculture Organization of the United Nations, 2018). Black tea is the most popular and commonly found tea in the retail market. It is available in retail packages and loose leaf/dust form. Green tea is not as popular as black tea and is found in lesser amounts in the retail market in packaged form. The total domestic consumption of green tea has not been accurately assessed in Sri Lanka because of the lack of data available on the inventory holding and direct factory sales each year.

The Colombo tea auction is the main channel for local packers and dealers to purchase primarily processed tea, while there could be other sources such as direct sales from tea manufacturing factories and reclaimed tea processors[3]. Local tea marketers do further value addition by cleaning, blending and packaging bulk tea to deliver to the local market for retail marketing in packaged and loose form.

Only 8 per cent of the total made tea production remains within the country, 7 per cent is black tea and 1 per cent of this national production is green tea, available for domestic consumption. Commercially packaged retail packets of loose tea and tea bags are the most popular form of tea consumed in most parts of the country. These forms of tea account for more tea than loose tea products that are not commercially packed.

There is no complete set of data available from the industry on actual domestic consumption within the five years under consideration. Information from the literature suggests that tea consumption in the country is considered to be 5 per cent of total production by Ganewatte and Edwards (2000), with estimates of 9 per cent by Ariyawardana (2001) and 10 per cent by several previous studies (Ganewatta et al*.,* 2005).

Only 10 per cent of the total made tea production on average during the past years has been held in the country as the remainder after exports, where a part of this has been used for domestic consumption. The balance between the national made tea production and total exports (excluding re-exports) is not a good measurement of the domestic consumption of tea, as annual exports and productions are prone to frequent fluctuations given the demand changes in export markets and adverse weather events leading to crop yield changes, respectively. However, considering that the annual national production is more stable than annual export volumes, the domestic consumption can be assumed to be 10 per cent of the total national production. This derivation will yield a more realistic estimation of domestic consumption annually.

In 1994, the most-consumed form of tea in Sri Lanka was black tea in loose bulk form, accounting for 80 per cent of the total domestic consumption, while only 20 per cent of consumed tea was in packet form (Ariyawardana, 2001). According to Ganewatta *et al.* (2005), the domestic demand for tea bags

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[3] Reclaimed tea processors are licensed refuse tea processors who extract black tea from factory remnants (see Silva, 2018).

and retail packets was not higher during the early 2000s, and the majority of consumers were using the traditional method of tea preparation with loose tea bought from tea stored in bulk form in retail shops. However, at the turn of the century, Ariyawardana (2001) saw there was potential to increase the domestic consumption of value-added tea in Sri Lanka as a result of advanced food consumption patterns influenced by lifestyle changes and consistently improving per capita income in Sri Lanka – with an estimate of an income elasticity of 1.004. As anticipated, then, a major share of current black tea consumption within the country is now in value-added forms in packets ranging in sizes from 50g to 500g and tea bags under different local brands. Supermarkets have only value-added black tea products with a brand while black tea in loose form can be available in retail shops in villages. The share of loose tea consumption domestically must have reduced drastically over years because of the introduction of tea packets in convenient sizes at affordable prices. Therefore, it is assumed that the total black tea consumption in the country comprises 90 per cent of value-added, and 10 per cent of loose tea, consumption.

The framework shown in Figure 1 above is based on several assumptions. First, production of green leaves by the farm sector in different tea growing regions is aggregated and considered under each grower sector (smallholder producer or large plantation) regardless of the tea growing region. It is assumed that the tea cultivation across growing regions is homogeneous, neglecting differences in yield and frequencies of field operations due to variations in the geography and climate. Similarly, slight differences in quality such as aroma, strength, body and taste, attributable to climate changes across growing regions, are considered small enough to enable aggregation and avoid undue complexity in the model.

Second, black tea, green tea, instant tea, and Ready to Drink (RTD) tea are considered as final products, while the very small share of Oolong tea production is neglected. Only the final black tea produce is considered in the framework regardless of the processing methods - CTC or orthodox. The quality of black tea made from both orthodox and CTC processing methods is assumed to be homogeneous, given that both processes result in the same end product regardless of differences in particle size.

Third, RTDs made only from black tea is considered in the framework, but RTDs can be made from green tea as well.

Fourth, bulk tea and large packets of volume above 3kg are aggregated and collectively known as bulk tea.

Finally, any imported black, green and instant teas are assumed to be re-exported and not used for domestic consumption. Import volumes are small, and there is no disaggregated information on domestic consumption by country of origin although there can be small proportions of imported tea consumed domestically.

Structure of the Model

The structure of the equilibrium displacement model (EDM) used in the tea industry is shown in Figure 2, which is based on a simplified version of the complete framework as shown in Figure 1 above.

Only black tea production is considered, excluding green tea, instant tea and RTD production, given their very small shares of total output. The black tea manufacturing sector is assumed to be a single sector, aggregating the produce from both private and estate tea manufacturers. The primary input, green leaves, produced and harvested from any grower sector can end up in any of the final tea products stated in the model based on the assumption that they all have a homogenous quality.

Figure 2. Structure of the equilibrium displacement model of the black tea industry
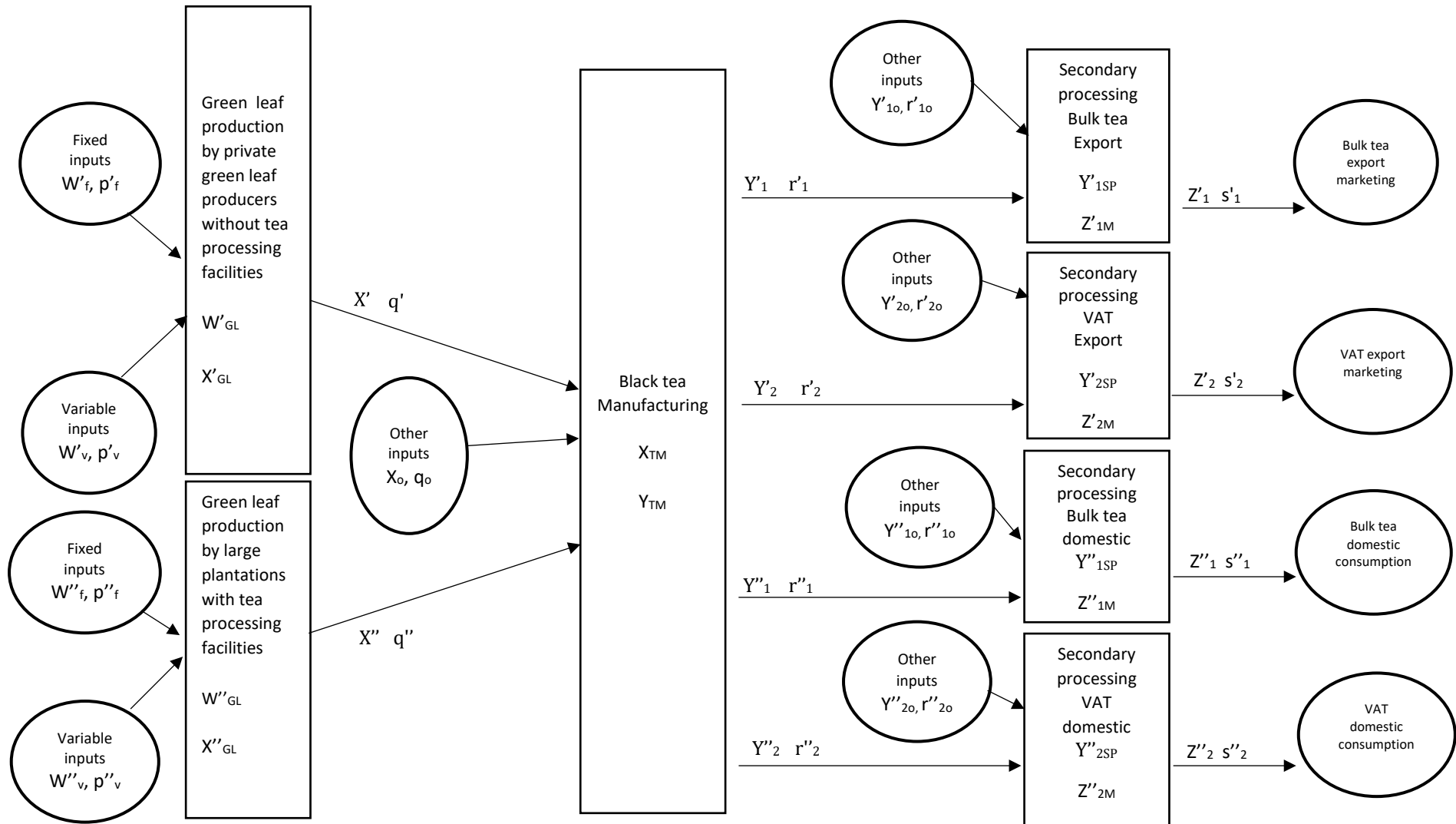
For convenience in designing the model, it is assumed that secondary processing does not affect the weight of the main product. Therefore, quantities of the input (black tea in the primary processed form) and the output (final black tea product from secondary processing) are the same.

Information on quantities of black tea exported from Sri Lanka in different product forms; bulk, tea bags or packets is published annually by the Sri Lanka Tea Board. Therefore, based on the above assumption, the same quantities are assumed for the intermediate stages of final black tea products.

Exports of black tea are only sourced from national black tea production and exclude black tea imports/re-exports. Finally, although there is a variation in these graded intermediate products based on the particle size, variation in quality is minimal. Furthermore, there is a limitation on disaggregated data of these intermediate grades and data is available for aggregated products at the market level. Therefore, the same quality is assumed across intermediate and final products.

In Figure 2, as is common practice, each production function is shown by a rectangle, while input/factor supplies, and product demands are shown by ovals where exogenous shifts are possible. Arrows depict demand and supply relationships, where the arrowhead and the arrow shaft represent the demand for the product and supply of the product, respectively.

The conceptual structure of the industry can be disaggregated horizontally and vertically into segments as explained below. This disaggregation is required in examining the welfare distribution of different exogenous shocks on the industry and across various sectors. The main product groups in the industry are represented in horizontal market segments of the framework. Accordingly, horizontal market segments given by the framework in Figure 2 are black tea in bulk form and value-added form for both domestic and export markets.

