A computable general equilibrium model of the COVID Pandemic impact and mitigation policy assessment in the Azores tourism-based economy.

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Abstract

This paper introduces the AzorCLUSTR computable general equilibrium model, which is designed to improve the quantification of the net economic costs of the COVID-19 pandemic on the Azores economy, with a particular focus on its rapidly expanding tourism sector. The AzorCLUSTR model is an adaptation of the existing AzCLUST model introduced in Fortuna et al. (2021) which includes tourism related data of the Azores in the form of a tourism satellite account following the recommendations by the United Nations World Tourism Organization in OMT et al. (2010). We introduce a Tourism Social Accounting Matrix that addresses these issues, and adjusts the original AzCLUST model to include tourism spending variables. The AzorCLUSTR model, contrary to Fortuna et al. (2021), is a static model. The same dataset is used, allowing for adequate comparisons. The inclusion of an adjusted Social Accounting Matrix largely comes to the same conclusions as Fortuna et al. (2021), be it of a different (mainly lower) magnitude. The paper concludes with several important points of further research to advance the applicability of computable general equilibrium modelling in tourism policy impact assessments.

Keywords: tourism, computable general equilibrium analysis, (Tourism) Social Accounting Matrix, Azores.

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1. Introduction

After a slow recovery from the financial crisis of 2009, the world economy has been shaken by a number of major crises over the past few years. It started with the spreading of COVID19 becoming a global pandemic, followed by the invasion of the Ukraine by Russia leading to an energy security crisis. The COVID19 pandemic prompted many governments to impose severe travel restrictions on global travel to prevent the pandemic from spreading rapidly in their regions and causing severe disruption to local economies. The costs to the local economies were significant, in particular to small economies that were dependent on tourism, like the Azores islands.

Fortuna et al. (2021) analyse the economic consequences of a reduction in spending on local tourism activities in the Azores following the COVID19 pandemic, with a regional computable general equilibrium model, the AzCLUST model. Allan et al. (2022) provide a similar analysis for the Scottish economy, applying a computable general equilibrium model based on the AMOS framework. Both studies externally limit consumption expenditure on tourism.

This paper depicts first research queries into the application of a regional computable general equilibrium model to analyse the impact of tourism policies on the Azores economy. We introduce the AzorCLUSTR model as an improvement of an existing model, the AzCLUST model, see Fortuna et al. (2021). The model introduces an explicit modelling of the tourism sector in the Azores in order to be able to calibrate it to the available data.

Detailed data on tourism spending can be found in so-called Tourism Satellite Accounts at the Portuguese Statistical Office. Fortuna et al. (2021) calibrate the original AzCLUST model on a Social Accounting Matrix (SAM) that has been developed in ECOMOD (2022) which includes such a Tourism Satellite Account.

The AzCLUST model, as described in Fortuna et al. (2021) is not satisfactory in the sense that it omits an explicit modeling of tourism, e.g. it lacks the inclusion of tourism specific spending in the form of inbound, outbound, and domestic tourism spending (see OMT et al. (2010)), or the modelling of the tourism sectors as a cluster (see Porter (1998)). Furthermore, following input-output modelling practice, the policy measure is just translated into a number of separate shocks on parameters. The latter omits the addition of a theory in CGE modelling assuming an explicit adjustment process towards a new (counterfactual) equilibrium in the economy following the policy shock. Consequentially, certain impacts might have been double counted.

The AzorCLUSTR regional computable general equilibrium model attempts to improve upon existing CGE modelling by calibrating the model on a Social Accounting Matrix that not only includes the same Tourism Satellite Account as in Fortuna et al. (2021), but it also attempts to address the data standards described in OMT et al. (2010), among others. To this end, in Section 2 we have extended the Social Accounting Matrix of Fortuna et al. (2021) with concepts like ’inbound’, ’outbound’, and ’domestic’ tourism expenditure to obtain what we refer to as a ’Tourism Social Accounting Matrix’ (TSAM). Section 3 provides an extensive description of the AzorCLUSTR model adaptation towards including the necessary model variables referring to these concepts.

An important concept in the acceptance of scientific results is the idea of reproducibility of results. Reproducing modelling results is also an important way in learning to use and apply a model. We therefore try to reproduce the results and subsequent analysis of Fortuna et al. (2021) in Section 4.

Section 5 presents a series of recommendations for further research that will enhance the AzorCLUSTR model by incorporating tourism spending. These adjustments include a better modelling of the tourism sector as a cluster, see Porter (1998). It also addresses the different approaches to final demand in an input-output model and a computable general equilibrium model. The latter model contains an explicit modelling of demand as function of prices, contrary to input-output models where demand is a given parameter that can be shocked explicitly. Solving this problem requires the interpretation as a mixed complementarity problem where demand can be rationed.

2. Data: The Social Accounting Matrix

The AzCLUST model is a single region, computable general equilibrium model that is specifically developed to analyse the impact of economic policies on the tourist cluster in the Azores. We refer to Fortuna et al. (2021) for further details on the model. The model is calibrated on a System of National Accounts, in the form of a Social Accounting Matrix (SAM), combined with a Tourist Satellite Account (TSA).

The SAM in Table 1 contains rows and columns associated with the production activities that represent the supply side of the economy, and consumption activities, the trade balances with other foreign regions, that represent the demand side of the economy. Supply and demand for each good, i.e. for each commodity and each production factor, meet on respectively the commodity markets and the factor markets where the price of the good clears its market, i.e. at this equilibrium market price demand for the good is met by its total supply.

Foreign trade partners are modelled in the form of a trade account or Balance of Payment (i.e. a capital account and a current account for each of these regions, represented by the budget of a microeconomic consumer household). The choice for these external regions in the AzCLUST model is likely more to be determined by them being the main trade partners of the Azores, or, in the case of ’Mainland Portugal’ as its ’home country’ where the government is located.

Each matrix element or cell in the SAM of Table 1 contains a value flow that refers to a cost in case the matrix element refers to the supply side, or an expenditure in case the matrix element refers to the demand side. Money flows from the columns to the rows of the SAM, while quantities flow in the opposite direction.

The goods in the economy can be distinguished in commodities, production factors such as labour and capital, and possibly more abstract goods, like tourism. Let us define commodities as the goods that are produced by a (possibly abstract) production sector or activity possessing the appropriate technology to transform the other goods into a particular commodity as its unique output good. If we would like to include a good ’tourism’, then we have to add an abstract good ’tourism’. It is an abstract good that can be seen as the output good of an abstract production activity. A possible interpretation of this abstract production activity is that it represents the tourism cluster of tourism related production sectors, e.g. hotels, restaurants, or the airline industry, in the Azores economy. The model’s commodities are chosen such that they allow for

	Production Activities		Commodity Markets		Factor Markets		Consumption			Trade Balance		Tourism Expenditure			Other Expenditure		
	Non-Tourism Activities	Tourism Activities	Non-Tourism Markets	Tourism Markets	Capital Market	Labour Market	Private Expenditure	Public Expenditure	Corporate Expenditure	Current Account	Capital Account	Domestic Tourism	Inbound Tourism	Outbound Tourism	Taxes	Inventory	Total
Non-Tourism Activities			Output												Production Subsidies		Production Revenue
Tourism Activities																	
Non-Tourism Markets	Intermediate Inputs		Margins				Private Consumption	Public Consumption		Exports	Investments	Margins			Export Subsidies	Inventory Additions	Demand Revenue
Tourism Markets												Private Consumption	Exports				
Capital Market	Factor Inputs																Factor Revenue
Labour Market																	
Private Expenditure					Factor Income		Transfers										Private Income
Public Expenditure															Tax Income		Public Income
Corporate Expenditure					Gross Capital Formation (GCF)												Corporate Income
Current Account			Commodity Imports		Factor Imports						Current Account Surplus						Import Income
Capital Account			Foreign Investments			Depreciation	Private Savings	Public Savings	Corporate Savings	Current Account Deficit							Savings Income
Domestic Tourism							Domestic Tourism								Tourism Taxes		Tourism Income
Inbound Tourism										Inbound Tourism							
Outbound Tourism				Outbound Tourism							Tourism Account Surplus						
Taxes	Production Taxes		Commodity Import Taxes				Income Taxes					Tourism Taxes					Tax Income
Inventory			Inventory Depletion														Inventory Income
Total	Production Cost		Supply Cost		Factor Cost		Private Expenditure	Public Expenditure	Corporate Expenditure	Export Expenditure	Investment Expenditure	Tourism Expenditure			Tax Expenditure	Inventory Expenditure	

Table 1: The Social Accounting Matrix of the data underlying the calibration of the AzCLUST model.

a proper impact assessment of tourism activities on the economy and environment of the Azores. The AzCLUST model refers to a so-called Tourism Satellite Account for its aggregation of commodities.

Table 2 consists of 18 commodities and 2 production factors, capital and labour. The commodities can be distinguished into 9 aggregate commodities that are related to touristic activities, and 9 other aggregate commodities. The 9 tourism related aggregate commodities constitute the tourism cluster in the AzCLUST model. The commodity aggregations are obtained from the Tourist Satellite Accounts at INE (2017) in the aggregation levels in Table 2.

Aggregation level of production sectors			Sectors at the disaggregated level	Associated sectors in AzorCLUSTR
A. Specific products				
	1. Characteristic products			
		1. Accommodation services		
			1. Hotels and Similar	hotels
			2. Other	
			3. Second Homes — On Own Account or Free	_secondary_residence
		2. Restaurants and Similar		
		3. Passenger Transport		
			1. Interurban Railway Transport	
			2. Long Distance Road Transport	transport_road
			3. Water Transport	transport_water
			4. Air Transport	transport_air
			5. Transport Supporting Services	
			6. Transport Equipment Rental Services	trans_rental
			7. Maintenance and Repair of Transportation Equipment	
		4. Travel Agencies and other Reservation Services		travel_agencies
		5. Cultural Services		leisure
		6. Recreation and other Entertainment Services		leisure
		7. Other Tourism Services		leisure
	2. Connected Products			
		Goods		
		Services		
B. Non-Specific products				
			1. Agriculture, Forestry, and Fishing	agriculture
			2. Extractive Industry	mining_construction
			3. Manufacturing Industry	manufacturing
			4. Electricity, Gas, and Water	electricity_water
			5. Construction	construction
			6. Wholesale and Retail Trade, Restaurants and Hotels	trade, hotels_restaurants
			7. Transport and Communications	transport
			8. Business Activities	other_services
			9. Other Service Activities	government

TABLE 2: Territory', Sheet 'Class Produtos' ('Classification of products').
Source: INE (2017). URL: https://www.ine.pt.

The SAM indicates that the production factors capital and labour are supplied to their respective markets by the private consumption households. It also follows from the data in this SAM that these factors are not internationally traded, hence the capital and labour markets are regional markets[4].

According to the SAM in Table 1, the demand side of the economy consists of 6 private consumption households representing *private expenditure*, one public or government household representing *public expenditure*, a corporate household representing *corporate expenditure*, 4 consumer households that each represent a *current account* with a foreign (trade) region and one *capital account* for the Azores which

[4] Although the Azores are an isolated group of islands in the Atlantic, they are part of Portugal and of the EU. This would imply that at least the labour market is not regional but part of the Portuguese labour market or even the EU labour market which, given the goals of the EU to enhance labour mobility in the EU, should be adjusted.

together constitute the *foreign trade account* of the Azores, an *inventory account*, and 6 *tax/subsidy accounts* that constitute the public or government income/expenditure.

Table 6 subdivides the private households in the SAM of Table 1 into 6 income classes. Each income class obtains income from selling their production factor endowments[5] at current factor market prices. This income is spent on the (private) consumption of each commodity. We also distinguish one public or government sector that obtains its income from taxation, and transfers to the government, and spends it on public consumption commodities, transfers to other households, and providing subsidies to the Azores economy. These transfers include transfers from Mainland Portugal and from the EU which are vital to the sustainability of an economy on the isolated Azores' economy. Fortuna et al. (2021) introduces a 'corporate household'. Although this household does not exhibit consumptive spending, it represents the investment of corporate savings in the supply of new capital goods to the economy. The disposable income of the corporate household consists of its share of capital income and of the (possibly negative) transfers received from other agents. Income (after transfers) is completely saved. These savings are then completely invested into the supply of newly obtained capital goods to the production activities on the underlying capital market, referred to as *gross fixed capital formation* (GFCF).

