



UNIVERSITY OF MACERATA
Department of Economics and Law

PhD Programme

QUANTITATIVE METHODS FOR POLICY EVALUATION

Curriculum

Computable General Equilibrium Models and Multisectoral Analysis for Policy Evaluation

XXXVII Cycle

**SAM-BASED COMPUTABLE GENERAL EQUILIBRIUM MODELS:
THEORY AND EMPIRICAL APPLICATIONS**

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Academic year 2024-2025



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Introduction

This doctoral dissertation integrates national accounting with general equilibrium in order to provide theoretical and empirical insights into addressing the current global challenges of food security, environmental protection, and competition in policy modeling and evaluation. The three chapters collectively demonstrate the properties and potential of Computable General Equilibrium (CGE) models calibrated on Social Accounting Matrices (SAMs) to bridge the disaggregated structure of the economic system, as evidenced in the database, with a rigorous scientific characterization of the behavior of the operators.

The SAM is the most suitable accounting scheme for presenting in matrix form the intricate interconnectedness of economic systems in a comprehensive, relevant, and internally consistent manner. In essence, the SAM captures the picture of the complete circular flow of income. General equilibrium provides the theoretical basis for CGE models, which formalize the core relationships between the operators through a system of simultaneous nonlinear equations that describe the interactions among markets, the formation of prices, and the determination of disposable incomes by institutional sector. This is achieved by deriving the system's reference behavioral and technological parameters and quotas from the SAM.

The first chapter, entitled “The disaggregated effects of policies for food security: the Pakistani case”, emphasizes the significance of food access and security in the assessment of economic policies, exemplified by a case study from Pakistan. In order to examine changes in GDP and its main components, income distribution, and food access, three policy scenarios are analyzed using a CGE model calibrated on a SAM for Pakistan. The SAM is complemented with data on calorie consumption, adapted from the Food and Agriculture Organization (FAO) data set, and categorizes households into sixteen groups based on geographic location and source of income. The calorie intake matrix provides a comprehensive account of food consumption patterns by food type and household group. The model provides insights into the potential shifts in consumption and nutritional processes that may result from the implementation of distinct policies. Ultimately, the objective is to equip policymakers with supplementary tools to assess the impact of economic policies on food access and security, moving beyond the conventional scope of resource allocation.

The second chapter, entitled “Tools and policy actions to reconcile economic targets and emission abatement”, presents a CGE model based on a SAM that integrates the cost of CO₂ abatement technology into the production cost function. The objective of this modeling approach is to assess the capacity of the economy to reduce carbon emissions from fossil fuel plants while maintaining a sustained economic performance. Specifically, to examine the transmission mechanisms of economic policies and shocks from the economic system to the environment, an environmental SAM is initially constructed, wherein CO₂ flows in physical terms by industry are valued at the average price observed in the Emission Trading System (ETS) market. The SAM also incorporates the abatement capital flows associated with the absorption of four fossil sources, namely coal, crude oil, gas, and coking, in production processes. Secondly, the CGE model calibrated on the environmental SAM formalizes the principal relationships between the actors of the system and endogenizes the costs of CO₂ emissions from fossil energy sources (i.e., the carbon tax) and the cost of abatement technology to curb these emissions. This chapter focuses on China, which is responsible for approximately

one-third of global CO₂ emissions and is the world's largest energy producer. However, this approach may represent a best practice that can be extended to the analysis of other countries' environmental policies.

The third chapter, entitled "Degree of monopoly and price formation in a multisectoral CGE model", draws upon the ongoing discourse surrounding competition in the Italian National Recovery and Resilience Plan (NRRP). From the perspective of the impact analysis of these reforms, it becomes evident that there is a need to reconcile the theoretical foundations of the partial equilibrium approach of imperfect competition with the multisectoral general equilibrium approach. The latter is capable of elucidating both the aggregate and disaggregated response of the economic system to a departure from the hypothesis of perfect competition. In light of these considerations, a theoretical and methodological advancement is proposed in a CGE model calibrated on a SAM for Italy. A mark-up on the price of goods and services is introduced in order to align the commodity market behaviors outlined by the model with the empirical evidence on imperfectly competitive markets. This analysis considers three policy scenarios, each representing a distinct degree of imperfection of the market structure. The first scenario reflects the assumption of perfect competition, the second introduces a low degree of monopoly, and the third establishes the assumption of a high degree of monopoly. This approach allows for an evaluation of the CGE model's capacity to accurately capture price formation in commodity markets characterized by differentiated degrees of monopoly, the allocation of resources across institutional sectors, and offer a more detailed picture of the transmission of policy effects.