The vertical disaggregation represents key sectors in the value/supply chain of the industry as green leaf production, made tea manufacturing, intermediate product manufacturing, secondary processing of made tea for retail and export marketing, and made tea marketing locally and internationally. Therefore, channels of black tea manufactured across different tea-growing regions merge at the point of tea trading at the Colombo tea auction at which the tea can end up in either domestic or international markets. Production processes of green leaves, black tea, and final value added products are homogeneous at each market level and result in outputs that have minimal quality variation.

Inputs and outputs in the model

It is assumed that production functions used in the model are multi-output, separable in inputs and outputs. Usually, outputs of the tea production process consist of the primary/main output that is mostly a form of made tea and secondary/potential outputs. These potential outputs could be any kind of outputs in production processes such as externalities in the form of energy waste and/or product waste. However, these secondary outputs are not taken into consideration in the model as there is no evidence that secondary outputs from black tea manufacturing are monitored or recorded.

The main input of an industry sector is a variable input that flows through market levels along the value chain of the industry. The main/primary output of one market level is the input for the next market level. The main/primary inputs and outputs in most market levels are made tea either in bulk or value-added form.

Other inputs at a particular market level are either variable or fixed. Other inputs are water, chemicals, packaging material, labour, machinery, factories, and warehouses that can be classified into variable and fixed inputs into labor, capital, etc. at most market levels. Only the inputs in the green leaf

production sector are classified as fixed and variable inputs in the model. This is because there is extensive publicly available data on inputs used at the farm level (Department of Census and Statistics, 2020; Sri Lanka Tea Board, 2017). While inputs other than the main input in every other market sector have been categorized as variable or fixed (Table 1), with limited publicly available data all these inputs at all other marker levels are aggregated and categorized as "other inputs". Additionally, the main focus is on the input substitution at the farm level and the disaggregated farm cost information is helpful in achieving that aim.

Table 1. Inputs of main market levels in tea industry

Market level	Variable inputs	Fixed inputs
Tea cultivation sector	Fertilizer	Tea bush stand/ land
	Agrochemicals (weedicides, pesticides and fungicides)	Chemical spraying machinery
	Labor	Weeding equipment - Grass cutters if used
	Water	Shade tree lopping equipment if used
	Other material	Vehicles
Made tea manufacturing (Taulo and Sebitosi 2016)	Green leaves	Machinery
	Labour wages	Storage and warehousing
	Water	Staff
	Energy (electricity, firewood, diesel)	Vehicles
	Auxiliary material (bulk tea packaging material)	
	Other material	
	Transportation	
Secondary tea processing for export marketing	Made tea	Machinery
	Labour wages	Storage and warehousing
	Water	Staff
	Energy (electricity, firewood, diesel)	Vehicles
	Auxiliary material (value-added and bulk tea packaging material)	
	Flavours/chemicals/additives	
	Other material	
	Transportation	
Secondary tea processing for domestic marketing	Made tea	Machinery
	Labour wages	Storage and warehousing
	Water	Staff
	Energy (electricity, firewood, diesel)	Vehicles
	Auxiliary material (value-added and bulk tea packaging material)	
	Flavours/chemicals/additives	
	Other material	
	Transportation	

Inputs

The main input in the green leaf production sector is the tea bush stand which is a fixed input complementary to land in factors of production. A constant tea bush cover is assumed in the medium run; therefore, it is assumed that pruning is done every five years. Additionally, all other sectors, including the tea production sector, generally use labour, water, energy, and auxiliary material as variable inputs, and machinery, storage buildings, staff, and vehicles as fixed inputs.

Defining variables and parameters in the model

Here, all the notations for the variables and parameters used in the EDM are defined and listed. Variables and market parameters, along with a brief description, are shown in Table 2. Quantity variables are denoted by W, X, Y, and Z for green leaf production, black tea manufacturing, and black tea secondary processing and tea marketing sectors, respectively. Price variables are given by p, q, r, and s for green leaf production, black tea manufacturing, and black tea secondary processing and tea marketing sectors, respectively. Subscripts and superscripts are mostly used to differentiate between comparable variables.

Superscripts ' and '' indicate the private tea landholding sector and estate sector, respectively, in the green leaf production sector, and export and domestic marketing, respectively, in the black tea marketing sector.

The list of subscripts used is as follows: f – fixed inputs in green leaf production; v – variable inputs in green leaf production; o – other inputs in production processes; 1 – black tea in bulk and large packet form; 2 – black tea in value-added form; GL – green leaf production; TM – tea manufacturing; M – export or domestic marketing.

Table 2. Definition of variables and parameters in the tea industry model

Endogenous variables	
W'_v, W'_f	Quantity of variable and fixed inputs used in green leaf production private landholding sector respectively
W''_v, W''_f	Quantity of variable and fixed inputs used in green leaf production estate sector respectively
p'_v, p'_f	Price of variable and fixed inputs used in green leaf production private landholding sector
p''_v, p''_f	Price of variable and fixed inputs used in green leaf production estate sector
W'_{GL}	Aggregate input index of green leaf production private landholding sector
W''_{GL}	Aggregate input index of green leaf production estate sector
X'	Quantity of green leaves supplied from the green leaf production private landholding sector to the black tea manufacturing sector
X''	Quantity of green leaves supplied from the green leaf production estate sector to the black tea manufacturing sector
X	Quantity of total green leaves supplied from the tea grower sector to black tea manufacturing sector
q'	Price per kg of green leaves received by private tea grower sector from the manufacturing sector
q''	Price per kg of green leaves received by estate tea grower sector from the manufacturing sector (internal transfer price of green leaf by vertically integrated processors)
q	Price per kg of green leaves paid by the black tea manufacturing sector
X'_{GL}	Aggregate output index of the green leaf production from the private landholding sector
X''_{GL}	Aggregate output index of the green leaf production from the estate sector
X_o	Quantity of other inputs used in black tea manufacturing

q_o	Price of other inputs used in black tea manufacturing
X_{TM}	Aggregate input index of black tea manufacturing
Y'_1, Y'_2	Quantity of black tea from the manufacturing sector to the export marketing sector for secondary processing (bulk and value-added forms respectively)
Y''_1, Y''_2	Quantity of black tea from the manufacturing sector to the domestic marketing sector for secondary processing (bulk and value-added forms respectively)
r'_1, r'_2, r''_1, r''_2	Price of black tea from the manufacturing sector to the secondary processing sector
Y_{TM}	Aggregate output index of back tea manufacturing
Y'_{1o}	Quantity of other inputs used in secondary processing of black tea for exports in bulk form
r'_{1o}	Price of other inputs used in secondary processing of black tea exports in bulk form
Y'_{1SP}	Aggregate input index of secondary processing of black tea for bulk tea exports
Z'_1	Quantity of bulk black tea from secondary processing to export market
s'_1	Price of bulk black tea to export market
Z'_{1M}	Aggregate output index of bulk black tea to export markets
Y'_{2o}	Quantity of other inputs used in secondary processing of black tea for exports in value-added form
r'_{2o}	Price of other inputs used in secondary processing of black tea exports in value-added form
Y'_{2SP}	Aggregate input index of secondary processing of black tea for value added tea exports
Z'_2	Quantity of value-added black tea from secondary processing to export market
s'_2	Price of value-added black tea to export market
Z'_{2M}	Aggregate output index of value-added form of black tea to export markets
Y''_{1o}	Quantity of other inputs used in secondary processing of black tea for domestic marketing in bulk form
r''_{1o}	Price of other inputs used in secondary processing of black tea for domestic marketing in bulk form
Y''_{1SP}	Aggregate input index of secondary processing of black tea for bulk tea domestic marketing
Z''_1	Quantity of bulk black tea from secondary processing to domestic market
s''_1	Price of bulk black tea to domestic market
Z''_{1M}	Aggregate output index of bulk black tea for domestic markets
Y''_{2o}	Quantity of other inputs used in secondary processing of black tea for domestic market in value-added form
r''_{2o}	Price of other inputs used in secondary processing of black tea for domestic market in value-added form
Y''_{2SP}	Aggregate input index of secondary processing of value-added tea black tea for domestic market
Z''_2	Quantity of value-added black tea from secondary processing to domestic market
s''_2	Price of value-added black tea to domestic market
Z''_{2M}	Aggregate output index of value-added black tea for domestic markets
	Exogenous variables
T_x	Supply shifter shifting up the supply curves vertically
t_x	Amount of shift as a percentage of price of green leaves
N_x	Demand shifter shifting up demand curves vertically
n_x	Amount of shift as a percentage of price of green leaves
	Parameters
$\eta_{i,j}$	Demand elasticity of input i with respect to price j
$\varepsilon_{i,j}$	Supply elasticity of input i with respect to price j
$\tilde{\eta}_{i,j}$	Constant- output input demand elasticity of input i with respect to price j
$\tilde{\varepsilon}_{i,j}$	Constant-input output supply elasticity of input i with respect to price j
$\sigma_{i,j}$	Elasticity of substitution between inputs i and j

$\tau_{i,j}$	Elasticity of transformation between outputs i and j
κ_i	Cost share of input i
λ_i	Revenue share of output j
$\rho x'$, $\rho x''$	Quantity shares of X' and X'', ie. $\rho x' = X'/(X'+X'')$, $\rho x'' = X''/(X'+X'')$

Model specification in general functional forms

A set of general functional forms are specified here according to the model structure shown in Figure 2 following previous descriptions by Zhao *et al.* (2000) and Mounter *et al.* (2005). These equations are specified based on assumptions that: i) all production functions exhibit constant returns to scale; ii) all multi-output production functions are separable in inputs and outputs; and iii) each market level in the model operates with the objective of profit maximization and perfect competition in firms. These assumptions are applied to all market levels in the EDM.

Equilibrium conditions

The assumption of constant returns to scale means that total cost and total revenue are equal in each market level in the industry; assuming zero pure profits under equilibrium conditions. Although it is assumed on every market level, some levels operate in circumstances close to the conditions of perfect competition. Both tea grower and manufacturing sectors have many firms, and there are many different options for private tea growers to choose from estate-owned or many privately operating tea-manufacturing factories, while plantations have their own tea factories, all reflecting that there is a relatively competitive market, i.e. perfect competition or monopolistic competition. The Colombo tea auction, where buyers and sellers of primarily processed made tea meet with prices decided on a bidding system, closely approximates a perfectly competitive market.