The System of National Accounts classifies consumers and producers according to (relatively) permanent characteristics, one of them being their country of residence. The AzorCLUSTR SAM refers to single region model, and therefore only looks at the region under consideration, in this case, the Azores. Any foreign region is represented by a microeconomic consumer household with a budget that refers to its 'Balance of Payments' with the domestic economy. Contrary to multi-regional SAMs, this does not concern the whole foreign economy, but only its specific trade relations with the domestic economy. The AzorCLUSTR data refer to 'Mainland Portugal', 'The Rest of the EU', and the 'USA' as foreign regions, though the SAM in Table 1 aggregates them all into one foreign region denotes 'Rest of the World'.

The tax income of the public sector consist of the following taxes or subsidies.

- the *production factor taxes*, levied on the input of capital and labour in each production activity.
- the *production (output) taxes*, levied on the output of each production activity. When negative, the model speaks of production subsidies.
- the *income taxes*, levied on the private income of each income class in Table 6.
- the *commodity taxes*, levied on the domestic and foreign demand for each commodity. Notice that this includes also the demand for the margin goods.
- the *trade taxes*, consisting of *import taxes*, levied on the consumption of each commodity imported from a foreign region, and *export taxes*, levied on the export of each domestically produced commodity to a foreign region.

The capital account refers to the balance between domestic savings and investments at home as well as abroad. Investment demand includes both gross fixed capital formation and changes in the value of inventories. As imposed by the System of National Accounts, total investment expenditure is equal to total savings and GFCF expenditure. In the literature, this is known as a 'closure rule', in particular the

[5] Unfortunately, Fortuna et al. (2021) does not specify this allocation of the economy's capital and labour endowments over the 6 income classes, making a more detailed analysis of labour market effects impossible.

neoclassical closure rule. The value of inventory changes, as well as changes in the value of total investments by the production activities are modelled as a share of the sales of each commodity.

Fortuna et al. (2021) refer to the subset of nine production activities that have an output good (partly) used for touristic purposes as a cluster. A *cluster* is a geographic concentration of interconnected companies, specialised suppliers, service providers, firms in related industries, and associated institutions (e.g., universities, standards agencies, trade associations) in a particular field that compete but also cooperate. This definition of a cluster has been obtained from Porter (1998).

According to OMT et al. (2010), tourism can be seen as a demand-side phenomenon or a supply-side phenomenon. As a *demand-side phenomenon*, tourism refers to the activities of visitors and their role in the acquisition of goods and services. As a *supply-side phenomenon*, it is understood as the set of productive activities that cater mainly to visitors. A *visitor* is a traveller taking a trip to a main destination outside his or her usual environment for less than a year and for any main purpose other than to be employed by a resident entity in the country or place visited, see United Nations and World Trade Organization (2008), paragraph 2.9. OMT et al. (2010) refer to business, leisure or other personal activities as a main purpose of visiting[6].

The tourist cluster in the AzorCLUSTR SAM not only caters its services to the (touristic) visitors, but also to other sectors. The output or supply of the production activity ”Hotels and similar lodgings” are hence supplied to more than one market, for example to a (newly introduced tourism market) as well as to the other markets, e.g. for business visitors. This indicates that the production activities in the AzorCLUSTR tourism set have joint production characteristics[7]. The current version of the AzorCLUSTR model applies the usual assumption in CGE models, thereby assuming that the tourism cluster only supplies a unique single output good to one market[8].

According to OMT et al. (2010), what makes tourism special is the temporary situation in which an individual in the capacity of consumer finds him- or herself. He or she is taking a visit to a place outside his or her environment for less than a year and for a purpose other than being employed by a resident entity[9]. take the trip. This implies a distinction into three types of tourism,

- *Domestic tourism* comprises the domestic activities of a resident visitor within the country of reference;
- *Inbound tourism* comprises the inbound activities of a non-resident visitor within the country of reference;
- *Outbound tourism* comprises the outbound activities of a resident visitor outside the country of reference.

Within the context of a System of National Accounts, we should actually be talking about the expenditure of domestic and foreign consumers on tourism activities in the region of reference, the Azores in case of the AzorCLUSTR model. Table 3 presents the Tourism Social Accounting Matrix (TSAM) upon which we calibrate the AzorCLUSTR computable general equilibrium model. The TSAM includes several consumptive

[6] I would not like to consider visiting for business purposes as a touristic activity. As the name already indicates, it is a business activity, which I would think more work related, thus not tourism.

[7] Instead of the usually assumed unique single output assumption made in CGE models.

[8] Assuming joint production would require a split of the output of the tourism production activities into at least two parts, one tourism related output and the other part as non-tourism related output. The confusing division of the set of production activities into tourism and non-tourism related production activities prevents this. See for example the presence of a hotel sector as part of a tourism related production activity and part of a non-tourism related production activity. Similarly, for transport.

[9] This means that we have to carefully consider the period under investigation in the AzorCLUSTR model, such that it takes account of population growth due to tourism. This might be a year, or even less.

	Supply Side		Good Markets						Demand Side							
	Non-Tourism related Activities	Tourism related Activities	Non-Tourism related Markets	Tourism related Markets	Private Tourism Markets	Foreign Tourism Markets	Capital Markets	Labour Markets	Private Households	Public Households	Corporate Households	Current Account	Capital Account	Inventory	Taxes	**Total**
Non-Tourism related Activities	0	0	Domestic Sales		0	0	0	0	0	0	0	Export Sales	0	0	Production Subsidies	Gross Sales Revenue
Tourism related Activities	0	0	0	0	Domestic Sales	Export Sales	0	0	0	0	0	0	0	0		
Non-Tourism related Markets	Intermediate Inputs		Margins		0	0	0	0	Private Consumption	Public Consumption	Corporate Consumption	0	$\left(\text{Domestic} - \text{Foreign}\right)^{+}$ Investments	Inventory $\left(\text{Additions} - \text{Depletions}\right)^{+}$	Export Subsidies	Commodity Demand
Tourism related Markets					Private Consumption	0	0	0	0			0				
Private Tourism Markets	0	0	0	0	0	0	0	0	Domestic Tourism	0	0	0	0	0	0	Tourism Demand
Foreign Tourism Markets	0	0	0	Commodity Imports	0	0	0	0	0	0	0	Inbound Tourism	0	0	0	
Capital Markets	Factor Inputs		0	0	0	0	0	0	0	0	0	Factor $\left(\text{Exports} - \text{Imports}\right)^{+}$	0	0	Factor Subsidies	Factor Demand
Labour Markets			0	0	0	0	0	0	0	0	0		0	0		
Private Households	0	0	0	0	0	0	Production Factors		Transfers				0	0	0	Private Income
Public Households	0	0	0	0	0	0	0	0					0	0	Tax Income	Public Income
Corporate Households	0	0	0	0	0	0	Gross Capital Formation	0					0	0	0	Corporate Income
Current Account	0	0	Commodity Imports	0	0	Outbound Tourism	Factor $\left(\text{Imports} - \text{Exports}\right)^{+}$						$\left(\text{Current Account Surplus}\right)^{+}$	0	0	Imports Income
Capital Account	0	0	$\left(\text{Foreign} - \text{Domestic}\right)^{+}$		0	0	Depreciation	0	Savings			$\left(\text{Current Account Deficit}\right)^{+}$	0	0	0	Savings Income
Inventory	0	0	Investments Inventory $\left(\text{Depletions} - \text{Additions}\right)^{+}$		0	0	0	0	0	0	0	0	0	0	0	Total Inventory Income
Taxes	Production Taxes		Commodity and Import Taxes		Tourism Taxes		0	0	Income Taxes		0	0	0	0	0	Tax Income
Total	Production Cost		Commodity Supply		Tourism Supply		Factor Supply		Private Expenditure	Public Expenditure	Corporate Expenditure	Exports Expenditure	Investment Expenditure	Total Inventory Expenditure	Tax Expenditure	

TABLE 3: The Tourism Social Accounting Matrix (TSAM) of the data underlying the calibration of the AzorCLUSTR model. Notice that the vector x^{+} contains elements $x_k^{+} = x_k$ if $x_k \geq 0$ and $x_k = 0$ otherwise. Then $x = x^{+} + (-x)^{+}$.

expenditure accounts related to domestic, inbound, and outbound spending. These accounts resemble a budget like equations where total income is determined by the spending of the underlying consumers, being total domestic private expenditures, export expenditure, or import expenditure respectively on the output goods of the nine tourism related production activities.

3. Model: The AzorCLUSTR computable general equilibrium model.

The AzorCLUSTR model is a static, single-region, regional computable general equilibrium model. A general equilibrium model is a theoretical economic model formulated in Arrow and Debreu (1954) and Debreu (1959), as a proof that there exists an economy that satisfies the two theorems of welfare, see any microeconomic textbook such as Varian (1992)[10]. The theoretical Arrow, Debreu (and MacKenzie) general equilibrium model can be seen as the theoretical proof underlying the efficiency of the (competitive) market equilibrium allocation under well-known assumptions. Contrary to a partial equilibrium model, a general equilibrium model considers the equilibrium on more than one market. An important feature of the model is that it allows for the substitution among various goods to obtain the highest possible level of welfare. The model thereby takes the inclusion of direct (on the market) and indirect (via other markets) effects into consideration.

The computable general equilibrium model as applied in many policy impact studies is a special case of a general equilibrium model known as a pure exchange economy with nonlinear constant returns to scale production technologies. Van der Laan and Kremers (1993) prove the existence and uniqueness of an equilibrium in this model. The computable general equilibrium model also assumes homothetic preferences. Like every computable general equilibrium model, the AzorCLUSTR model can be seen as a static, regional version of this model calibrated on a Social Accounting Matrix, specific to the Azores, here the Tourism SAM introduced in Section 2, Table 3.

Each commodity j depicted in the Tourism Satellite Account of Table 2 is produced by a unique production sector $a \in \mathscr{A}$ at an output price p_a^{O}, i.e. we abstain from the possibility of joint production. If $a2j(a)$ denotes the set of output commodities of sector $a \in \mathscr{A}$, then the abstinence of joint production implies that $a2j(a) = \{j\}$. The output good $a2j(a)$ is supplied to a competitive, domestic commodity market $j \in \mathscr{M}$ cleared by the market price p_j^{D} and exported at a world market price $e_r.p_j^{\mathsf{W}}$ in the domestic currency using the exchange rate e_r, for $j \in a2j(a)$. Let p_j^{D} denote the domestic market price vector of commodities, p_j^{W} denote the world market price vector, and p_j^{O} the output market price vector of each production sector.

Production Factor	$f \in \mathscr{F}$	**Description**
Capital	kap	capital good
Labour	lab	labour good

TABLE 4: The production factors $f \in \mathscr{F}$.

[10] According to Varian (1992), the *First Theorem of Welfare* states that every equilibrium in this economy is efficient. The *Second Theorem of Welfare* states that every efficient equilibrium can be obtained through an appropriate reallocation of resources. Notice that economists talk about an allocation of goods being efficient with respect to welfare. An allocation is called (Pareto) *efficient* when there does not exist another allocation where at least one agent is better off and all other agents are not worse off.

Each production factor f is traded on a competitive, local factor market $f \in \mathcal{F}$ cleared by the factor price p^{F}_f. p^{F} denotes the market price vector of the production factors. Table 4 provides an overview of the production factors used in the model. Production factors are not traded internationally.