The SAM-based CGE models continue to serve as a crucial and pervasive illustration of the close connections between economic theory and quantitative methods for designing and evaluating policy measures adopted by governments and institutions at the international, national, and local levels. In the current era, there is a greater need than ever for policymakers to rely on scientific research and the technical progress of quantitative simulation tools. In this context, SAM-based CGE models can be used to estimate and compare the multisectoral direct, indirect, and induced effects of hypothetical scenarios in advance, facilitating the formulation of responsible and credible decisions for the community.

Chapter 1

The disaggregated effects of policies for food security: the Pakistani case

Abstract

The United Nations Sustainable Development Goals prioritize food security as one of their cornerstones. The Government of Pakistan has identified food security as a top priority in its 2022–2026 national defense policy program, thus adding balanced dietary requirements to economic goals. The objective of this study is to provide policymakers with a set of instruments that can be used to assess the effects of economic policies from a perspective that extends beyond the mere allocation of resources, namely food access and security.

The study employs a SAM-based CGE model, specifically developed for Pakistan, to analyze three scenarios and evaluate changes in GDP and its components, income distribution, and food access at both the aggregated and disaggregated levels. The database contains information on the calories consumed by food item and by households grouped according to location and source of income.

In order to achieve the research objective, the SAM is integrated with the calorie intake matrix, which provides a supplementary description of the total calories consumed by households and by food commodity. The model formalizes the main relations between consumption and calories and provides indications of the potential shifts occurring in consumption and nutritional patterns by household group within the economy as a result of different policy actions.

Keywords: Computable General Equilibrium Models, Social Accounting Matrix, Policy Designs and Consistency, Food Security

JEL classification codes: C68, D58, E61, L66

1.1 The state of global food access and security

National security is a prominent concern for governments. Over the years, the concept of national security has progressively acquired a multidimensional vision. There has been growing awareness that country security builds on the defense of internal integrity and external borders alongside social matters. News from different world corners demonstrates that peaceful inner coexistence can only persist if civil and human rights are granted. These rights nowadays include safer healthcare systems, gender balance, climate change mitigation, and food security.

The Food and Agriculture Organization (FAO) introduced the term food security in 1974 but referred only to the food supply dimension. In 1996, the World Food Summit offered a broader and multifaceted definition, which has become the widely adopted definition for policy purposes. A significant outcome of this event was the recognition of the need for adequate intakes of micro- and macronutrients to build up physical and cognitive maturity. This also served to highlight the critical conditions of food security systems in several regions where nutrient contents and energy proved insufficient to support balanced psycho-physical growth.

As defined by the 1996 World Food Summit, four dimensions simultaneously ensure food security: availability, physical and economic access, utilization, and stability of the previous three (FAO, 2008). Food availability, physical and economic access are considered to reflect the supply and demand sides of the food system, respectively. On the one hand, food availability must be ensured through domestic and foreign production. On the other hand, physical and economic access embody the social and civil rights that should enable people to reach the places where food is supplied and to purchase it. The set of infrastructures and services that provide people with food of a certain quality belong to the utilization side, including, among others, sanitary water and health care. These three dimensions, when stable over time, constitute a secure food system. Temporal stability is a crucial element because it prevents external shocks from affecting the food system in the long run.