In contrast, in the black tea secondary processing and marketing sectors, there is some (dated) evidence of oligopoly and oligopsony power (Weerahewa, 2003). While there is a lack of research to say whether the situation has changed over the time, the growth in the volume and types of value-added teas would suggest keen competition for the available black tea. In this version of the model, perfect competition is assumed across all market levels attributable to products, with mininmal variations, full information across buyers and sellers, minimal influence on prices by companies or their market shares in the market, and other standard features of perfectly competitive markets.

Seven equilibrium conditions are specified for green leaf production, with separate treatment of the estate sector and the private sector, black tea manufacturing, secondary processing of black tea for export marketing in bulk and value-added forms separately, and for domestic retail marketing, in bulk and value-added forms separately.

Production function specification

All production sectors are characterized by multi-output technologies/production functions. All production functions are assumed to show constant returns to scale, profit maximizing behavior, perfect competition across all sectors and multi- output production functions separable in inputs and outputs, again following Zhao *et al.* (2000).

There are seven product transformation functions: green leaf production in tea by the private landholding sector, green leaf production in tea by the estate sector, black tea manufacturing, secondary processing of made tea for export marketing in bulk form, secondary processing of made tea for export marketing in value-added form, secondary processing of made tea for domestic

marketing in bulk form, and secondary processing of made tea for domestic retail marketing in value-added form.

Cost functions and derived demand schedules

The profit maximizing behavior in firms consist of two components: cost minimization for a given level of output; and revenue maximization for a given input mix (see Zhao *et al.* (2000)). First, the multi-output cost function can be simplified to a single-output cost function based on the assumption that the technology is output separable[4]. Output separability helps represent the technology in single-product terms.

Seven cost functions related to all production functions can therefore be specified and used to derive output-constrained input demand functions for all sectors in the model.

Revenue functions and derived supply schedules

The second section of the profit maximization behavior in firms is revenue maximization for a given input mix. The revenue function can be simplified to a single input revenue function based on the assumptions of input separability.

Seven revenue functions can be specified and used to derive the input-constrained output supply functions for all the relevant sectors in the model in section.

Profit functions and exogenous factor supply

A number of inputs are exogenous to the EDM system, so the decision variables associated with their supplies cannot be specified within the model. Following Zhao *et al.* (2000), a profit function approach is used to derive the supply relationships of these exogenous inputs.

Utility functions and exogenous demand

There are four demands for the final products of black tea considered exogenous to the model: demand for exports in bulk form; exports in value-added form; domestic retail in bulk form; and domestic retail in value-added form.

The quality of the bulk and value-added black tea is different in terms of the packaging sizes and degree of blending with other constituents, and reaching different consumer markets. Most of the value-added tea in the form of tea bags are exported to Russia, Syria, and Jordan (Hilal and Mubarak, 2016). Russia and Iran are the top two countries importing Sri Lankan tea in bulk form for further value-addition and selling (Sri Lanka Tea Board, 2017). The highest proportion of black tea exported to foreign markets is in the bulk form that averaged to 0.6 per cent of total exports between 2010 to 2014. Therefore, the demand for black tea exports in bulk and in value-added tea form are assumed to be independent and reflect preferences of different consumers.

The logic used by Zhao *et al.* (2000) to derive the demand relationships of these exogenous final products is to specify an indirect utility function. An indirect utility function gives the maximum level of utility from a given set of prices and income, consistent with the consumer's constrained optimization problem. The Marshallian demand equations can be derived from these functions. Here,

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[4] Output separability makes it convenient for representing the technology in single-product terms.

the demand for black tea exports in bulk and value-added form are independent of the rest of the model and are only related to own price.

With respect to domestic demands of black tea products, bulk and value-added forms are substitutes for Sri Lankan consumers. Bulk tea comes without brands, while value-added tea products in the domestic market are available in a wide array of brands in different package sizes convenient for consumers' use. Consumers purchase bulk and VAT depending on the relative prices of the two tea products and on other available beverages such as coffee, and soft drinks. In this case the same process is followed except that cross-price elasticities are allowed in the domestic demand functions.

The Equilibrium Displacement Model

The process described above was followed to result in a pair of supply and demand functions for each product and a pair of equilibrium conditions in each industry level that sums up to a total of 52 equations. In total there are 38 price and quantity variables from the 19 factor/product markets involved and 14 aggregated input and output index variables representing the seven multi-output markets in the black tea industry. The exogenous shifters are the 13 potential shifters of demand and supply products. These shifters allow measures of the impact of a change in the cost of production, a change in yield or a change in consumer willingness to pay.

These general functional forms of the model specify the equilibrium status in all markets involved in the industry. These equilibriums need to be converted to displaced forms to facilitate the study of impacts of exogenous shocks on the industry that lead to shifts away from the base equilibrium. Total differentiation of the set of equations specifying endogenous price and quantity variables at the initial equilibrium points provides the respective displaced form as a percentage change. This method provides informative estimates of quantity and price changes resulting from exogenous shocks, even without specifying the true functional forms of demand and supply equations based on the assumption that exogenous shifts cause small and parallel shifts.

Integrability conditions are then imposed. Using a linear demand and supply system that meets integrability conditions at the base equilibrium tends to minimize associated errors for relatively small displacements (Zhao *et al.*, 2000).

The full model in equilibrium displacement form is shown in Appendix A.

Input Data, Exogenous Shifts and Welfare Measurements

Input data

Base equilibrium quantity values

Price and quantity data for each sector of the tea industry were obtained from published sources including annual reports, annual market updates and performance reports from institutions that work closely with the tea industry in Sri Lanka such as the Sri Lanka Tea Board, the Tea Research Institute of Sri Lanka, the Tea Small Holdings Development Authority, the Ministry of Plantation Industries, the Export Development Board, Department of Census and Statistics and the Central Bank of Sri Lanka.

The five-year interval from 2010 to 2014 was used in specifying base equilibrium average quantities and prices as reported by the annual reports of the Sri Lanka Tea Board. These years were selected to avoid years with direct and indirect impacts on prices and quantities in markets because of the ban on

glyphosate imposed between 2015 and 2018. Considering a medium run with average values over five years ensures that the effects of unusual values present in single years will be evened out.

All quantities and prices are calibrated in terms of black tea equivalent million kilograms and Rs/kg respectively. The Sri Lanka Tea Board (2017) uses the out-turn ratio of 21.5 per cent between green leaves and made tea. In other words, 4.65 kilograms of green leaves are required to manufacture one kilogram of black tea. Thus, the ratio 4.65 is used as the conversion factor in converting made tea into green leaf quantities and prices. This conversion factor depends on the manufacturing process and other factors including the quality of the green leaf harvest.

Base equilibrium price values

The variable cost of production per year of tea smallholders for the years 2010 – 2014 was taken from the green leaf production cost calculation by the Tea Small Holdings Development Authority annual reports. Cost of production of green leaves by the estate sector was extracted from the made tea production cost information given by the Department of Census and Statistics (2020) for the same years. There is no consistent breakdown of information on the cost of green leaf production in the estate sector as most entities are vertically integrated, so their primary concern is the cost of production of the final product, made tea. The general situation in the farm sector is that the share of fixed costs in total cost of production in the estate sector is higher than that in the private grower sector because of higher costs incurred on wages and other conditions for their residential labour force, salary for staff, and other fixed inputs such as larger items of machinery. Although some estimates of variable cost of production in the estate sector derived from secondary sources give higher costs than the private sector, an adjustment has been made here in the assumed prices of inputs of the estate sector in order to be slightly lower than prices in the private sector. This is to satisfy the condition of a higher share of fixed input costs in the estate sector than in the private sector.

The average price received per kilogram of green leaves annually is also provided by the Tea Small Holdings Development Authority annual reports. The price received for the green tea harvest by smallholders is the price paid by black tea manufacturing factories based on the 'reasonable price' formula regulated by the government as specified by the Tea Control Act of the Tea Board. It depends on the monthly net sale average of tea factories. This price also varies across tea growing regions, but an average value across all tea growing regions is used in the model in black tea-equivalent terms. Since green leaf harvest in the estate sector does not receive direct revenue from green leaves, the same green leaf price decided by the Sri Lanka Tea Board was assumed as the opportunity cost for the estate sector green leaves.

The intermediate stages of final black tea products in the bulk form receive different prices in the auction as there are differences implicit to final products based on attributes such as the grade and quality variations unique to tea growing elevation/regions. Usually, large particle size teas fetch higher prices while tea dust receives lower prices in the tea auction. There is limited published data on prices received by each final product type in the auction, but average prices are formed based on the elevation. Therefore, while acknowledging quality variations in tea, based on the assumption not to differentiate the quality of final tea products evaluated in the model, it is considered that all teas in the auction receive the same price. Tea processors are price takers. The average price received at the Colombo tea auction annually was used in this case as given by annual reports of the Sri Lanka Tea Board.

Prices received for secondary processed tea are the Freight on Board (FOB) prices for exported tea as given in the annual reports of the Sri Lanka Tea Board and the retail prices of loose bulk tea and value-added tea in the domestic market given by the Department of Census and Statistics (2010; 2016). The

Sri Lanka Tea Board gives FOB prices for bulk tea, tea bags, and tea packets separately. Tea bags have the highest FOB price and the price decreases as the volume of the packs increase. The FOB prices for the final black tea products exported, bulk and value-added tea are calculated using weighted averages of prices of each product category given by the Sri Lanka Tea Board.

The Bulletin of Selected Retail and Producer Prices published by the Department of Census and Statistics (2010; 2016) provides prices of unbranded loose tea leaves per kg and prices per 100g of a branded tea packet (this was converted to per kilogram price).

Cost and revenue shares

The equilibrium quantity and price values explained above are used in deriving the cost and revenue shares needed in the model for all market sectors. The cost share of "other inputs" variables of all market sectors are calculated as residuals using equilibrium conditions.

The total value, cost shares of inputs and revenue shares of outputs of each market level for the period 2010 to 2014 are summarized in Table 3.

Market parameters

Market parameters are needed for every market level in the EDM. These parameters include elasticities of demand, supply, input substitution and product transformation of intermediate and final black tea products, farm and other inputs. Price elasticity values provide a numerical estimation of the responsiveness of quantity variables to price changes.

Elasticity estimates play a critical role in the EDM. Price elasticities of demand and supply can be obtained from existing econometric estimations or estimated by the use of economic theory and subjective judgement. Since many of the required price elasticities are not readily available from prior research, it is difficult to obtain robust estimates of them. Elasticity estimates tend to vary based on several factors such as functional forms, estimation methods, model specification, and over time with changes in the external environment (Griffith *et al.,* 2001). In such instances, most studies rely on expert opinion and subjective judgment that help arrive at best guesses of elasticity values.