3.1. The Supply Side

The *supply side* of the economy consists of all goods and production activities or production sectors included in the set $\mathcal{A}$. The goods consist of commodities that are the output good of a unique production activity in $\mathcal{A}$, and the production factors labour and capital, collected in the set $\mathcal{F}$. The produced goods are all traded goods of a type 'Armington', i.e. a composite of domestic and imported variants. Each production activity is represented by a (microeconomic) production household that is characterised with a (*constant returns to scale*) production technology that defines a production possibilities set from which the production household chooses a *profit maximising* production or input-output bundle, given the prices on the good markets.

3.1.1. The Armington good

The definition of a good in input-output modelling does not coincide with the definition in general equilibrium theory as stated in Debreu (1959). The latter defines a good as dependent on place, time, and its characteristics. Contrary to input-output modelling, goods produced in different regions are hence considered as different goods. Consequentially, the definition of a good applied in input-output modelling causes the trade of commodities between regions to result in a specialisation of each region in producing the commodity where it has a comparative advantage. The AzorCLUSTR model therefore follows Armington (1969) in preventing commodities from different trading regions to become perfect substitutes by assuming a non-elasticity of substitution between the domestically produced commodity, whose corresponding price and

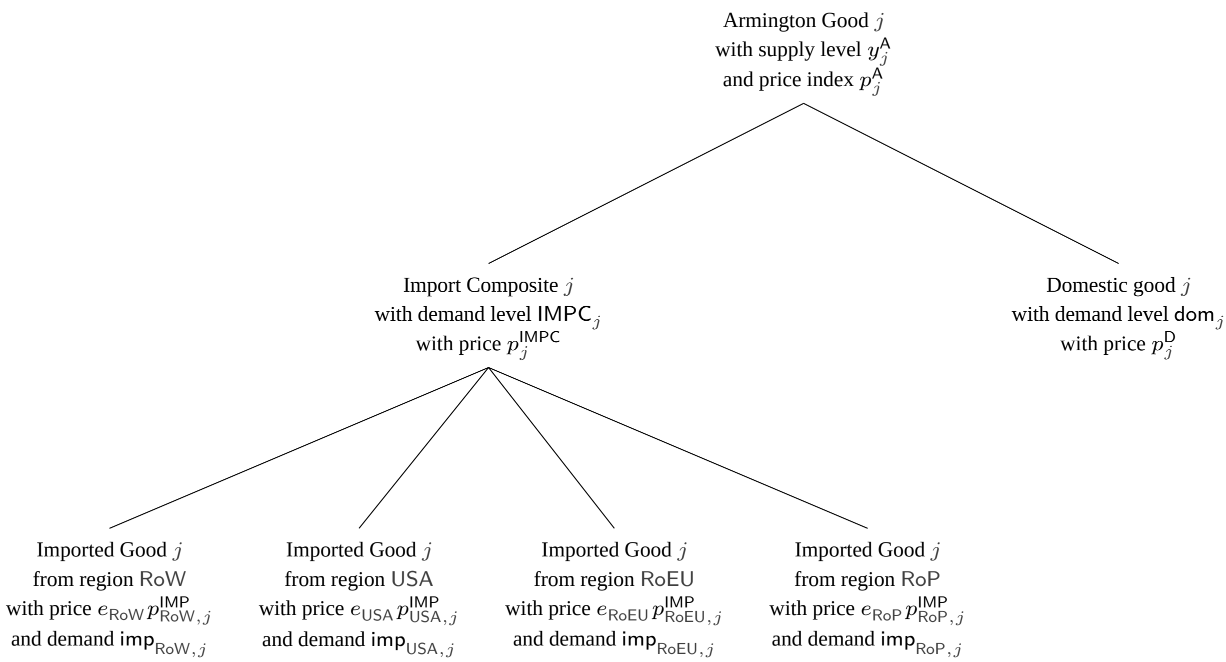

FIGURE 1: Graphical depiction of the composition of the Armington good j with a price p^{A}_j and quantity y^{A}_j from the domestic good j with price p^{D}_j and quantity dom_j produced by production activity $a \in a2j^{-1}(j)$, and the imported composite IMPC_j with price p^{IMPC}_j and quantity IMPC_j, using a CES function with elasticity of substitution σ^{A}_j. IMPC_j is a composite of the good j imported from the foreign trade regions $r \in \mathcal{R}$ with $\mathcal{R} = \{\mathsf{RoP}, \mathsf{RoEU}, \mathsf{USA}, \mathsf{RoW}\}$ at import prices $e_r\, p^{\mathsf{IMP}}_{r,j}$ and quantities $\mathsf{imp}_{r,j}$ using a CES function with elasticity of substitution $\sigma^{\mathsf{IMPC}}_{r,j}$.

quantity variables are indexed with DOM, and commodities, whose corresponding price and quantity variables are indexed with IMP, imported from the foreign regions $r \in \mathscr{R}$. This assumption is known as the '*Armington Assumption*', and it results into the construction of an '*Armington good*', whose price and quantity variables are super indexed with A, see Figure 1.

The AzorCLUSTR model distinguishes imports from the regions which have important trade relationships with the Azores[11]. Since the Azores are an autonomous region of islands within Portugal, 'Mainland Portugal' or the 'Rest of Portugal' (RoP) is its most important trading partner, directly followed by the 'Rest of the EU' (RoEU), Portugal being a member state of the EU. This leaves us with adding the USA (USA) and the 'Rest of the World' (RoW). Table 5 provides us with an overview of the trading partners, or the regional aggregation[12].

$r \in \mathscr{R}$	**Region**
RoP	Mainland Portugal
RoEU	Rest of the EU
USA	United States of America
RoW	Rest of the Workd

TABLE 5: Balance of Payments: Current Account with foreign regions $r \in \mathscr{R}$.

3.1.2. The production activities

Each commodity is the unique output good of a production sector $a \in \mathscr{A}$. This production sector is represented by a microeconomic producer household who transforms a bundle of (intermediate) input commodities and factor inputs into its output commodity using a production technology that exhibits constant returns to scale in production. The set of all feasible production possibility vectors constitutes a production possibilities set from which the producer chooses a bundle of commodities and factors that maximises profits, taking all prices as given. Notice that, under the assumption of constant returns to scale production, profit maximisation is equivalent to minimising the costs per unit of output, at given market prices. The production possibilities set is defined by a nested constant elasticity of substitution production function, where Figure 2 depicts this functional form as a nested production structure or tree.

Production theory assumes that only the production factors add value in the production of a good. Figure 2 aggregates all these factor inputs into an abstract good named 'Value-Added' (va). Similarly, we have aggregated the intermediate inputs into a good named 'Intermediate Composite' (ic).

The production sector $a \in \mathscr{A}$ produces commodity j for domestic use and exports to each foreign region $r \in \mathscr{R}$, using a nested constant elasticity of transformation functional form depicted in Figure 3[13].

[11] AzorCLUSTR, as well as the original AzCLUST model, is a model that does not concentrate on trade flows, but on tourism flows. The question is hence whether the model should look at the main foreign regions that provides tourism to the Azores.

[12] Notice that the SAM used to calibrate the AzCLUST model only refer to an aggregate 'Rest of the World' foreign region. We used available data to disaggregate this composite 'Rest of the World' region into the foreign regions of $\mathscr{R}$ in Table 5.

[13] This construction allows for the inclusion of joint production by introducing a first nest where a composite of domestic output goods is produced and a composite of export composites. In the second layer, the domestic output composite is decomposed into the output of each commodity $j \in a2j(a)$, and the exported output composite into a regionally specific output composite of commodity $j \in a2j(a)$. The latter export composite of commodity $j \in a2j(a)$ is decomposed into the exports to region $r \in \mathscr{R}$.

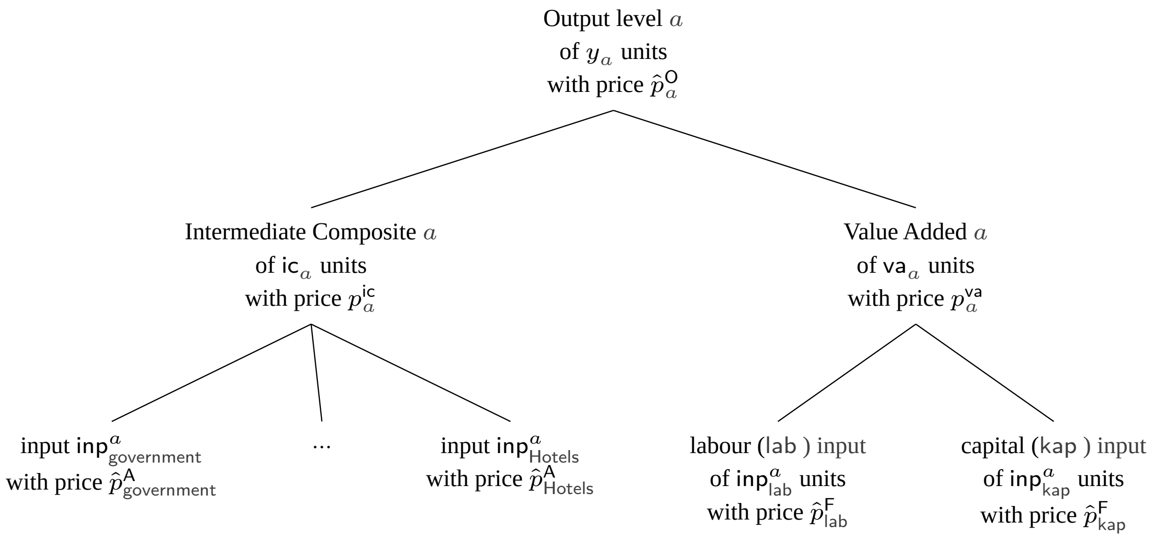

FIGURE 2: The nested constant elasticity of substitution production function of each production activity $a \in \mathscr{A}$ with (activity) output levels y_a at price (including taxes) $\hat{p}^{\mathsf{O}}_a$, a value added composite va_a with price p^{va}_a, and an intermediate composite ic_a with price p^{ic}_a. Disaggregation of these composites along the tree follows a constant elasticity of substitution function with substitution elasticity σ^P_a in the top nest, and $\sigma^P_{a,\mathsf{va}}$ respectively $\sigma^P_{a,\mathsf{ic}}$ in the second or bottom nests. Cost minimisation per unit of output, results in factor input demand functions $\mathsf{inp}(\hat{p}^{\mathsf{F}}_{\mathsf{lab}}, \hat{p}^{\mathsf{F}}_{\mathsf{kap}})$, and intermediate input demand functions $\mathsf{inp}(\hat{p}^{\mathsf{A}}_{\mathsf{hotels}}, \ldots, \hat{p}^{\mathsf{A}}_{\mathsf{government}})$.

Since we abstain from joint production[14], the output composite of each production sector $a \in \mathscr{A}$ is decomposed into the domestic output of commodity $j \in a2j(a)$ and the exported output of commodity $j \in a2j(a)$ to each region $r \in \mathscr{R}$. This construction is in line with the aforementioned Armington Assumption in the sense that the output commodity $j \in a2j(a)$ differs according to whether it is produced for domestic use or for export purposes.

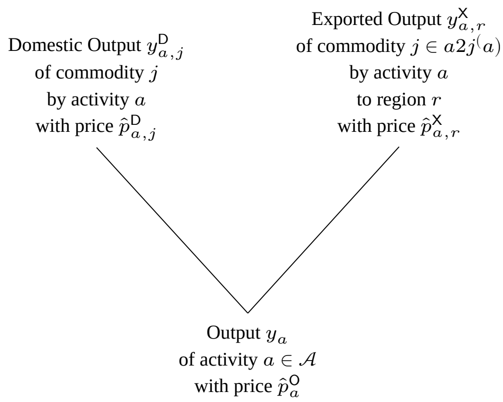

FIGURE 3: Graphical depiction of the decomposition of output y_a of production sector $a \in \mathscr{A}$, with a price $\hat{p}^{\mathsf{O}}_a$ that includes production taxes, into y^{D}_a units at domestic price $\hat{p}^{\mathsf{D}}_a$ and $y^{\mathsf{X}}_{a,r}$ units at composite export price $\hat{p}^{\mathsf{X}}_{a,r}$ using a constant elasticity of transformation function with elasticity of transformation σ^{T}_a.

[14] The original idea behind joint production would be that the tourism related production sectors' output is partly partly meant to cover the tourism demand and partly non tourism demand. The non-tourism related production sectors' output only covers non tourism demand. Notice that in the SAM of Table 1, certain non-tourism activities such as transport or hotels, could be part of the tourism related production sectors, e.g. 'hotels and restaurants'. In order to model this as joint production, for example the 'hotels' production activity should be re-aggregated to 'hotels and restaurants' and its data should refer to non-tourism activities.

The exports of the tourism related goods refer to the consumptive expenditure of foreign tourists in the Azores, hence to inbound tourism (expenditure) on this good, following the discussion in Section 2. Usually, each of these goods are also demanded for non-touristic purposes. The SAM in Table 1 used to calibrate the model however does not accurately provide data on a possible split-up of these exports according to tourism and non-tourism demand.

3.2. The Demand Side Activities

The *demand side* of the economy distinguishes among private, public, and corporate (consumptive) expenditure. These households are modelled by a microeconomic consumption household whose decisions have an *income side* and an *expenditure side*. The household's *income* defines a budget which the household spends on a consumption and savings bundle that maximise welfare or utility, at given prices in the economy. Following microeconomic theory, see Varian (1992), the behaviour of each consumer can be described as utility maximisation under a budget constraint, or expenditure minimisation to obtain a minimal level of welfare or utility. Notice that, under the assumption of a *homothetic* utility function, the expenditure minimisation problem becomes the minimisation of expenditure to obtain one unit of utility (cp. the cost minimisation problem for the producer household). Figure 4 decomposes the (private, public, or corporate)

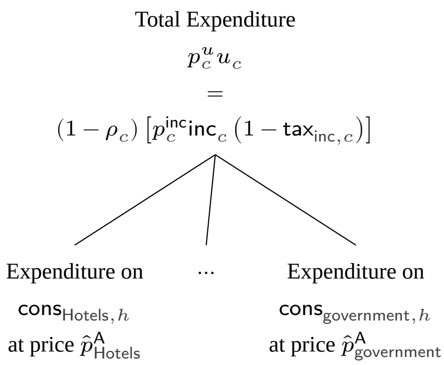

FIGURE 4: Graphical depiction of the decomposition of total consumptive expenditure $p_c^u u_c$ into a consumptive expenditure on $\mathsf{cons}_{j,c}$ units of good $j \in \mathscr{M}$ at market price $\hat{p}_j^{\mathsf{A}}$, using a CD functional form.

expenditure into consumptive expenditure for each good along a nested constant elasticity of substitution function represented by its tree structure. The demand side of the economy also consists of several other accounts that can be characterised with the availability of a budget. A *trade account* that depicts the trade relationships of the Azores with foreign regions. An *inventory account* which depicts stock value additions and depletions in the Azores economy. And several *tax accounts* that depict the income from taxation or expenditure on subsidisation in the Azores economy.

3.2.1. Private Expenditure

Table 6 provides our private households according to the income class they adhere to[15]. The table refers to annual income levels. We distinguish 6 income classes.

The private household is assumed to be in possession of the economy's resources, here labour and capital, which it completely supplies to the market and thus obtains an income, at given market prices.

[15] This distinction in income classes is often made to consider the impact of policies on the lower income classes. In Fortuna et al. (2012), this distinction in income classes could have been used to consider the different impacts of COVID related policies on these income classes. Unfortunately, Fortuna et al. (2021) did not take this distinction into consideration.

$h \in \mathscr{H}$	**Income class**
HQ_1	income until 5.200 Euro
HQ_2	income between 5.200 and 10.400 Euro
HQ_3	income between 10.400 and 15.600 Euro
HQ_4	income between 15.600 and 20.800 Euro
HQ_5	income between 20.800 and 31.200 Euro
HQ_6	income over 31.200 Euro

TABLE 6: (Annual) Income classes defining private households $h \in \mathscr{H}$.

Furthermore, transfers from the other consumptive agents are added to the consumer's income, while transfers to the other agents are subtracted from its income. The income of each private household can hence be distinguished into a *factor income* and a *transfer income*. See Figure 5, which allows for a possible substitution among income sources. The usual income definition is obtained by assuming a Leontief functional form in each nest.

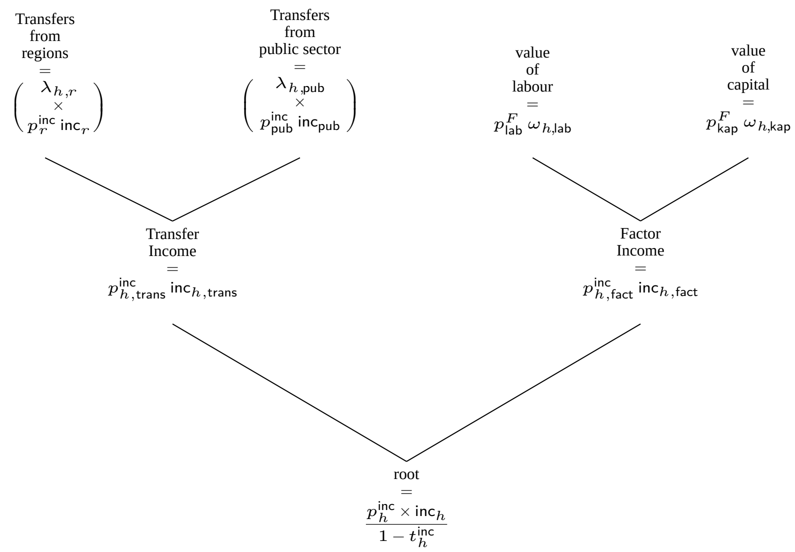

FIGURE 5: Graphical depiction of the decomposition of private income $(p_h^{\mathsf{inc}}\mathsf{inc}_h)/(1 - t_h^{\mathsf{inc}})$ into factor income obtained from selling endowments in production factors $\sum_f p_f^F \omega_{h,f}$ and net transfer income obtained from transfers to and from other consumers or to and from other regions $\sum_c \lambda_{h,c}\mathsf{inc}_h$. We currently assume Leontief cost structures in all nests.

3.2.2. The modelling of consumptive expenditure on domestic tourism.

Tourism demand refers to the expenditure on tourism-related goods by the private households. This implies a split up of total private expenditure on the consumption of goods into the expenditure on tourism-related commodities, and the expenditure on non-tourism-related commodities. The disaggregation of private consumptive expenditure in Figure 4 should therefore be adjusted along these lines, see Figure 6.

Figure 6 considers a distinction between tourism-related private expenditure and non-tourism related private expenditure. Combining the discussion in Section 2 with the consumption of an Armington good in Figure 6, the tourism related private expenditure in Figure 6 can be distinguished according to OMT et al. (2010) into domestic tourism (expenditure) and outbound tourism (expenditure). It is the distinction between tourism and non-tourism related private expenditure made in Figure 6 that brought us to the inclusion of domestic and outbound tourism (expenditure) into the Tourism Social Accounting Matrix TSAM in Table 3.

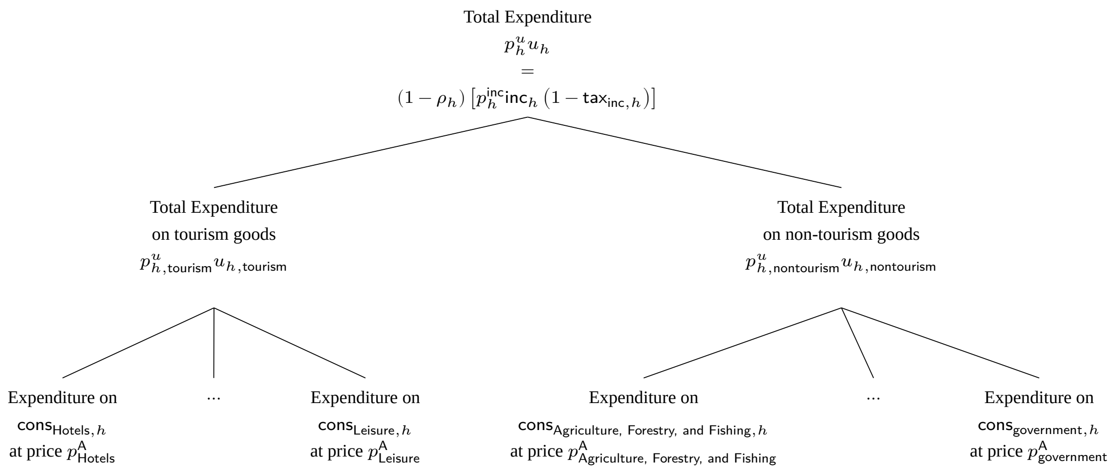

FIGURE 6: Graphical depiction of the decomposition of total private consumptive expenditure $p_h^u u_h$ into the expenditure $p^u_{h,\mathsf{tourism}} u_{h,\mathsf{tourism}}$ on tourism, and non-tourism, expenditure $p^u_{h,\mathsf{nontourism}} u_{h,\mathsf{nontourism}}$, for private consumers $h \in \mathscr{H}$.

3.2.3. Public Expenditure.

While private income is obtained, among others, from selling the factor endowments on the respective factor

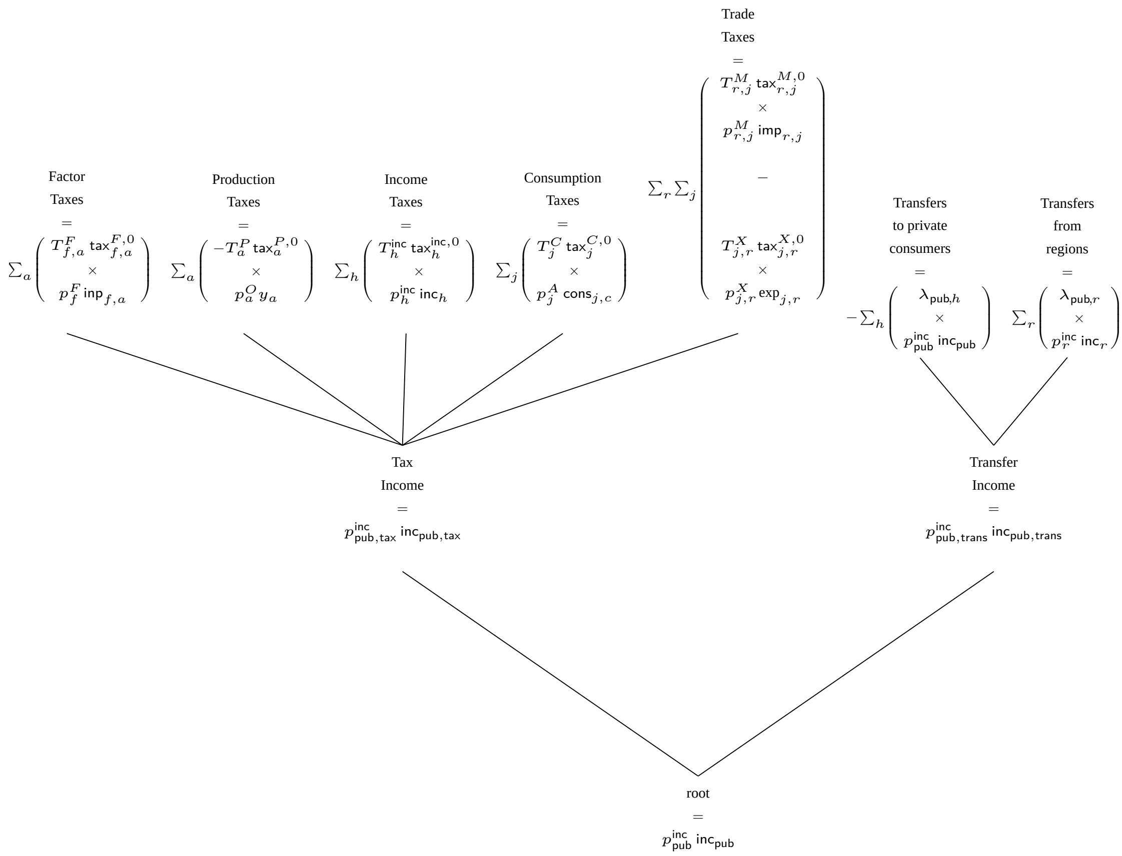

FIGURE 7: Graphical depiction of the decomposition of public income $p^{\mathsf{inc}}_{\mathsf{pub}}\mathsf{inc}_{\mathsf{pub}}$ into tax income obtained from collecting taxes and net transfer income obtained from transfers to and from other consumers and foreign regions. We currently assume Leontief cost structures in all nests.

markets at given market prices, *public income* is the result of the total (net) tax income as well as the (net) transfer value obtained from or spent to the other consumer households. Notice that subsidies are regarded as negative taxes. Furthermore, it is important to consider the transfers from Mainland Portugal to the Azores as well as from the EU to the Azores since the viability of the Azores' economy depends largely on these transfers. Public income or public revenues are distinguished into *Tax Income* or *Tax Revenues* and *Transfer Income* or *Transfer Revenues*. Figure 7 depicts the income decision of the public sector.