Furthermore, price elasticities of demand and supply can take different magnitudes across the value chain of the industry owing to varying responses to price changes and production technologies at each market level. For an instance, price elasticities at the farm gate are usually lower than those at the retail market levels, because of factors including perishability of agricultural produce and lower degrees of substitutability. However, finding elasticity estimates for all market levels along the value chain is a major challenge in industries where not a lot of previous work has been done.

As mentioned above, it is essential for market elasticity estimates to meet integrability for all demand and supply functions in the model in terms of concavity and convexity conditions. This study follows the broad approach taken by Zhao *et al.* (2000) in obtaining elasticity values.

Demand for black tea products in markets of the EDM can be explained using own-price and cross-price elasticities of demand. Previous empirical studies have found that demand for tea in most of the tea consuming countries is price inelastic over an extended time period (Broster, 1939; Ramanujam, 1984; Weerahewa, 2003; Ganewatta *et al.*, 2005; Food and Agriculture Organization of the United Nations, 2012; Chang, 2015).

Table 3. Base equilibrium prices, quantities and cost and revenue shares (average of 2010-2014)

Market sector	Quantity (million kg)	Prices (Rs. /kg)	Total value (million Rs)	Cost share	Revenue share
Green leaf production					
Private growers	**X'= 238.84**	**q = 275.78**	65,867.3	$\kappa_{W'v}$ = 0.80 $\kappa_{W'f}$ = 0.20	$\lambda X'$ = 1
Estate growers	**X'' = 91.01**	**q = 275.78**	25,098.74	$\kappa_{W''v}$ = 0.78 $\kappa_{W''f}$ = 0.22	$\lambda X''$ = 1
	X = 329.85	**q = 275.78**	90,966.04		
Black tea manufacturing					
For secondary processing into bulk tea exports	**Y'1 = 178.9**	**r'1 = 405.68**	72,576.15	κ_X = 0.68	$\lambda Y'1$ = 0.5424
For secondary processing into VAT exports	**Y'2 = 118.3**	**r'2 = 405.68**	47,991.94	κ_{Xo} = 0.32	$\lambda Y'2$ = 0.3585
For secondary processing into loose tea domestic markets	**Y''1= 2.3**	**r''1 = 405.68**	933.06		$\lambda Y''1$ = 0.0085
For secondary processing into VAT domestic markets	**Y''2 = 20.8**	**r''2 = 405.68**	8,438.14		$\lambda Y''2$ = 0.0906
Secondary processing of black tea for marketing					
Secondary processing of made tea for export marketing in bulk form	**Z'1 = 178.9**	**s'1 = 498.75**	89,226.38	$\kappa_{Y'1}$ = 0.81 $\kappa_{Y'1o}$ = 0.19	$\lambda Z'1$ = 1
Secondary processing of made tea for export marketing in VAT form	**Z'2 = 118.3**	**s'2 = 624.48**	73,875.98	$\kappa_{Y'2}$ = 0.65 $\kappa_{Y'2o}$ = 0.35	$\lambda Z'2$ = 1
Secondary processing of made tea for domestic marketing in loose form	**Z''1 = 2.3**	**s''1 = 674.23**	1,550.73	$\kappa_{Y''1}$ = 0.60 $\kappa_{Y''1o}$ = 0.40	$\lambda Z''1$ = 1
Secondary processing of made tea for domestic marketing in VAT form	**Z''2 = 20.8**	**s''2 = 960.43**	19,976.94	$\kappa_{Y''2}$ = 0.42 $\kappa_{Y''2o}$ = 0.58	$\lambda Z''2$ = 1

The recent study by Chang (2015) concluded that price elasticity estimates for black tea vary between -0.32 and -0.8, while many factors including demographic variables such as age, education, occupation, cultural background, and health benefits can influence demand in addition to traditional variables such as price and income. Additionally, demand elasticities can vary in the long run across types of economies with -0.07, -0.14, and -0.48 as estimates from developed, developing, and centrally planned economies (Ganewatta *et al.*, 2005).

Exogenous demand elasticities in the EDM of the study are required at domestic and export market levels of black tea products. Products of black tea available in the domestic market are branded value-added tea and unbranded bulk/loose tea as explained earlier. Although tea is the most-consumed beverage in Sri Lanka, its domestic demand is not well-specialized, yet domestic prices of tea products and the income are considered as factors determining the country's demand (Ariyawardana, 2001). However, the price elasticities of demand for tea domestically were calculated in a few past studies as shown in the following Table 4.

Table 4. Price elasticity of demand estimations in previous studies

Study	Price elasticity of demand
Yuliando and Akira (2006)	-0.588
Ariyawardana (2001)	-0.4209
Ramanujam (1984)	-0.2596 (short run)
	-0.9058 (long run)
Tyler (1976)	-0.54

Although the recent consumption patterns of black tea have diverted towards value-added tea products as mentioned above, there is no separate information on elasticity estimates on value-added tea and bulk/loose tea consumed domestically. Since there is growing demand for VAT, it is logically assumed that the price elasticity of demand for unbranded loose/bulk tea would be more elastic than that of VATs as the preference would be more towards the latter. Hence, based on estimates from past studies, 0.4 and 0.8 were chosen as price elasticities of demand for VAT and bulk/loose tea respectively.

A major share of annual tea exports is traded by a few exporters; mainly multinational companies (Wijayasiri, 2013). Sri Lankan black tea reaches international tea market destinations in the form of value added and bulk teas. As already explained earlier, bulk tea is mainly purchased by secondary processors in importing countries to be re-packed and sold in their own marketing channels, while VAT reach either retail markets or companies that re-distribute them under different brands. Demand for tea by importing countries mainly depends on consumption patterns and economic conditions of those countries. Additionally, prevailing market conditions, cost for importation, marketing, packaging and distribution also influence the demand for tea. Currently, the global preference is changing to value added tea products.

There are a very limited number of studies on export demand elasticities for Sri Lankan black tea products separately, but there is general agreement that export demand elasticities are elastic. Since bulk tea is an intermediate product traded in the export market, derived demand elasticities are used. Herath and Weersink (2007) have pointed out that the derived demand for bulk black teas by processors in importing countries is elastic because of the ability of tea consumers in the United Kingdom to substitute Sri Lankan tea with other origin teas from India and China (Weerahewa *et al.*, 1997). The top black tea export destinations of Sri Lanka in recent years according to the Sri Lanka Tea Board (2017) were Turkey, Russia and the CIS region, Iran and Iraq in the Middle East, the Oceania region including Japan and China, Australia, the European Union region, and the United States.

Studies that examined export demand elasticities of VAT in Sri Lanka are scarce. Therefore, it is assumed that VATs are more elastic than bulk tea because of the availability of many substitutes and differentiated products for VAT in the global market from value addition by both producing and non-producing countries. Furthermore, bulk tea being a raw material in the value addition process of VAT tend to have an inelastic demand. Based on these arguments, export demand elasticities for bulk tea and VAT are estimated as 4.0 and 5.0, respectively.

Input supply elasticities are defined for exogenous inputs used in each market level of production in the EDM. Since own price elasticities of input supplies were used mostly in the model, cross-price elasticities have not been reviewed. Elasticity of input supply explains the responsiveness of factor supplies to changes in its own price. Inputs used in production processes can be categorized under land, labour and capital and further elaborating them as fertilizer, agro-chemicals, energy sources, machinery, packaging material etc. These inputs are aggregated in each market level to one category as other inputs that are specified exogenous to the model.

Given the limited evidence on supply elasticity estimations on inputs, earlier studies by Zhao *et al.* have classified inputs into two as fixed and human capital aggregated together and inputs such as labour, chemical, and other inputs under mobile factors with relatively elastic supplies. That study has chosen 0.7 and 1 as the supply elasticity estimates of fixed factor inputs and mobile factor inputs respectively. Fixed capital and human capital have been allocated a relatively inelastic supply elasticity because of the technical aspects of such inputs, while identifying mobile input factors as very much closer to perfect elasticity indicating the non-specific nature.

Applying the same concept on the EDM of the tea industry, in this study farm inputs were classified into fixed and variable inputs. Elasticity estimates of estate sector farm production found by Roberts (1989) were helpful to be used as inputs in the EDM. Although those market parameters date to 30 years back, it can be assumed that they still apply to the present context. This is because tea production at the farm levels is a labour-intensive activity depending on labour for most of the field activities and there have not been significant advances in the technology of farming systems, especially in labour-saving technology, that has changed the input of labour much since then.

Fixed inputs in the two farm sectors constitute land, capital, and human capital in varying degrees. Tea being a perennial crop tends to have input factors such as land, and capital such as buildings and vehicles fixed over the medium run. Fixed inputs in the estate sector tend to be much more technical and highly specialized than the private grower sector. Additionally, there is the separate human capital - estate management is a fixed input in the estate sector that is not found in private growers. It is assumed that the supply of fixed inputs in the estate sector is more inelastic than in the private sector. Roberts (1989) has found out that supply elasticities of field labour and vehicles in the estate sector as 0.3 and 0.2, respectively. Taking into account this distribution of fixed inputs across two grower sectors, 0.7 and 0.5 are used as supply elasticities of fixed inputs in private and estate grower sectors, respectively.

On the other hand, a major share of variable inputs in the farm sector is labour as tea cultivation is labour-intensive. The residential labour force in the estate sector is usually specialized for separate field activities rather than the casual labour hired in the private sector, thus, are relatively inelastic. Supply elasticities of field labour in estates were calculated to be 0.99 by Roberts (1989). Based on this data, variable input supply elasticities for the private and estate sector are assigned 1 and 0.9 respectively.

Furthermore, black tea manufacturing and secondary processing requires highly sophisticated and capital-intensive equipment and machinery in addition to specialized human capital. A value of 1.0 of other input supply elasticity is assumed in all those market levels.

Input substitution is possible in a production function when there are multiple inputs. The elasticity of input substitution gives an indication of the degree of substitutability between inputs at a market level. The significance of input substitution was discussed by earlier studies and Zhao *et al.* (2003) have pointed out arguments made by Freebairn *et al.* (1982) and Alston and Scobie (1983). Accordingly, elasticities of input substitution are critical in the EDM, where distributions of benefits or costs along market levels from an exogenous shock are dependent on the substitution estimates. In instances when inputs are used in fixed proportions - no substitution between inputs - in a sector, returns would equally be distributed across market levels, whereas with input substitution possible in a market level, with a shock on the sector the same level gets a larger proportion of total returns.