3.2.4. Corporate Expenditure.

The AzorCLUSTR model introduces a (microeconomic) consumer household to which we refer as the *corporate household* (corp) which represents the savings-investments decisions of the production households. Contrary to the other consumer households, the corporate household does not consume any of the goods, hence the income it obtains from selling its production factors, here capital goods, are completely saved. Actually, this means that the corporate household invests its savings into capital goods which are supplied to the capital markets, on top of the capital goods already supplied by the private consumption sectors. Figure 8 depicts the income decisions of the corporate sector, which is similar to that of the private households in Figure 5. Notice that the original AzCLUST model refers to the *factor income* of the corporate firm as 'gross capital formation'. According to Fortuna et al. (2021), corporate expenditure on gross fixed capital formation is obtained by subtracting the cost of changes in inventories from total investment expenditure, and is distributed among commodities in fixed shares. This implies implicitly that the production function of the new capital goods is Cobb-Douglas.

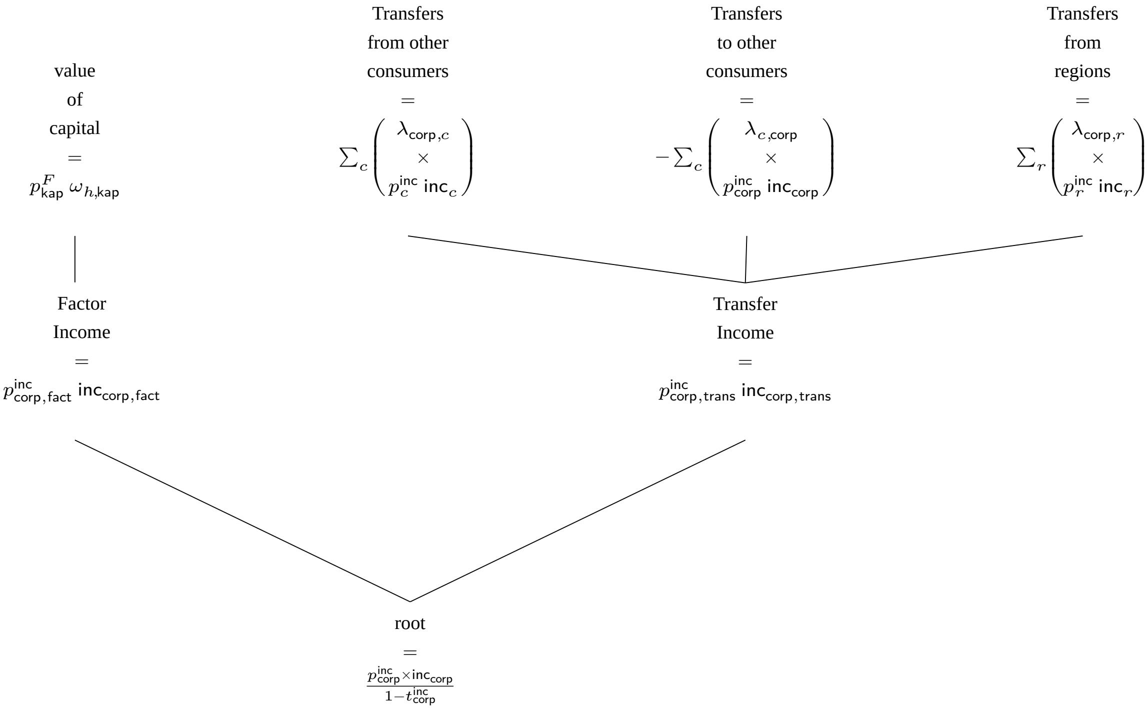

FIGURE 8: Graphical depiction of the decomposition of corporate income $(p^{\mathsf{inc}}_{\mathsf{corp}}\mathsf{inc}_{\mathsf{corp}})/(1 - t^{\mathsf{inc}}_{\mathsf{corp}})$ into factor income obtained from selling endowments in production factors $\sum_f p^{\mathsf{F}}_f \omega_{h,f}$ and net transfer income obtained from transfers to and from other consumers or to and from other regions $\sum_c \lambda_{\mathsf{corp},c}\ \mathsf{inc}_{\mathsf{corp}}$. We currently assume Leontief cost structures in all nests.

3.2.5. Investments in inventories.

We intermingle the use of 'inventories' ('inv') and 'stocks' ('stk'), although they are slightly different. Stock items are the goods you sell to customers. Inventory includes the products you sell, as well as the materials and equipment needed to make them. According to Fortuna et al. (2021), inventories in each commodity $j \in \mathscr{M}$ are a share of the sales of each Armington commodity j. In this way, also imports of commodity j are added to its inventory.

3.3. The Trade Account

The *Trade Account* (TA) or *Balance of Payments* (BoP) represents the financial and material flows of the Azores with the outside world. It consists of two separate (sub-)accounts, the *Current Account* (CUR_r) with respect to each foreign region $r \in \mathscr{R}$ and the *Capital Account* (CAP). The current account represents the material in- (cp. income value from exports) and outflows (expenditure value of imports) in value terms. The balance between import and export value with respect to each foreign region $r \in \mathscr{R}$ is referred to as the *Current Account Balance* (CUB_r) of the Azores with region r. The *Capital Account* represents the financial in- (cp. income value of foreign investments, re-evaluations of inventories, etc.) and outflows (cp. expenditure value of domestic and foreign savings into assets, etc.).

In equilibrium, the Trade Account (TA) or Balance of Payments (BoP) then satisfies,

$$\mathsf{BoP} : \text{Imports} - \text{Exports} - \text{net transfers} = \text{Investments} - \text{Savings}$$

which can be rewritten into

$$\mathsf{BoP} : \sum_{r \in \mathscr{R}} \left(\text{Imports}_r - \text{Exports}_r - \text{net transfers}_r\right) - \mathsf{CAB} = 0$$

stating that 'net expenditure' equals net income on the Balance of Payments account. This equation can be seen as defining a budget set of a microeconomic consumer household. Many economic models assume that

$$\text{Investments} = \text{Savings}$$

thereby *closing* the model. This particular '*closure rule*' is referred to as *neoclassical*.

3.3.1. The Current Account

The *Current Account* with respect to each region $r \in \mathscr{R}$ represents the value of exports and imports of both goods and services, as well as international transfers of capital. As such, it is depicted in the model as,

$$\begin{pmatrix} \mathsf{Value} \\ \mathsf{of} \\ \mathsf{Imports}_r \end{pmatrix} + \mathsf{CUB}_r - \begin{pmatrix} \mathsf{Value} \\ \mathsf{of} \\ \mathsf{Exports}_r \end{pmatrix} - \mathsf{net\ transfers}_r = 0,$$

for each region $r \in \mathscr{R}$. This equation can be seen as a budget of a (microeconomic) consumer household who obtains income in the form of the value of its exports as well as the value of transfers from foreign regions. This income is then spent on buying imports from these regions. The slack value or the balance between exports and imports is then referred to as the Current Account Balance with foreign region $r \in \mathscr{R}$ or CUB_r. Notice that, instead of depicting each foreign region in the Tourism Social Accounting Matrix (TSAM) of Table 1 with the region itself, our single region SAM actually defines the current account with the foreign region as a microeconomic consumer household's budget. The latter equation determines the current account balance CUB_r with each region $r \in \mathscr{R}$. The import demand for commodity j results from the cost minimising decisions to construct the Armington commodity j, given its price $e_r p_{j,r}^{\mathsf{W}}$ and given the price p_j^{D} of the domestically produced alternative, see Figure 1. Exports of commodity j however are part of the total supply or output of the associated production activity[16] at the world market price $e_r p_{j,r}^{\mathsf{W}}$ of commodity j. Commodity j is not determined by location, hence there is only one world market for this commodity which determines the price $p_{j,r}^{\mathsf{W}}$ or exchange rate e_r with foreign region $r \in \mathscr{R}$ by confronting the supply with the region-specific demand for this commodity[17]. Due to the location independent characteristics of the commodities, demand for exports by the foreign countries is determined by a constant elasticity of demand function with a price-elasticity of demand, σ_j^{X} from region $r \in \mathscr{R}$ for exports of commodity j.

$$\sum_r \left[\sum_{a \in a2j^{-1}(j)} \left(\frac{y_{a,r}^{\mathsf{X}}}{y_{a,r}^{\mathsf{X},0}} \right) - \left(\frac{e_r p_j^{\mathsf{W}}}{e_r^0 p_j^{\mathsf{W},0}} \right)^{\sigma_j^{\mathsf{X}}} \right] = 0$$

This equation determines e_r for each region $r \in \mathscr{R}$ as a function to the world market price of commodity j, $p_{j,r}^{\mathsf{W}}$. Then, $p_{j,r}^{\mathsf{W}}$ is determined from this equation after substituting this relationship for e_r in it. Notice that this equation assumes a neo-classical closure. Furthermore, we need to add a further closure in choosing either e_r or p_j^{W} fixed on its benchmark value.

3.3.2. The Capital Account

The *capital account* of the region, here the Azores, represents the net flow of investment into an economy, i.e. the difference between savings and investments. In our model, we include the following equation to represent the capital account,

$$\sum_j \left(\mathsf{Net\ Investments}_j + \mathsf{Net\ Inventory\ Additions}_j \right) + \mathsf{CAB} - \mathsf{Savings} = 0,$$

which can also be interpreted as the budget of a microeconomic consumer household who obtains income from its savings that is spends one investments, and inventory additions. The slack variable or balance between investments and savings CAB is then referred to as the *Capital Account Balance*. The latter equation then determines this capital account balance.

3.4. The Commodity Markets

The output of each commodity $j \in \mathscr{M}$ is determined by the total domestic demand for this commodity and the exported demand for this commodity to foreign regions. The latter demand consists of the part of production that is supplied to these regions, i.e. $\sum_{r \in \mathscr{R}} y_{a,r}^{\mathsf{X}}$. Following the constant returns to scale assumption underlying each production activity's technology, this output level is determined by the total demand for this good, i.e. we are talking about a completely elastic supply.

$$\textstyle\sum_{j \in a2j(a)} \mathsf{DOM}_j + \sum_{r \in \mathcal{R}} y_{a,r}^{\mathsf{X}} - y_a \leq 0 \quad \perp \quad \hat{p}_a^{\mathsf{O}} \geq 0,$$

---

[16] Contrary to Fortuna et al. (2021), who include the exports as demand instead of supply.