There is no previous work that studied the substitutability of inputs in market levels along the value chain of the tea industry. Depending on the insubstantial degrees of substitution between inputs in

the farm and other tea processing sectors, it is assumed that inputs are used in fixed proportions hence there is no substitution.

According to Powell and Gruen (1968, p.315), the elasticity of product transformation is "the responsiveness of a product-mix ratio to changes in the marginal rate of transformation." It describes the degree of substitution between products for a given level of inputs as a response to relative price changes in outputs.

Most of the market levels in the tea value chain have single products except for the black tea manufacturing sector that produces the four black tea product types differentiated based on the final marketing channel after undergoing secondary processing. The rest of the other sectors have one main input. Given the limited flexibility to change the product mix ratio because on the nature of the black tea manufacturing and scarce information on product transformation elasticities, in the EDM a fixed ratio in the product mix was assumed. Therefore, the elasticity of product transformation is zero.

Market elasticity values for the base equilibrium conditions in each market level are given in the Table 5.

Table 5. Market elasticity values for the base equilibrium condition

			Demand elasticities	Supply elasticities	Input substitution elasticities	Product transformation elasticities
Green leaf production	Private growers	tea		$\varepsilon_{W'vp'v} = 1$ $\varepsilon_{W'fp'f} = 0.7$	$\sigma_{W'vW'f} = 0$	
	Estate growers	tea		$\varepsilon_{W''vp''v} = 0.9$ $\varepsilon_{W''fp''f} = 0.5$	$\sigma_{W''vW''f} = 0$	
Black tea manufacturing				$\varepsilon_{Xoqo} = 1$	$\sigma_{XXo} = 0$	$\tau_{Y'1Y'2} = 0$ $\tau_{Y'1Y''1} = 0$ $\tau_{Y'1Y''2} = 0$ $\tau_{Y'2Y''1} = 0$ $\tau_{Y'2Y''2} = 0$ $\tau_{Y''2Y''1} = 0$
Secondary processing of made tea for export marketing in bulk form			$\eta_{Z'1s'1} = -4$	$\varepsilon_{Y'1or'1o} = 1$	$\sigma_{Y'1Y'1o} = 0$	
Secondary processing of made tea for export marketing in value-added form			$\eta_{Z'2s'2} = -5$	$\varepsilon_{Y'2or'2o} = 1$	$\sigma_{Y'2Y'2o} = 0$	
Secondary processing of made tea for domestic marketing in bulk form			$\eta_{Z''1s''1} = -0.8$	$\varepsilon_{Y''1or''1o} = 1$	$\sigma_{Y''1Y''1o} = 0$	
Secondary processing of made tea for domestic marketing in value-added form			$\eta_{Z''2s''2} = -0.4$	$\varepsilon_{Y''2or''2o} = 1$	$\sigma_{Y''2Y''2o} = 0$	

A sensitivity analysis was carried out to test some of the critical assumptions made while assigning elasticity estimates through subjective judgements. The outcomes of the EDM is sensitive to market parameter estimates, thus conducting a sensitivity analysis is important to monitor changes in model outcomes.

Measuring economic surplus changes

Subsequent displacements in quantities and prices from the initial equilibrium of the system of equations in the EDM representing demand and supply of market levels resulting from an external shock can be measured by calculating the economic surplus changes. In this model, changes in

producer and consumer surplus at the relevant market levels are calculated using well-known formulae (Zhao *et al.*, 2000; Mounter *et al.,* 2008). These formulae are shown in Appendix B.

Technical Validation of the EDM Using Hypothetical Exogenous Shifts

The EDM developed on the tea industry in Sri Lanka includes 13 possible exogenous shift variables - four demand shifters and nine supply shifters. These demand and supply shifters are used to implement different shocks or displacement scenarios at any of the different market levels. Changes in total economic surplus can be calculated as well as the distribution across the respective sectors.

The model that was set up after specifying its equations and expressed in terms of base equilibrium quantities, prices and market parameters is validated using several hypothetical scenarios. They were helpful in technically validating the model using a simple test to check whether the hypothetical shift produced the same order of magnitude of costs or benefits as expected from theory. Under each scenario, an exogenous demand or supply variable in a market level is shocked by 1 per cent and the respective surplus change reflecting the impact of each shock on the system is investigated. The welfare change of each of these hypothetical scenarios should be similar to 1 per cent of the total revenue at that market level. For example, when 1 per cent shocks on variable inputs in both grower sectors are applied, they should yield a change in total economic surplus that is approximately equal to 1 per cent of the gross value of the weighted average variable cost share of farm sector inputs. As shifts from external shocks are assumed to be parallel and relatively small, the distribution of welfare changes in market levels will be independent of the magnitude of the shift (Zhao *et al.*, 2000).

In Table 6 a summary of three hypothetical scenarios is provided with descriptions on exogenous shift variables, magnitudes and direction of shifts.

Table 6. Description of hypothetical scenarios and results of welfare changes

Market level undergoing shock	Description of the hypothetical scenario	Result
Farm sector	$t_{w'v}$ = 0.01, $t_{w''v}$ = 0.01, rest $t_{(.)}$ =0 and $n_{(.)}$ = 0 Cost of production increase in green leaf production resulting from imposition of an input use restriction policy on the tea grower sector, eg; ban on Glyphosate	Changes in Producer surplus = (469.69) Consumer surplus = (253.76) Total surplus = (723.45)
Black tea manufacturing sector	t_{XO} = 0.01, rest $t_{(.)}$ =0 and $n_{(.)}$ = 0 Cost of production increase in tea manufacturing sector resulting from imposition of an input restriction policy on the sector	Changes in Producer surplus = (579.42) Consumer surplus = (150.32) Total surplus = (429.10)
Export marketing bulk export sector	$n_{Z'1}$ = -0.01, rest $t_{(.)}$ =0 and $n_{(.)}$ = 0 Reduction in the demand for bulk black tea exports by processors in importing countries because of a quality degradation in products	Changes in Producer surplus = (579.01) Consumer surplus = (312.20) Total surplus = (891.21)

Percentage changes in prices, quantities and distribution of welfare across key market levels in the value chain of the tea industry are provided in Appendix C, D, and E respectively. In the section below, each scenario is explained using information on percentage changes in prices, quantities and welfare distributions following the hypothetical 1 per cent external schock as explained in each scenario.

Scenario 1

This scenario models an increase in the cost of variable inputs in both grower groups in the farm sector as an upward shift in their supply curves. Reductions in demand for variable inputs by grower groups take place as a result of a movement along the demand curve for fixed inputs.

This results in a decrease in quantities used and an increase of prices of variable inputs. Since the elasticity of substitution between variable and fixed inputs is zero (fixed proportion of inputs used in the production process) in the model, a change in prices of variable inputs means a shift in the demand of fixed inputs. However, supply curves of fixed inputs remain stationary because they are not displaced by endogenous shocks. This results in reduced quantities and prices of fixed inputs in grower groups. Subsequently, since the input factor prices and quantities decline, the supply curves of green leaves shift upwards reflecting a decrease in supply. The same process takes place along all market levels at the downstream resulting in endogenous shifts supply (upwards) of main inputs such as green leaves to manufacturing sector and made tea to secondary processing sectors, and (downward) in demands for other inputs. The latter incident happens because of the increased price of the complementary good (main input) at the same market level and specified fixed proportion in production processes (no substitution between inputs). No shift in supply curves of other inputs at all market levels takes place as they are exogenous to the model. Thus, quantities and prices of other inputs in black tea manufacturing and secondary processing sectors decrease. On the other hand, quantities decrease, and their prices increase as an outcome of displacements in supply curves of tea products or derivatives in market levels endogenously with subsequent demand reductions in quantities of main inputs.

The displacements in supply and demand curves with the shock on variable inputs (one per cent increase in variable costs) in the farm sector because of the increase in weeding cost have resulted in a total economic loss of LKR 723.45 million. The highest impact of this has been on producers with a loss of LKR 470 million (65 per cent of the total loss) and almost half of that was incurred on the farm sector with a loss of LKR 235 million (32.5 per cent of the total loss) followed by black tea manufacturing sector (a loss of LKR 98 million; 12.5 per cent of the total loss). The private grower sector has faced the highest loss of LKR 130 million accounting to 18 per cent of the total loss. Consumers have been affected by a loss of LKR 254 million (35 per cent of the total loss) while domestic consumers of VAT were the highest affected.

Scenario 2

The exogenous shock on other inputs in made tea manufacturing is a shift in the supply curve upwards. This is a price increase in other inputs. The demand curve of other inputs is stationary with no shift (the equilibrium point moves along the demand curve). This leads to reduced quantity of other inputs traded in the market level. The initial external shift results in a shift in the demand curve of green leaves as an input in made tea manufacturing and movement along the supply curve of green leaves. The outcome is a reduction of quantity and decline in price of green leaves.

This reduction in quantity of green leaves traded between the farm level (for both smallholder and estate sectors separately) and manufacturing level decreases the revenue, hence profit received by green leaf producers. It leads to a downward shift in demand curves of both variable and fixed inputs, and a movement along supply curves of those inputs separately in both grower sectors. As a result, prices and quantities decline in each market.

In the downstream from the manufacturing sector to secondary processing sectors of final products following the exogenous shock on other inputs in manufacturing sector creates different effects on market levels. Increase in production cost of made tea manufacturing with increased cost on other inputs means a shift in the supply curve of made tea as well. The demand curve of made tea products

traded at the auction remains stationary and the equilibrium point moves along the demand curve. This results in an increase in price and quantity reduction of made tea at the auction.

Quantity reduction of made tea traded at the auction results in a shift in demand curve of other inputs in all secondary processing sectors. There is no shift in supply curves of other inputs as the exogenous shock on an input in the upstream market level does not affect them. Hence, a decline in price and quantity takes place at each market level engaged in secondary processing.

The shrink in quantities in secondary processing sectors poses a shock on supply curves, with no displacement in demand curves of all final tea products separately. This eventually decreases quantities traded and increases prices of all final tea products in export and domestic markets.

The shifts in supply and demand curves with the shock on other inputs (one per cent increase in variable costs) in the made tea manufacturing resulted in a total economic loss of LKR 428.52 million. The highest impact of this has been on producers with a loss of LKR 278 million (65 per cent of the total loss) and almost half of that was incurred on the farm sector with a loss of LKR 140 million (32.61 per cent of the total loss) followed by the black tea manufacturing sector (a loss of LKR 58 million; 13.5 per cent of the total loss). The private grower sector has faced the highest loss of LKR 130 million accounting to 18 per cent of the total loss. Consumers have been affected by a loss of LKR 150 million (35 per cent of the total loss) while domestic consumers of VAT were the highest affected.

Scenario 3

Shock on the demand curve for bulk tea exports displaces the demand curve of bulk black tea exports downwards as a result of quantity decline. Hence, the price of bulk tea exports decline.

This in turn is an endogenous shock on made tea and other inputs in the secondary processing sector of exported bulk tea, that displaces demand curves of both inputs (other inputs and made tea) downwards. Supply curves of both markets remain stationery and prices and quantities of inputs traded decline.

With assumed zero output transformation elasticities between made tea products in made tea manufacturing, made tea supplied to the rest of the secondary processing sectors shrink, displacing each supply curve upwards. While demand curves of each of these market levels remain still, quantities decline and prices of made tea traded to secondary processing sectors increase. Decreased quantities of made tea traded to secondary processing sectors lead to a downward shift in demand curves and no shift in supply curves of other inputs in respective market levels subsequently. This results in price declines in other inputs for secondary processing sectors.

Simultaneous reductions in quantities of made tea traded in auctions is a downward shock on the demands for inputs (green leaves and other inputs) at the made tea manufacturing sector as profits received from made tea sales decrease. This subsequently leads to declined prices and quantities of inputs. The same situation repeats in all upstream input market levels; variable and fixed inputs in the two grower sectors.

Since the exogenous shock on the demand for exported bulk tea decreases quantities of all made tea produced at the made tea manufacturing sector, this eventually displaces the supply curves of final tea products (exported VAT, loose and VAT for domestic markets). While demand for those final tea products is not affected, as cross price elasticities are not considered between them in domestic and export markets, prices increase, and quantities traded at consumer markets decrease.

Shifts in supply and demand curves with the exogenous shock on exported bulk tea (one per cent decrease in quantity demanded) resulted in a total economic loss of LKR 891 million. The highest impact of this has been on producers with a loss of LKR 579 million (65 per cent of the total loss) and nearly half of that was incurred on the farm sector with a loss of LKR 290 million (33 per cent of the total loss) followed by the made tea manufacturing sector (a loss of LKR 120 million; 13.5 per cent of the total loss). Consumers have been affected by a loss of LKR 312 million (35 per cent of the total loss) while domestic consumers of VAT were the highest affected (a loss of LKR 201 million; 22.6 per cent of the total loss).

In summary

The proportionate changes in quantities at different market levels are the same in each scenario because of the assumed parallel shifts in demand and supply curves. The percentage changes are all below one per cent. However, the percentage changes in prices vary between market levels according to the relevant elasticity values and the change is closer to one per cent in the level where the shock occurs. Otherwise, values are less than one per cent most of the time. Domestic VAT consumers are the most affected group because of the inelasticity in their demand.

Sensitivity Analysis of the Hypothetical Exogenous Shifts

A sensitivity analysis was carried out to test some of the critical assumptions made while assigning elasticity estimates through subjective judgements. Generally, the outcomes of an EDM analysis are sensitive to market parameter estimates, thus conducting a sensitivity analysis is important to monitor changes in model outcomes. Uncertainties in elasticity estimates were minimized by assigning probability distributions to parameters and performing a Monte Carlo simulation using the @RISK computer software. This was applied on the first hypothetical scenario that assumed a 1 per cent increase in the cost of variable inputs of both grower groups in the farm sector. Truncated normal distributions were assumed for all elasticity estimates used in the model that comprise exogenous demand, input supply, input substitution and product transformation elasticities. Furthermore, correlation coefficients were defined for elasticity values to address correlations across products in related market levels. Random sampling was conducted 10,000 times for the given scenario, each one using different combinations of parameter values. Hence, the program generated 10,000 sets of price and quantity change combinations and eventually 10,000 sets of surplus change results across each market level.

The results obtained from the @RISK program are provided in Appendix F. Outputs from the @RISK program are indicated in terms of the minimum, maximum, mean, fifth percentile and 95th percentile values in surplus changes of each market level in the tea industry providing a better understanding of the distribution of each surplus change. The means of the @Risk distributions of surplus changes are very close to the point estimates shown in Appendix F and all surplus changes remain negative, as expected. The estimated distributions are also quite tight; for example, 90 per cent of the estimated values for total economic surplus lie within a band that is only 2.4 per cent of the mean.

Further Research

Several assumptions were made about production processes in market levels to set up the simplified version of the EDM on tea industry. For example, assumptions on zero elasticity of substitution between outputs in made tea manufacturing, and homogeneous products in terms of quality, to avoid variations across market levels were made to keep the model simple. Further research can be extended in such areas to address variable proportions of outputs in production possibility frontiers and heterogeneous quality of tea products across market levels.

Furthermore, given that results obtained in EDM are highly sensitive to price elasticities, changes can be made on market parameters to reflect any changes in producer or consumer behaviours as needed for more precision and better expression of the tea industry in the model.

Summary and Conclusion

In this paper the process of specifying and calibrating an equilibrium displacement model of the tea industry in Sri Lanka is described. The model specification follows a detailed review of the industry context and the key elements of the tea value chain that extend from tea cultivation to black tea trading and marketing in export and domestic markets. Standard conceptual frameworks are then used to define all necessary production, cost, revenue and indirect utility functions in terms of general functional forms which are then differentiated to produce a system of equations in displacement form – the EDM.

The inputs needed to implement the EDM include base equilibrium price and quantity values for all inputs and outputs that outline the equilibrium status of the system, market parameters illustrating the market responsiveness of quantities to changes in prices, and values for all exogenous shift variables for simulated scenarios quantifying the effects of external shocks studied. The general lack of up-to-date estimates of most key market parameters meant that most estimates had to rely upon subjective judgements.

A number of simulated scenarios with potential shocks leading to 1 per cent shifts of supply or demand curves were used to partially validate the model structure as a reasonable representation of the tea industry in Sri Lanka. A sensitivity analysis was also conducted using the @Risk program.

The EDM on the tea industry in Sri Lanka can now be used with confidence to examine real industry issues and proposals. One such study underway is to quantify the welfare effects of exogenous shocks that resulted in displacement of supply and demand curves in market levels owing to the Government policy banning the use of glyphosate in tea production at the farm level (Rathnayake *et al.*, 2021).

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Appendix A. Model in Displacement Form

Green leaf production
Input supply to private green leaf production sector

(1) $EW'_v = \varepsilon_{W'v,\,p'v} * (Ep'_v + t_{W'v})$

(2) $EW'_f = \varepsilon_{W'f,\,p'f} * (Ep'_f + t_{W'f})$

Input supply to estate green leaf production sector

(3) $EW''_v = \varepsilon_{W''v,\,p''v} * (Ep''_v + t_{W''v})$

(4) $EW''_f = \varepsilon_{W''f,\,p''f} * (Ep''_f + t_{W''f})$

Output-constrained input demand of private green leaf production sector

(5) $EW'_v = -\kappa_{W'f} * \sigma_{W'v,\,W'f} * Ep'_v + \kappa_{W'f} * \sigma_{W'v,\,W'f} * Ep'_f + EX'_{GL}$

(6) $EW'_f = -\kappa_{W'v} * \sigma_{W'v,\,W'f} * Ep'_f + \kappa_{W'v} * \sigma_{W'v,\,W'f} * Ep'_v + EX'_{GL}$

Output-constrained input demand of estate green leaf production sector

(7) $EW''_v = -\kappa_{W''f} * \sigma_{W''v,\,W''f} * Ep''_v + \kappa_{W''f} * \sigma_{W''v,\,W''f} * Ep''_f + EX''_{GL}$

(8) $EW''_f = -\kappa_{W''v} * \sigma_{W''v,\,W''f} * Ep''_f + \kappa_{W''v} * \sigma_{W''v,\,W''f} * Ep''_v + EX''_{GL}$

Input-constrained output supply of private green leaf production

(9) $EX' = -\lambda_{x'} \tau * Eq' + EW'_{GL}$

Input-constrained output supply of estate green leaf production

(10) $EX'' = -\lambda_{x''} \tau * Eq'' + EW''_{GL}$

Input-constrained output supply equality

(11) $EX = \rho x' * EX' + \rho x'' * EX''$

Equilibrium conditions of private green leaf production

(12) $\kappa_{W'v} * EW'_v + \kappa_{W'f} * EW'_f = \lambda_{X'} * EX'$

(13) $\kappa_{W'v} * Ep'_v + \kappa_{W'f} * Ep'_f = \lambda_{X'} * Eq'$

Equilibrium conditions of estate green leaf production

(14) $\kappa_{W''v} * EW''_v + \kappa_{W''f} * EW''_f = \lambda_{X''} * EX''$

(15) $\kappa_{W''v} * Ep''_v + \kappa_{W''f} * Ep''_f = \lambda_{X''} * Eq''$

Black tea manufacturing
Other input supply to black tea manufacturing

(16) $EX_o = \varepsilon_{Xo,\,qo} * (Eq_o + t_{Xo})$

Output-constrained input demand of black tea manufacturing

(17) $EX = -\kappa_{Xo} * \sigma_{X,\,Xo} * Eq + \kappa_{Xo} * \sigma_{X,\,Xo} * Eq_o + EY_{TM}$

(18) $EX_o = -\kappa_x * \sigma_{X,\,Xo} * Eq_o + \kappa_x * \sigma_{X,\,Xo} * Eq + EY_{TM}$

Input-constrained output supply of black tea manufacturing

(19) $EY'_1 = -(\lambda_{Y'2} * \tau_{Y'1,\,Y'2} + \lambda_{Y''1} * \tau_{Y'1,\,Y''1} + \lambda_{Y''2} * \tau_{Y'1,\,Y''2}) * Er'_1 + \lambda_{Y'2} * \tau_{Y'1,\,Y'2} * Er'_2 + \lambda_{Y''1} * \tau_{Y'1,\,Y''1} * Er''_1 + \lambda_{Y''2} * \tau_{Y'1,\,Y''2} * Er''_2 + EX_{TM}$