[17] The export data in the SAM do not represent foreign region's $r \in \mathscr{R}$ total demand for this commodity. A large part of this demand comes from the other regions on the world market. This is the reason to include exports as output instead of demand.

where $\hat{p}^{\mathsf{O}}_a$ denotes the gross price of the output good of activity $a \in \mathscr{A}$, i.e. including production taxes or subsidies.

It is assumed here that the domestically supplied and exported commodities are not perfectly transformable into one another. We make the same assumption with respect to the domestic and imported versions of this commodities. This has been referred to as the Armington assumption which has led to the construction of a so-called Armington good from its domestic and imported variants, in Figure 1. Within our TSAM, this means that there exists a market $j \in \mathscr{M}$ for the Armington good j, which determines the output level y^{A}_j,

$$\sum_{a\in\mathcal{A}} \mathsf{inp}^a_j + \mathsf{margins} + \sum_{h\in\mathcal{H}} \mathsf{cons}_{j,h} + \mathsf{cons}_{j,\mathsf{pub}} - y^{\mathsf{A}}_j \leq 0 \quad \perp \quad p^{\mathsf{A}}_j \geq 0.$$

3.5. The Production Factor Markets

3.5.1. The Labour Market

The labour market is usually assumed to clear i.e., its market price being the wage rate $p^{\mathsf{F}}_{\mathsf{lab}}$, is determined such that total labour demand $\sum_{a\in\mathscr{A}} \mathsf{inp}^a_{\mathsf{lab}}$ by the production activities $a \in \mathscr{A}$ is met by total labour supply $\sum_{h\in\mathscr{H}} p^{\mathsf{F}}_{\mathsf{lab}}\omega_{h,\mathsf{lab}}$ by the private consumer households $h \in \mathscr{H}$. This results in a complementarity condition,

$$\sum_{a\in\mathcal{A}} \mathsf{inp}^a_{\mathsf{lab}} - \sum_{h\in\mathcal{H}} p^F_{\mathsf{lab}}\omega_{h,\mathsf{lab}} \leq 0 \quad \perp \quad p^F_{\mathsf{lab}} \geq 0.$$

A clearing labour market assumes the absence of price rigidities. This excludes for example a minimum wage rate under which case the wage rate may not be able to adjust itself to equilibrium values below this minimal rate, causing unemployment on the labour market in the economy. *Unemployment* exists when total labour supply exceeds demand, which results in the latter complementarity condition exhibiting a positive slack variable when the wage rate $p^{\mathsf{F}}_{\mathsf{lab}}$ is stuck on its fixed rate, e.g. the minimum wage rate. We refer to this slack variable as unemployment. Total unemployment consists of the unemployed ω^{u}_h, in each private household $h \in \mathscr{H}$[18].

Fortuna et al. (2021) include unemployment into their AzCLUST model by introducing a wage curve to explain the functioning of the labour market. The *wage curve* has been introduced in Blanchflower and Oswald (1995) with a more elaborate treatment in Blanchflower and Oswald (1994), and further experiments to estimate a wage curve for several regions in Blanchflower and Oswald (2005).

The wage curve was introduced in an attempt to understand the forces that determine the level of unemployment and the level of wages. The wage curve is a downward sloping locus depicting a link between the level of unemployment and the level of wages. Following Blanchflower and Oswald (1995), this relationship tells us that, a rise in unemployment will result in a fall in wages. The lower the rate of unemployment, the fewer the number of people available for a particular job, and hence the higher is the wage per employee. This interpretation contradicts the common knowledge on the labour market that the

[18] This definition of unemployment as well as the inclusion into the model mainly follows the usual use of the concept in statistical offices. Notice however the distinction of unemployment into *voluntary* and *involuntary* unemployment. People may decide to be voluntarily unemployed if they consider themselves better off without a job, e.g. when having obtained a large inheritance. We could model this behaviour by referring to the ideas introduced in Benassy (1975), following a discussion on the modelling of unemployment between Malinvaud (1977), and Drèze (1975). According to Benassy (1975), unemployment is the difference between the notional supply of labour and the effective supply of labour, where the *effective* supply of labour is defined as the (rationed) supply of labour under (non-market clearing) wage restrictions, and the *notional* supply of labour is defined as the unrestricted supply of labour. Notice that these restrictions on the labour market result in a notional and effective demand for commodities on the other markets.

existence of unemployment leads to a scarcity of labour supply resulting in high wages. Blanchflower and Oswald (1995) postulate the following wage curve,

$$p_{\mathsf{lab}}^{F} = \sigma_{\mathsf{u}} \ln \left(\sum_{h \in \mathcal{H}} \omega_h^{\mathsf{u}} \right),$$

where σ_{u} represents the *unemployment elasticity of pay*. Blanchflower and Oswald later confirmed in Blanchflower and Oswald (2005), estimate an elasticity $\sigma_{\mathsf{u}} = -0{,}01$ for all regions. Nijkamp and Poot (2005) conclude that there is evidence of publication bias and, after controlling for publication bias, they estimate that, based on study characteristics, the 'true' wage curve elasticity is about -0,07. Montuenga, García, and Fernández (2003) provide evidence with respect to the existence of a wage curve in Portugal.

Let $\mathsf{unemp} = \sum_{h \in \mathscr{H}} \omega_h^{\mathsf{u}}$ [19] define regional unemployment. Then, we replace the complementarity condition representing the labour market equilibrium in a competitive situation, with the following one,

$$\sum_{a \in \mathcal{A}} \mathsf{inp}_{\mathsf{lab}}^{a} + \mathsf{unemp} - \sum_{h \in \mathcal{H}} p_{\mathsf{lab}}^{F} \omega_{h,\mathsf{lab}} \leq 0 \quad \perp \quad p_{\mathsf{lab}}^{F} \geq 0$$

with unemp possibly non-zero, under the existence of price rigidities in the form of a wage curve. As for the wage curve, we use the following complementarity condition,

$$p_{\mathsf{lab}}^{F} - \sigma_{\mathsf{u}} \ln(\mathsf{unemp}) \geq 0 \quad \perp \quad \mathsf{unemp} \geq 0.$$

This complementarity condition on the determination of the wage rate $p_{\mathsf{lab}}^{\mathsf{F}}$ can be interpreted as follows. The wage rate $p_{\mathsf{lab}}^{\mathsf{F}}$ either equals the value prescribed by the wage curve and there exists unemployment, i.e. $\mathsf{unemp} \geq 0$, since this wage rate does not clear the market, or, the market clearing wage rate $p_{\mathsf{lab}}^{\mathsf{F}}$ is larger than the wage rate determined by the wage curve, and hence there is no unemployment.

3.5.2. The Capital Market

The capital market is cleared by the price of capital $p_{\mathsf{kap}}^{\mathsf{F}}$, i.e. $p_{\mathsf{kap}}^{\mathsf{F}}$ is determined such that total capital demand $\sum_{a \in \mathscr{A}} \mathsf{inp}_{\mathsf{kap}}^{a}$ by the production activities $a \in \mathscr{A}$ is met by the total supply of capital consisting of the total capital supply $\sum_{h \in \mathscr{H}} p_{\mathsf{kap}}^{\mathsf{F}} \omega_{h,\mathsf{kap}}$ by the private consumer households $h \in \mathscr{H}$, and the investments of the corporate household's savings into the supply of new capital to the capital market, $p_{\mathsf{kap}}^{\mathsf{F}} \omega_{h,\mathsf{kap}}$. This results in a complementarity condition

$$\sum_{a \in \mathcal{A}} \mathsf{inp}_{\mathsf{kap}}^{a} - \sum_{h \in \mathcal{H}} p_{\mathsf{kap}}^{F} \omega_{h,\mathsf{kap}} - p_{\mathsf{kap}}^{F} \, \omega_{h,\mathsf{kap}} \leq 0 \quad \perp \quad p_{\mathsf{kap}}^{F} \geq 0.$$

4. The economic consequences of the COVID pandemic on the Azores economy.

During the outbreak of the COVID pandemic from 2020, the developed world reacted with severe measures to prevent a further outbreak of the pandemic. Everyone is currently familiar with the necessity to wear

[19] We have 5 different private households, hence 5 different levels of labour supply to the labour market. Consequentially, these 5 households are confronted with 5 different levels of unemployment. Fortuna et al. (2021) only refer to one level of unemployment on the labour market without explaining each household's unemployment levels. Since, income classes do not actually play a major role in the analysis, it might have been smarter to concentrate on one aggregate private household in order to prevent these kinds of problems.

hygienic or medicinal mouth caps among large groups of people or in hospitals. Art exhibitions and concerts were forbidden. Many governments have imposed constraints on local, regional, and international travel to prevent the disease from spreading too rapidly. All these measures have prevented the economy to grow sufficiently in order to recover from the many crises during the preceding decade.

The Azores economy is currently largely dependent on the rapidly growing tourist sector which is making an attempt to adjust to an increase in international demand for touristic activities in the Azores. The tourist sector has been one of the production sectors that was significantly impacted by international measures to fight the spread of COVID. Table 2 enumerates the production sectors relevant to tourism as used in the AzorCLUSTR model. Since the Azores are a group of 9 isolated islands in the Atlantic Ocean, international accessibility depends mainly on transport by air and sea, where the latter type of transport mainly refers to cruise ships attending the Ponta Delgada harbour. The following table, Table 7, depicts the Azores tourist cluster obtained from the Tourism Satellite Account in Table 2 with the subsequent input from the transport sectors.

$a \in \mathscr{A}$	mkt_transport_air	mkt_transport_water	mkt_transport_road	Exports
act_hotels	2,30	0,20	0,30	20,10
act_secondary_residences	0,10			14,20
act_restaurants		1,90	0,10	22,70
act_transport_road	0,60		1,00	3,20
act_transport_water	0,10	7,00		21,80
act_transport_air	90,70		0,10	182,90
act_transport_rental	0,10			
act_travel_agencies	49,30	0,10	0,40	36,60
act_leisure	49,30			1,00
Imports	252,50	2,00	0,30	

Table 7: Input value of air, water, and road transport in the tourism cluster of the Azores (TSA 2016).

The data in Table 7 make it clear that, besides the airline industry in the Azores, it is the travel agency sector that depends most on the supply of air transport to and from the Azores. This paper hence concentrates on the economic consequences of the implementation of international government pandemic ruling on air transport in the Azores. The effects on the other sectors can be seen mainly as indirect effects resulting from limitations on their input demand for air transport.

According to Table 7 the economic consequences of implementing international pandemic ruling mainly entails the exports, imports, and input of air transport into the tourist cluster of the Azores. Fortuna et al. (2021) concentrate on the implications of the COVID pandemic on the exports of the Azores tourist cluster, the economy's subsequent capital stock use, and factor productivity. They define three counterfactual scenarios depending on the reduction of these exports over time, within the context of a recursive dynamic version of the AzCLUST model. We currently stick to the static variant of this model calibrated on the Tourism SAM. We redefine these scenarios into three counterfactual equilibria, in Table 8.

In the Social Accounting Matrix, Table 1, exports are not included as a demand, but as a part of the

Shocks	Counterfactual 1	Counterfactual 2	Counterfactual 3
Export demand tourism products	-50%	-80%	-80%
Export demand other products	-10%	-10%	-10%
Capital stock use tourism activities	-50%	-80%	-80%
Capital stock use other activities	-10%	-10%	-10%
Total factor productivity shock tourism activities	-5%	-10%	-10%
Total factor productivity shock other activities	-2%	-5%	-5%
Labour supply (active population)			-10%

Table 8: Three counterfactuals with respect to COVID related shocks on the production sectors in the Azores. See also Fortuna et al. (2021).

output of the production sectors. This is due to the definition of a good in social accounting matrix. In a SAM, a good is treated as the same good whether it is a domestically produced good, or a foreign, imported good. The Armington Assumption does not change this definition but ad hoc assumes a non-perfect substitution between domestic and imported goods. Consequentially, the SAM does not depict the total foreign demand for these goods, only the foreign demand for the goods produced domestically. This is of importance in the use of the demand data in the general equilibrium model to calibrate the foreign demand functions of each good.

The demand in an input output model is an external parameter and can be shocked as such. This is in contrast to a CGE model where demand is endogenously determined as a function of the economic variables, i.e. prices and income, following utility maximisation by the microeconomic consumer. Export supply is modelled as,

$$\frac{y^{\mathsf{X}}_{a,r}}{y^{\mathsf{X},0}_{a,r}} = \left(\frac{e_r\, p^{\mathsf{W}}_{a2j,r}}{e^0_r\, p^{\mathsf{W},0}_{a2j,r}}\right)^{\sigma^{\mathsf{T}}_{a2j,r}}$$

where $\sigma^{\mathsf{T}}_{a2j,r}$ is the export price elasticity of the output commodity *a2j* of sector $a \in \mathscr{A}$ to region $r \in \mathscr{R}$. The super index 0 indicates the initial value of the corresponding variable.

Contrary to Fortuna et al. (2021), who treat exports as demand, we treat exports as a part of the production sectors' output, as depicted in Figure 3. The shocks depicted in Table 8 referring to the export shock are then implemented by imposing an upper bound,

$$\text{Counterfactual 1:} \quad y^{\mathsf{X,UP}}_{a,r} = 0{,}5 y^{\mathsf{X},0}_{a,r}$$

$$\text{Counterfactual 2:} \quad y^{\mathsf{X,UP}}_{a,r} = 0{,}2 y^{\mathsf{X},0}_{a,r}$$

$$\text{Counterfactual 3:} \quad y^{\mathsf{X,UP}}_{a,r} = 0{,}2 y^{\mathsf{X},0}_{a,r}$$

for production sectors $a \in \mathscr{A}_{\mathsf{tour}}$, and an upper bound,

$$\text{Counterfactual 1:} \quad y_{a,r}^{\mathsf{X,UP}} = 0{,}9 y_{a,r}^{\mathsf{X},0}$$
$$\text{Counterfactual 2:} \quad y_{a,r}^{\mathsf{X,UP}} = 0{,}9 y_{a,r}^{\mathsf{X},0}$$
$$\text{Counterfactual 3:} \quad y_{a,r}^{\mathsf{X,UP}} = 0{,}9 y_{a,r}^{\mathsf{X},0}$$

on the exported output of the non tourism production sectors $a \in \mathscr{A}_{\mathsf{ntour}}$. This results in the following mixed complementarity problem on the determination of exported output quantities $y_{a,r}^{\mathsf{X}}$ and its complementary price variables $p_{a,r}^{\mathsf{X}}$.

Total factor productivity refers to the share or productivity parameter associated with the value added composite in the constant elasticity of substitution function that produces the output good of production activity $a \in \mathscr{A}$, see Figure 2. We follow Fortuna et al. (2021) by shocking the scale parameter in the tourism

$$\frac{p_{a,r}^{\mathsf{X}}}{p_{a,r}^{\mathsf{X},0}} - \left(\frac{e_r p_{a2j,r}^{\mathsf{W}}}{e_r^0 p_{a2j,r}^{\mathsf{W},0}}\right)^{\sigma_{a2j,r}^{\mathsf{T}}} \geq 0 \quad \perp \quad 0 = \frac{y_{a,r}^{\mathsf{X}}}{y_{a,r}^{\mathsf{X},0}}$$

$$\frac{p_{a,r}^{\mathsf{X}}}{p_{a,r}^{\mathsf{X},0}} - \left(\frac{e_r p_{a2j,r}^{\mathsf{W}}}{e_r^0 p_{a2j,r}^{\mathsf{W},0}}\right)^{\sigma_{a2j,r}^{\mathsf{T}}} = 0 \quad \perp \quad 0 \leq \frac{y_{a,r}^{\mathsf{X}}}{y_{a,r}^{\mathsf{X},0}} \leq \frac{y_{a,r}^{\mathsf{X,UP}}}{y_{a,r}^{\mathsf{X},0}}$$

$$\frac{p_{a,r}^{\mathsf{X}}}{p_{a,r}^{\mathsf{X},0}} - \left(\frac{e_r p_{a2j,r}^{\mathsf{W}}}{e_r^0 p_{a2j,r}^{\mathsf{W},0}}\right)^{\sigma_{a2j,r}^{\mathsf{T}}} \leq 0 \quad \perp \quad \frac{y_{a,r}^{\mathsf{X}}}{y_{a,r}^{\mathsf{X},0}} = \frac{y_{a,r}^{\mathsf{X,UP}}}{y_{a,r}^{\mathsf{X},0}}$$

production function of the value added composite, va to $0.95\mathsf{va}$ for Counterfactual 1, and to $0.90\mathsf{va}$ for counterfactuals 2 and 3. With respect to the non tourism production functions, the scale parameter va is shocked to $0.98\mathsf{va}$ for Counterfactual 1, and $0.95\mathsf{va}$ for counterfactuals 2 and 3.

Counterfactuals 2 and 3 are the same except for a labour market effect in the form of a drop in labour supply in Counterfactual 3, probably due to the impact of COVID on the labour force. Private households supply labour as one of their production factors. Fortuna et al. (2021) include a stock parameter $\omega_{\mathsf{lab}}(h)$ for each private consumer households $h \in \mathscr{H}$. They implement a $10\,\%$ reduction in labour supply in the Azores economy which we implement by decreasing labour supply $\omega_{\mathsf{lab}}(h)$ of each private consumer household $h \in \mathscr{H}$ with $10\,\%$, i.e. $\omega_{\mathsf{lab}}(h) = 0.9\omega_{\mathsf{lab}}(h)$, since there is no information available to suggest otherwise[20].

Table 9 enumerates the macroeconomic impacts of the three COVID-19 counterfactuals defined in Table 8 for the Azores Economy (in % change compared to the baseline counterfactual). We define changes in Gross Domestic Product ($\Delta\mathsf{GDP}$) as

$$\Delta\mathsf{GDP} = \sum_{a \in \mathscr{A}} \left(p_a^{\mathsf{C}} y_a^{\mathsf{C}} - p_a^{\mathsf{B}} y_a^{\mathsf{B}}\right)$$

Gross domestic product (GDP) is a monetary measure of the market value of all the final goods and services produced and sold in a specific time period by a country. In the context of general equilibrium theory, this

[20] In Table 8, Fortuna et al. (2021) only provide a decrease in total labour supply of $10\,\%$ neglecting the existence of several income classes of private households. This foregoes an important opportunity to consider the COVID impact on labour supply in the lower income classes which might be significantly different from the high income classes.

indicator comes down to where the super index B refers to the benchmark value of the associated variable, and C refers to the counterfactual value of the associated variable.

GDP attempts to measure the net costs to society of implementing a certain policy measure and is therefore required by many policy makers that have to make a decision on whether to implement the policy or not. During the last decade, this measure of 'social' cost has come under heavy scrutiny since it does not depict the right (welfare) costs to the economy, let it be society. Consequently, many other indicators are and have been proposed that are supposed to be the better alternative.

General Equilibrium theory applies the so-called *Hicksian Equivalent Variation* (HEV) as an alternative to measure the (net) welfare costs to the economy. According to https://en.wikipedia.org/wiki/Equivalent_variation {Wikipedia}, the *Equivalent Variation* (EV) is a measure of economic welfare changes associated with changes in prices. John Hicks is attributed with introducing the concept of *Compensating Variation* (CV) and *Equivalent Variation* (EV). The *Hicksian Equivalent Variation* (HEV) is hence defined as follows,

> “The *Hicksian Equivalent Variation* is the change in wealth, at current prices, that would have the same effect on consumer welfare as would the change in prices, with income unchanged. It is a useful tool when the present prices are the best place to make a comparison.”

For the economic theory behind this concept, we refer to Mas-Colell, Whinston, and Green (1995). Within General Equilibrium theory, HEV_h denotes the difference in consumer expenditure for private consumer $h \in \mathscr{H}$ at benchmark prices, i.e.

$$\mathsf{HEV}_h = p_h^{\mathsf{B},u} \left(u_h^{\mathsf{C}} - u_h^{\mathsf{B}} \right)$$

for every private consumer household $h \in \mathscr{H}$. Notice that the Hicksian Equivalent Variation takes the preferences of the private consumers under consideration. In our case, the Hicksian Equivalent Variation is equivalent to the change in real disposable income for each consumer household.

We apply the AzorCLUSTR model as defined in Section 3 to compute the change in GDP, $\Delta\mathsf{GDP}$, and the Hicksian Equivalent Variation, HEV, when implementing each scenario defined in Table 8.

Indicator	Counterfactual 1	Counterfactual 2	Counterfactual 3
Change in GDP ($\Delta\mathsf{GDP}$, in %)	-12,28%	-15,70%	-21,33%
Real Wage	-5,09%	-6,33%	-4,50%
Unemployment Rate	7,36%	9,16%	7,24%
Number of unemployed	-132,78	165,36	117,64
Real Disposable Income ($\mathsf{HQ}_1, \ldots, \mathsf{HQ}_5$)	-8,04%	-8,49%	-14,85%
Real Disposable Income (HQ_6)	-8,27%	-8,66%	-14,91%

Table 9: Macroeconomic impacts of COVID-19 in the Azores economy.

The macroeconomic results are presented in Table 9. The unemployment rate approaches around 7% in the first scenario and 9% in the moderate impact scenario 2, The lower rate in scenario 3 has to do, once again, with the labor force exodus assumption. Real disposable income falls between 8% and 8,7% in the first two scenarios. The third scenario, the extra unemployment shock results in less labour income, henceforth the significant decrease in real disposable income.

Fortuna et al. (2021) break down the macroeconomic results pointed out in Table 9 into its component parts in the SAM, highlighting the impacts on the tourism cluster versus the other sectors or the whole economy, Table 10 presents the tourism related impacts on household expenditure.

Consumption Household	Expenditure on Domestic Tourism	Expenditure on Inbound Tourism	Expenditure on Outbound Tourism
$HQ_1, \ldots, HQ_5$	-8,04%		
HQ_6	-8,27%		
Rest of Portugal		-18,03%	-50,21%
Rest of EU		-14,89%	-50,29%
USA		-14,48%	-50,29%
Rest of the World		-14,45%	-50,31%

Table 10: Tourism related impacts on private household expenditure.

Domestic tourism expenditure refers to the total value of domestic consumptive spending by the consumer households on tourism-related goods in tour. Domestic tourism expenditure has been much less impacted by COVID pandemic related international policies. The Azores are a group of remote islands in the Atlantic making the airline industry of significant importance for internal communication and trade. Hence, there exists a negative impact here too be it of a lesser magnitude than other types of tourism expenditure[21].

5. Points of further research.

The AzorCLUSTR model as it stands in this paper is just a starting point for further research into tourism related impact studies with accompanying modelling development to make the model more suitable to such research. Like all CGE models, the modelling essentially depends on the policy question. For a successful implementation and further development of the AzorCLUSTR model, intensive cooperation with experts on the field is required. It is their insights that need to take care of the successful application and further development of the AzorCLUSTR model. This section, Section 5, therefore closes the paper with an open end towards further research.

A first issue in the further development of the AzorCLUSTR model is the representation of the tourism industry as a so-called cluster of production activities. A *cluster* is a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities. The geographic scope of clusters ranges from a region, a state, or even a single city to

[21] Again, the results for the various households are all suspiciously equal, except for the last, highest income class, HQ_6. This may have to do with the fact that the computed levels of the Hicksian Equivalent Variation (HEV) for each income group are similarly equal. Perhaps, the income classes have been determined such that each group has an equal impact on their welfare as defined by HEV, leaving the last income group differing due to it containing 'a rest group'. These modelling characteristic prevents us from considering the impact of the COVID pandemic related policy measures on the various income groups. Hence, why distinguish among various income groups at all.

span nearby or neighbouring countries (e.g., southern Germany and German-speaking Switzerland). The geographic scope of a cluster relates to the distance over which informational, transactional, incentive, and other efficiencies occur. The appropriate definition of a cluster can differ in different locations, depending on the segments in which the member companies compete and the strategies they employ.