(20) $EY'_2 = -(\lambda_{Y'1} * \tau_{Y'2,\,Y'1} + \lambda_{Y''1} * \tau_{Y'2,\,Y''1} + \lambda_{Y''2} * \tau_{Y'2,\,Y''2}) * Er'_2 + \lambda_{Y'1} * \tau_{Y'2,\,Y'1} * Er'_1 + \lambda_{Y''1} * \tau_{Y'2,\,Y''1} * Er''_1 + \lambda_{Y''2} * \tau_{Y'2,\,Y''2} * Er''_2 + EX_{TM}$

(21) $EY''_1 = -(\lambda_{Y'1} * \tau_{Y'1,\,Y''1} + \lambda_{Y'2} * \tau_{Y'2,\,Y''1} + \lambda_{Y''2} * \tau_{Y''2,\,Y''1}) * Er''_1 + \lambda_{Y'1} * \tau_{Y''1,\,Y'1} * Er'_1 + \lambda_{Y'2} * \tau_{Y''1,\,Y'2} * Er'_2 + \lambda_{Y''2} * \tau_{Y''1,\,Y''2} * Er''_2 + EX_{TM}$

(22) $EY''_2 = -(\lambda_{Y'1} * \tau_{Y'1,\,Y''2} + \lambda_{Y'2} * \tau_{Y'2,\,Y''2} + \lambda_{Y''1} * \tau_{Y''1,\,Y''2}) * Er''_2 + \lambda_{Y'1} * \tau_{Y''2,\,Y'1} * Er'_1 + \lambda_{Y'2} * \tau_{Y''2,\,Y'2} * Er'_2 + \lambda_{Y''1} * \tau_{Y''2,\,Y''1} * Er''_1 + EX_{TM}$

Equilibrium conditions of black tea manufacturing

(23) $\kappa_X * EX + \kappa_{Xo} * EX_o = \lambda_{Y'1} * EY'_1 + \lambda_{Y'2} * EY'_2 + \lambda_{Y''1} * EY''_1 + \lambda_{Y''2} * EY''_2$

(24) $\kappa_X * Eq + \kappa_{Xo} * Eq_o = \lambda_{Y'1} * Er'_1 + \lambda_{Y'2} * Er'_2 + \lambda_{Y''1} * Er''_1 + \lambda_{Y''2} * Er''_2$

Secondary processing of made tea for export marketing in bulk form
Other input supply to secondary processing of made tea for export marketing in bulk form

(25) $EY'_{1o} = \varepsilon_{Y'1o,\,r'1o} * (Er'_{1o} + t_{Y'1o})$

Output-constrained input demand of secondary processing of made tea for export marketing in bulk form

(26) $EY'_1 = - \kappa_{Y'1o} * \sigma_{Y'1, Y'1o} * Er'_1 + \kappa_{Y'1o} * \sigma_{Y'1, Y'1o} * Er'_{1o} + EZ'_{1M}$

(27) $EY'_{1o} = - \kappa_{Y'1} * \sigma_{Y'1, Y'1o} * Er'_{1o} + \kappa_{Y'1} * \sigma_{Y'1, Y'1o} * Er'_1 + EZ'_{1M}$

Input-constrained output supply of secondary processing of made tea for export marketing in bulk form

(28) $EZ'_1 = -\lambda \tau * Es'_1 + EY'_{1SP}$

Equilibrium condition of secondary processing of made tea for export marketing in bulk form

(29) $\kappa_{Y'1} * EY'_1 + \kappa_{Y'1o} * EY'_{1o} = \lambda_{Z'1} * EZ'_1$

(30) $\kappa_{Y'1} * Er'_1 + \kappa_{Y'1o} * Er'_{1o} = \lambda_{Z'1} * Es'_1$

Export demand for tea in bulk form

(31) $EZ'_1 = \eta_{Z'1, s'1} * (Es'_1 + n_{Z'1})$

Secondary processing of made tea for export marketing in value-added form

Other input supply to secondary processing of made tea for export marketing in value-added form

(32) $E Y'_{2o} = \varepsilon_{Y'2o, r'2o} * (Er'_{2o} + t_{Y'2o})$

Output-constrained input demand of secondary processing of made tea for export marketing in value-added form

(33) $EY'_2 = - \kappa_{Y'2o} * \sigma_{Y'2, Y'2o} * Er'_2 + \kappa_{Y'2o} * \sigma_{Y'2, Y'2o} * Er'_{2o} + EZ'_{2M}$

(34) $EY'_{2o} = - \kappa_{Y'2} * \sigma_{Y'2, Y'2o} * Er'_{2o} + \kappa_{Y'2} * \sigma_{Y'2, Y'2o} * Er'_2 + EZ'_{2M}$

Input-constrained output supply of secondary processing of made tea for export marketing in value-added form

(35) $EZ'_2 = -\lambda \tau_{Z'2, s'2} * Es'_2 + EY'_{2SP}$

Equilibrium condition of secondary processing of made tea for export marketing in value-added form

(36) $\kappa_{Y'2} * EY'_2 + \kappa_{Y'2o} * EY'_{2o} = \lambda_{Z'2} * EZ'_2$

(37) $\kappa_{Y'2} * Er'_2 + \kappa_{Y'2o} * Er'_{2o} = \lambda_{Z'2} * Es'_2$

Export demand for tea in value-added form

(38) $EZ'_2 = \eta_{Z'2, s'2} * (Es'_2 + n_{Z'2})$

Secondary processing of made tea for domestic marketing in bulk form

Other input supply to secondary processing of made tea for domestic marketing in bulk form

(39) $E Y''_{1o} = \varepsilon_{Y''1o, r''1o} * (Er''_{1o} + t_{Y''1o})$

Output-constrained input demand of secondary processing of made tea for domestic marketing in bulk form

(40) $EY''_1 = - \kappa_{Y''1o} * \sigma_{Y''1, Y''1o} * Er''_1 + \kappa_{Y''1o} * \sigma_{Y''1, Y''1o} * Er''_{1o} + EZ''_{1M}$

(41) $EY''_{1o} = - \kappa_{Y''1} * \sigma_{Y''1, Y''1o} * Er''_{1o} + \kappa_{Y''1} * \sigma_{Y''1, Y''1o} * Er''_1 + EZ''_{1M}$

Input-constrained output supply of secondary processing of made tea for domestic marketing in bulk form

(42) $EZ''_1 = -\lambda \tau * Es''_1 + EY''_{1SP}$

Equilibrium condition of secondary processing of made tea for domestic marketing in bulk form

(43) $\kappa_{Y''1} * EY''_1 + \kappa_{Y''1o} * EY''_{1o} = \lambda_{Z''1} * EZ''_1$

(44) $\kappa_{Y''1} * Er''_1 + \kappa_{Y''1o} * Er''_{1o} = \lambda_{Z''1} * Es''_1$

Domestic demand for tea in bulk form

(45) $EZ''_1 = \eta_{Z''1, s''1} * (Es''_1 + n_{Z''1})$

Secondary processing of made tea for domestic marketing in value-added form

Other input supply to secondary processing of made tea for domestic marketing in value-added form

(46) $EY''_{2o} = \varepsilon_{Y''2o, r''2o} * (Er''_{2o} + t_{Y''2o})$

Output-constrained input demand of secondary processing of made tea for domestic marketing in value-added form

(47) $EY''_2 = - \kappa_{Y''2o} * \sigma_{Y''2, Y''2o} * Er''_2 + \kappa_{Y''2o} * \sigma_{Y''2, Y''2o} * Er''_{2o} + EZ''_{2M}$

(48) $EY''_{2o} = -\kappa_{Y''2} * \sigma_{Y''2, Y''2o} * Er''_{2o} + \kappa_{Y''2} * \sigma_{Y''2, Y''2o} * Er''_2 + EZ''_{2M}$

Input-constrained output supply of secondary processing of made tea for domestic marketing in value-added form

(49) $EZ''_2 = -\lambda \tau * Es''_2 + EY''_{2SP}$

Equilibrium condition of secondary processing of made tea for domestic marketing in value-added form

(50) $\kappa_{Y''2} * EY''_2 + \kappa_{Y''2o} * EY''_{2o} = \lambda_{Z''2} * EZ''_2$

(51) $\kappa_{Y'2} * Er''_2 + \kappa_{Y''2o} * Er''_{2o} = \lambda_{Z''2} * Es''_2$

Domestic demand for tea in value-added form

(52) $EZ''_2 = \eta_{Z''2, s''2} * (Es''_2 + n_{Z''2})$

Appendix B. Economic Surplus Formulae

Factor producer surplus changes	
Private grower sector variable input suppliers	$\Delta PSw'v = p'v^{(1)} W'v^{(1)} (Ep'v - tw'v) (1+0.5EW'v)$
Private grower sector fixed input suppliers	$\Delta PSw'f = p'f^{(1)} W'f^{(1)} (Ep'f - tw'f) (1+0.5EW'f)$
Estate grower sector variable input suppliers	$\Delta PSw''v = p''v^{(1)} W''v^{(1)} (Ep''v - tw''v) (1+0.5EW''v)$
Estate grower sector fixed input suppliers	$\Delta PSw''f = p''f^{(1)} W''f^{(1)} (Ep''f - tw''f) (1+0.5EW''f)$
Black tea manufacturing other input suppliers	$\Delta PSXo = qo^{(1)} Xo^{(1)} (Eqo - txo) (1+0.5Exo)$
Secondary processing of tea for bulk tea exports other input suppliers	$\Delta PSY'1o = r'1o^{(1)} Y'1o^{(1)} (Er'1o - ty'1o) (1+0.5Ey'1o)$
Secondary processing of tea for VAT exports other input suppliers	$\Delta PSY'2o = r'2o^{(1)} Y'2o^{(1)} (Er'2o - ty'2o) (1+0.5Ey'2o)$
Secondary processing of tea for bulk tea domestic marketing other input suppliers	$\Delta PSY''1o = r''1o^{(1)} Y''1o^{(1)} (Er''1o - ty''1o) (1+0.5Ey''1o)$
Secondary processing of tea for VAT domestic marketing other input suppliers	$\Delta PSY''2o = r''2o^{(1)} Y''2o^{(1)} (Er''2o - ty''2o) (1+0.5Ey''2o)$
Consumer surplus changes	
Bulk black tea exporters	$\Delta CSz'1 = s'1^{(1)} Z'1^{(1)} (Es'1 - nz'1) (1+0.5EZ'1)$
VAT exporters	$\Delta CSz'2 = s'2^{(1)} Z'2^{(1)} (Es'2 - nz'2) (1+0.5EZ'2)$
Bulk black tea domestic consumers	$\Delta CSz''1 = s''1^{(1)} Z''1^{(1)} (Es''1 - nz''1) (1+0.5EZ''1)$
VAT domestic consumers	$\Delta CSz''2 = s''2^{(1)} Z''2^{(1)} (Es''2 - nz''2) (1+0.5EZ''2)$
Total economic surplus	
Farm sector ($t_{W'v} = -0.01$)	$\Delta TS = - p'v^{(2)} W'v^{(1)} t_{W'v} (1+0.5E W'v)$
Black tea manufacturing sector ($t_{Xo} = -0.01$)	$\Delta TS = - qo^{(2)} Xo^{(1)} t_{Xo} (1+0.5E Xo)$
Secondary processing bulk export sector ($t_{Y'1o} = -0.01$)	$\Delta TS = - r'1o^{(2)} Y'1o^{(1)} t_{Y'1o} (1+0.5E Y'1o)$
Export marketing bulk export sector ($n_{Z'1} = -0.01$)	$\Delta TS = - s'1o^{(2)} Z'1^{(1)} t_{Z'1} (1+0.5E Z'1)$