Porter (1990) proposes a micro-economically based theory of national, state, and local competitiveness in the global economy, in which clusters have a prominent role. Clusters suggest that a good deal of competitive advantage lies outside companies and even outside their industries, residing instead in the locations at which their business units are based. Clusters represent a new unit of competitive analysis along with the firm and industry.

Clusters encompass an array of linked industries and other entities important to competition, e.g. suppliers of specialised inputs such as components, machinery, and services (German car industry with providers of specialised products) as well as providers of specialised infrastructure. Clusters also often extend downstream to channels or customers and laterally to manufacturers of complementary products or companies related by skills, technologies, or common inputs. Many clusters include governmental and other institutions (e.g., universities, think tanks, vocational training providers, standards-setting agencies, trade associations) that provide specialised training, education, information, research, and technical support. Many clusters include trade associations and other collective bodies involving cluster members. Finally, foreign firms can be and are part of clusters, but only if they make permanent investments in a significant local presence.

Ferreira and Estevao (2009) also mention that a tourism cluster is associated with a touristic product and a touristic destination. Actually, it looks like tourism is more a service than a product. Fortuna et al. (2021) implement the idea of a tourism cluster as a set of nine separate production activities whose output levels are completely dedicated to address the demand of the tourism sector, see Table 2. Notice that there are nine remaining production activities among them 'non-tourism specific' production activities that are entailed in one or more of the nine tourism-related production sectors. It remains unclear whether these sectors may partly represent the output of the tourism related sectors to satisfy the demand of local residents.

A better implementation of a cluster would be the inclusion of an abstract production activity that produces an abstract output good or a product named 'tourism' using parts of the output of the nine tourism related production activities as intermediate inputs. According to Ferreira (2003), the tourism cluster includes, in addition to the activities considered in the tourism sector, namely accommodation, catering, entertainment and various attractions, operators and travel agencies, guides, crafts, car rentals and touristic transport, also other services and related and support activities, like organisations and support services, transport infrastructure, education and training, consultancy and other business services. These activities are considered the intermediate inputs to the service called 'tourism'. Brown and Geddes (2007) seem to mentions other actors relevant to the supply of tourism services. The tourism related production activities can be seen to have a joint output in tourism related output, as an input to the abstract 'tourism' sector and non-tourism related output, as an input to their own domestic markets, thereby removing the confusing production activities in the non-tourism activities set of Fortuna et al. (2021).

A second issue refers to the specification and calibration of the consumers' utility functions and the producers' production functions in the standard CGE model. In the standard CGE model, consumers and producers are modelled with time-independent utility and production functions. We therefore should introduce utility and production functions that vary over time in order to grasp touristic preferences that adapt to the preferences of a growing international public over time.

Most research in the area of tourism activities can be related to research on the preferences of international tourists for the local amenities. This data could be used to calibrate the CGE's consumer preferences. This opens a possibility for cooperation with researchers from the field of tourism, mainly marketing oriented.

The AzorCLUSTR model only describes a preference ordering over the usual commodities that we know from trade models. This does not suffice. We need a preference ordering over touristic goods such as museums, natural resources etc. The characteristics that make the Azores of growing interest to a rising international audience are mainly in its natural resources. This implies a dedicated modelling of land use into the AzorCLUSTR model.

This brings us to a possible third issue for further development of the AzorCLUSTR model. Land-use plays a very significant role in tourism. According to Cabagueira (2005) most of the activities and services that constitute the touristic product are usually linked to a natural or cultural attraction. Tourism services cannot be distinguished from its location or from its land-use. As such, it is a prime example following the Arrow-Debreu definition of a good, which among others differentiates goods according to place. This implies a certain type of land-use that is of interest to tourists. Or should we talk about a region's natural resources? The Azores are rich of such natural resources which are of major interest to tourists around the world. We should refer to such land-use as natural resources? In such case, the natural resources input into the tourist production sector refers such natural tourist sights. Notice that, similar to land, these inputs are subject to (economic) decisions on where to use the land, i.e. as a natural tourist sight, or as an input to the agricultural sector, or to build a parking lot.

A fourth issue has already been addressed in Section 2 when we introduced a 'Tourism Social Accounting Matrix' in order to incorporate recommendations in OMT et al. (2010) with respect to the collection and representation of tourism data. We only addressed a small part of these recommendations and the AzorCLUSTR model should be developed further along this way. United Nations and World Trade Organization (2008) for example recommends to classify travellers and visitors on the basis of their country of residence, and introduces the concept of usual environment to complement the concept of country of residence usually referred to in the National Accounts and Balance of Payments, and that of place of usual residence used in household statistics. The *usual environment* of an individual is a key concept in tourism and is defined as the geographical area within which an individual conducts his or her regular life routines. The purpose of introducing the concept of usual environment is to exclude from visitors those travellers commuting regularly between their place of usual residence and place of work or study, or frequently visiting places within their current life routine. Tourism statistics should therefore provide the precise meaning of what is termed regular and frequent. This may have significant repercussions for the geographical background of a CGE model. It redefines the usual definition of a (microeconomic) consumer and producer household in the CGE model.

CGE models not only take countries as a reference region, but also cities, in so-called urban CGE models. In such case, the model has to deal with visitors from another city as well as from another region. In that case, we should of course adjust the definitions of domestic, inbound and outbound trips.

Fifth, possible public investments by (government) institutions (as represented by a microeconomic consumer household) in local or regional tourism add to the production factor capital of the production activity 'tourism'. Notice that tourism related industries not only put labour in their tourism related activities but also in other activities. I would include this fact into the model by letting the tourism related industries supply the labour relevant for their tourism activities as a production factor in the tourism production activity. Labour in the tourism cluster would be the amount of labour hours invested into tourism activities by for example tourist offices and the like, i.e. activities that specifically take tourism as its output. The production factor land refers to the geographical scale underlying the definition of a cluster, as mentioned in Porter (1998). It can be seen as a part of the land use or land input of the related production activities. Similarly to the labour production factor, each tourism related production activity supplies the relevant part of its land-use as a factor input to the tourism production sector.

Sixth, tourism is a leisure activity. In case the CGE model contains a certain tradeoff in labour supply and demand for leisure in the consumer's preferences, we should consider the relationship between a consumer's demand for leisure and the demand for tourism. Would this oblige us to include a sort of budget equation for available time, or a time constraint into the consumer's utility maximisation problem?

The output levels y of the production activities in the AzCLUST model are determined by the total demand for its output good, following the constant returns to scale assumption underlying each production technology in the model, i.e. supply is fully elastic. According to Figure 3, total output y_a for each production activity $a \in \mathscr{A}$ can be distinguished into the domestic output level $y_{a,r}^{\mathsf{YD}}$ and the exported output level $y_{a,r}^{\mathsf{YX}}$. The exported output level $y_{a,r}^{\mathsf{YX}}$ is hence determined by the international demand for each good. International travel regulations would limit or ration the amount of exports of air transport into the Azores, i.e. put an upper limit, $y_{a,r}^{\mathsf{YD,UP}} < y_{a,r}^{\mathsf{YD,UP}}$ on the export of the air transport good $j = \mathsf{transair}$. Fortuna et al. (2021) however implement this rationing n three different counterfactuals defined in Table 8, export demand for tourism products $j \in \mathscr{M}_{\mathsf{tour}}$, hence export output levels $y_{a,r}^{\mathsf{YX}}$ for good $j \in a2j$, is shocked with -50% (-80%) for Counterfactual 1 (Counterfactual 2 and 3). For the other, non-tourism goods $j \in \mathscr{M}_{\mathsf{ntour}}$, export output levels $y_{a,r}^{\mathsf{YX}}$ for good $j \in a2j$, is shocked with -10% (-10%) for Counterfactual 1 (Counterfactual 2 and 3).

Imports in commodity $j \in \mathscr{M}$ are determined by its input $\mathsf{import}_j = \mathsf{imp}_j \cdot \mathsf{IMPC}_j y_j^A$ into the supply y_j^A of the abstract Armington good j. Table 7 indicates that the import of air transport, interpreted as the air connections into the Azores, are by far the most important imports. International travel regulations would limit or ration the amount of imports of air transport into the Azores, i.e. put an upper limit, $\mathsf{import}_j^{\mathsf{UP}} \leq \mathsf{import}_j^{\mathsf{B}}$ on the imports of good $j = \mathsf{transair}$. Fortuna et al. (2021) omit this option.

The supply of the Armington good $'\mathsf{transair}'$ is moreover being limited due to the limited availability of imports. We conclude that there are two markets directly involved, i.e. the market for import good $'\mathsf{transair}'$ where demand is being limited, and the market for Armington good $'\mathsf{transair}'$ where supply is being hindered by the limitations of the import input. The AzorCLUSTR model is a single region CGE model, with no regional characterisation of the traded commodities. International trade in the form of exports and imports of the goods are located on the current account with the foreign region, and not on an international market for that good. Limitations of exports and imports hence result in an adjusted current account balance with each foreign region.

The limitations on the availability of imports of each good puts a ration on the supply of the Armington equivalent of these goods. Figure 1 shows that an Armington good is constructed from the domestically produced good and an imported good from each region, using a CES functional form with an elasticity of substitution between these two variants. Consequently, limited availability of imports on a good results into more domestic production of the good being substituted for imports, if possible.

Kremers et al. (2019) analyse the inclusion of upper bounds on production in the form of production capacities, $\mathsf{output}_a^{\max}$ in a CGE model[22]. They discuss how to adjust the standard CGE model for the inclusion of possible upper bound related nonnegative profits. To include a capacity limit on the supply of output good j by production sector a results in the following adjusted complementarity condition on its output market,

$$\begin{array}{llllll} \hat{p}_a - \mathsf{cost}_a(p_a^{\mathsf{va}}, p_a^{\mathsf{ic}}) \le 0 & \perp & 0 & = & y_a & \\ \hat{p}_a - \mathsf{cost}_a(p_a^{\mathsf{va}}, p_a^{\mathsf{ic}}) = 0 & \perp & 0 & \le & y_a & \le \mathsf{output}_a^{\max} \\ \hat{p}_a - \mathsf{cost}_a(p_a^{\mathsf{va}}, p_a^{\mathsf{ic}}) \ge 0 & \perp & & & y_a & = \mathsf{output}_a^{\max}. \end{array}$$

According to Figure 2, the cost per unit output of the activity a consists of the cost of value added input per unit output at a market price p_a^{va}, and the cost of the intermediate composite input per unit output at a market price p_a^{ic}, i.e.

$$\mathsf{cost}_a(p_a^{\mathsf{va}}, p_a^{\mathsf{ic}}) y_a = \left(p_a^{\mathsf{va}} \mathsf{va}_a + p_a^{\mathsf{ic}} \mathsf{ic}_a\right) y_a.$$

Notice that cost_adenotes the marginal cost of output of activity a which, under the constant returns to scale assumption on the production technologies, equals the average cost of output.

The rationing of an economic variable results in an equilibrium that differs from the original un-rationed equilibrium. This implies that the rationing itself has consequences for the simulation results for other variables such as capital use and unemployment in Section 4. Following practices in input-output modelling Fortuna et al. (2021) try to approximate the consequences of rationing on these variables by shocking the corresponding scale or share parameters. This implies that the total simulation results are polluted with artificially introduced shocks[23].

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[22] The resulting complementarity problem, including lower and upper bounds on its variables, is referred to as the *Mixed Complementarity Problem* (MCP), see Rutherford (1995). The PATH solver applied in GAMS takes the MCP as the standard mathematical programming problem to be solved. This implies that we only have to add an upper bound on the variable representing imports in the determination of the Armington good.

[23] This is the consequence of the CGE model assuming the presence of a particular underlying (general equilibrium) economic model describing the classical economic adjustment processes, contrary to input-output models

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