Appendix C. Percentage changes in prices by scenarios

Price variable	Scenario 1: Cost of production increase in green leaf production	Scenario 2: Cost of production increase in tea manufacturing sector	Scenario 3: Reduction in the demand for bulk black tea exports
Price of variable inputs used in green leaf production private landholding sector	0.0075	-0.0014	-0.0030
Price of fixed inputs used in green leaf production private landholding sector	-0.0035	-0.0020	-0.0042
Price of variable inputs used in green leaf production estate sector	0.0080	-0.0013	-0.0027
Price of fixed inputs used in green leaf production estate sector	-0.0036	-0.0023	-0.0049
Price of GL	0.0054	-0.0015	-0.0032
Price of other inputs used in black tea manufacturing	-0.0023	0.0086	-0.0028
Auction price of made tea for bulk black tea exports	0.0012	0.0007	-0.0108
Price of other inputs used in secondary processing of black tea exports in bulk form	-0.0023	-0.0014	-0.0028
Auction price of made tea for value-added black tea exports	0.0019	0.0011	0.0024
Price of other inputs used in secondary processing of black tea exports in value-added form	-0.0023	-0.0014	-0.0028
Auction price of made tea for domestic marketing of bulk loose tea	0.0063	0.0037	0.0077
Price of other inputs used in secondary processing of black tea for domestic marketing in loose form	-0.0023	-0.0014	-0.0028
Auction price of made tea for domestic marketing of value-added black tea	0.0166	0.0098	0.0205
Price of other inputs used in secondary processing of black tea for domestic market in value-added form	-0.0023	-0.0014	-0.0028
Price of bulk black tea to export market	0.0006	0.0003	-0.0093
Price of value-added black tea to export market	0.0005	0.0003	0.0006
Price of bulk black tea to domestic market	0.0029	0.0017	0.0035
Price of value-added black tea to domestic market	0.0057	0.0034	0.0070

Appendix D. Percentage changes in quanties by scenarios

Quantity variable	Scenario 1: Increase in cost of variable inputs in green leaf production	Scenario 2: Cost of production increase in tea manufacturing sector	Scenario 3: Reduction in the demand for bulk black tea exports
Quantity of variable inputs used in green leaf production private landholding sector respectively	-0.0024	-0.0014	-0.0029
Quantity of fixed inputs used in green leaf production private landholding sector	-0.0024	-0.0014	-0.0029
Quantity of variable inputs used in green leaf production estate sector	-0.0018	-0.0011	-0.0024
Quantity of fixed inputs used in green leaf production estate sector	-0.0018	-0.0011	-0.0024
Quantity of green leaves supplied from the green leaf production private landholding sector to the black tea manufacturing sector	-0.0025	-0.0014	-0.0030
Quantity of green leaves supplied from the green leaf production estate sector to the black tea manufacturing sector	-0.0018	-0.0012	-0.0024
Total national green leaf production	-0.0023	-0.0014	-0.0028
Quantity of other inputs used in black tea manufacturing	-0.0023	-0.0014	-0.0028
Quantity of black tea from the manufacturing sector to the bulk tea export marketing sector for secondary processing	-0.0023	-0.0014	-0.0028
Quantity of other inputs used in secondary processing of black tea for exports in bulk form	-0.0023	-0.0014	-0.0028
Quantity of black tea from the manufacturing sector to the VAT export marketing sector for secondary processing	-0.0023	-0.0014	-0.0028
Quantity of other inputs used in secondary processing of black tea for exports in value-added form	-0.0023	-0.0014	-0.0028
Quantity of black tea from the manufacturing sector to the loose bulk tea domestic marketing sector for secondary processing	-0.0023	-0.0014	-0.0028
Quantity of other inputs used in secondary processing of black tea for domestic marketing in bulk form	-0.0023	-0.0014	-0.0028
Quantity of black tea from the manufacturing sector to the VAT domestic marketing sector for secondary processing	-0.0023	-0.0014	-0.0028
Quantity of other inputs used in secondary processing of black tea for domestic market in value-added form	-0.0023	-0.0014	-0.0028
Quantity of bulk black tea from secondary processing to export market	-0.0023	-0.0014	-0.0028

Quantity of value-added black tea from secondary processing to export market	-0.0023	-0.0014	-0.0028
Quantity of bulk black tea from secondary processing to domestic market	-0.0023	-0.0014	-0.0028
Quantity of value-added black tea from secondary processing to domestic market	-0.0023	-0.0014	-0.0028

Appendix E. Surplus changes for a 1 per cent increase in variable input costs in both the private and estate tea grower sectors

			Scenario 1: Cost of production increase in green leaf production		Scenario 2: Cost of production increase in tea manufacturing sector		Scenario 3: Reduction in the demand for bulk black tea exports	
			Million Rs.	Distribution				
Producer surplus								
Green leaf production								
Private grower sector								
Producer surplus for W'v			(130.18)	18 %	(75.15)	18%	(156.07)	18 %
Producer surplus for W'f			(45.32)	6 %	(26.17)	6%	(54.34)	6 %
	Subtotal		(175.50)	24.25 %	(101.32)	23.61%	(210.41)	23.60 %
Estate grower sector								
Producer surplus for W''v			(39.3)	5 %	(25.4)	6%	(52.7)	6 %
Producer surplus for W''f			(20.5)	3%	(13.2)	3%	(27.5)	3 %
	Subtotal		(59.8)	8.26 %	(38.6)	8.99%	(80.2)	8.99 %
	Total		(235.3)	32.52 %	(139.7)	32.61%	(290.6)	32.60 %
Black tea manufacturing								
Producer surplus for Xo			(97.82)	13.52 %	(57.87)	13.50%	(120.35)	13.50 %
Secondary processing of tea for bulk tea exports								
Producer surplus for Y'1o			(37.99)	5.25 %	(22.47)	5.24%	(46.74)	5.24 %
Secondary processing of tea for VAT exports								
Producer surplus for Y'2o			(59.04)	8.16 %	(34.92)	8.15%	(72.64)	8.15 %
Secondary processing of tea for domestic consumption in loose form								
Producer surplus for Y''1o			(1.71)	0.23 %	(1.01)	(0.24) %	(2.11)	0.23 %
Secondary processing of tea for VAT consumption in domestic markets								
Producer surplus for Y''2o			(37.83)	5.23 %	(22.38)	5.22 %	(46.55)	5.22 %
Total producer surplus			(469.69)	64.92 %	(278.41)	64.97 %	(579.01)	64.96 %
Consumer surplus								
Black tea exports in bulk form								
Consumer surplus for Z'1			(50.89)	7.03 %	(30.10)	7.03 %	(62.62)	7.02 %
Black tea exports in value-added form								
Consumer surplus for Z'2			(33.70)	4.65 %	(19.93)	4.65 %	(41.46)	4.65 %
Black tea in loose form for domestic consumption								
Consumer surplus for Z''1			(5.38)	0.74 %	(3.18)	0.74 %	(6.62)	0.74 %
Black tea in value-added form for domestic consumption								
Consumer surplus for Z''2			(163.77)	22.63 %	(96.88)	22.61 %	(201.49)	22.60 %
Total consumer surplus			(253.76)	35.07 %	(150.11)	35.03 %	(312.21)	35.03 %
Total Economic Surplus			(723.45)	100%	(428.52)	100%	(891.21)	100%

Appendix F. Probability distributions of surplus changes from a 1 per cent increase in variable input costs in both the private and estate tea grower sectors (Scenario 1)

Market level	Graph	Minimum value	Mean value	Maximum value	5%	95%	Standard deviation
Farm sector							
Private grower sector		(224.41)	(175.50)	(135.49)	(200.8)	(152.4)	14.78
Estate grower sector		(78.39)	(59.80)	(44.51)	(69.04)	(50.98)	5.63
Black tea manufacturing sector		(134.41)	(97.82)	(71.99)	(117.7)	(81.1)	11.44
Secondary processing of black tea for bulk exports		(45.39)	(37.99)	(30.20)	(41.35)	(33.54)	2.35
Secondary processing of black tea for VAT exports		(82.55)	(59.04)	(41.78)	(72.39)	(47.78)	7.68
Secondary processing of black tea for domestic marketing of loose bulk tea		(2.42)	(1.71)	(1.19)	(2.12)	(1.38)	0.23
Secondary processing of black tea for domestic marketing of VAT		(54.38)	(37.83)	(26.23)	(47.04)	(30.26)	5.28

Producer sector		(527.35)	(469.69)	(402.17)	(502.0)	(432.4)	21.09
Bulk tea export sector		(75.63)	(50.89)	(34.39)	(64.84)	(40.04)	7.73
VAT export sector		(54.78)	(33.70)	(20.97)	(45.73)	(25.36)	6.44
Domestic consumption of loose bulk tea		(8.25)	(5.38)	(3.45)	(7.10)	(4.10)	0.94
Domestic consumption of VAT		(226.99)	(163.77)	(114.98)	(200.5)	(132.7)	21.06
Consumer sector		(326.99)	(253.76)	(190.27)	(293.1)	(218.5)	22.54
Tea industry		(731.70)	(723.45)	(710.93)	(728.7)	(716.6)	3.62