At present, the two greatest threats to food system stability are the potential for the spread of future pandemics and the effects of climate change. The United Nations has stated that COVID-19 could turn hunger into a structural issue for nearly 8.9% of the world's population due to a sharp decline in labor demand and disposable income that might lead people into a poverty trap from which they cannot escape (WFP, 2020). The UN has already estimated that the prevalence of stunting would increase by 24.4% among children under the age of five at the onset of the pandemic in 2020 compared to 2015. Furthermore, the incidence of anemia among pregnant women would increase due to inadequate and discontinued nutrient intake (UN E/2021/58).¹

Even though the world is now in a post-pandemic period, the Coronavirus disease has sharpened social and economic inequalities, with some consequences (alterations in dietary habits and a certain degree of disruption in supply chains) likely to persist for an extended period. These factors may potentially exacerbate the risks associated with future pandemics (Laborde et al., 2021). Since the onset of the COVID-19 pandemic, some people have become unable to reach or buy the usual food varieties, either because of social distancing

¹ Available at: <https://documents.un.org/doc/undoc/gen/n21/109/71/pdf/n2110971.pdf>

protocols or income losses in non-food branches. Affected households have also tried to disinvest to deal with upcoming food needs, but in low-income countries, savings have not been sufficient to cover periods exceeding one month (Abate et al., 2020). Extreme climate events exacerbate this alarming outlook, especially for agriculture and livestock-based economies (Banerjee et al., 2015). The dual crises of COVID-19 and climate change, particularly in the form of extreme weather events such as hurricanes and floods, have been identified as the leading causes of a deterioration of food security in South Asia (Rasul, 2021). In light of this evolving landscape, countries such as Pakistan have initiated the integration of the food security dimension into their national development plans.

The Government of Pakistan has recently approved the dissemination of the first official document on national security policy objectives between 2022 and 2026 (NSD, 2022). Section VIII clearly states that one of the pillars of human security is unrestricted access to healthy and nutritious food. Pakistan is the fifth largest country in the world and is highly dependent on agriculture. However, the country has not paid much attention to crop differentiation since most of the arable land is devoted to wheat cultivation: agricultural census statistics report that 93% of rural areas are dedicated to growing wheat (PBS, 2020a). From April to August 2022, the country experienced a series of extreme weather events, including droughts and floods, which significantly disrupted wheat cultivation, the primary source of calories for the Pakistani population (PBS, 2020b).

The accelerated pace of global warming is transforming habitats and geographical boundaries, endangering biodiversity. The Government of Pakistan is acutely aware of its significant reliance on wheat cultivation and the potential consequences of this reliance in the context of global warming. The concern is that the exclusion of other agricultural crops may jeopardize the food supply and compromise food security. In particular, low-income households with limited access to education are particularly vulnerable to nutritional deficiencies, which can lead to the vicious cycle of malnutrition (Gillespie & Flores, 2000). The Government of Pakistan has expressed its intention to encourage improvements in farming processes, seed development, and resource management in order to ensure a sustainable future. Therefore, prior to the formulation of suitable economic policies, it is essential to ascertain the sources of caloric intake within the population's food basket in order to monitor dietary habits and their evolution.

In this regard, this study attempts to fill the gap in caloric accounting within the context of national policy design. The purpose is to construct a supplementary key instrument to understand and interpret the effects of fiscal policies. Once food consumption patterns are detected, they provide further detail to the traditional macroeconomic information on changes in aggregate variables. Indeed, the food system and dietary conditions have attracted increasing theoretical and methodological interest (Emmert-Fees et al., 2021). Microsimulations represent the most prevalent estimation method, as they can be readily adapted to fit the specific structure of observational surveys, and thus simulate impacts at the agent level (Rutten, 2013).

In the context of the general equilibrium framework, micro-founded Computable General Equilibrium (CGE) models can enrich these techniques with a broad vision of the economic system. Such models can investigate how relative prices mediate market forces and illustrate the mutual interactions between institutional sectors. When the Social Accounting Matrix (SAM) describes the baseline characteristics of the

economy, CGE models can address multiple socioeconomic facets (Deriu et al., 2022). They can support the development of instruments that reflect the impact of economic policies carried out at different stages of the circular flow of income, which are interlinked with dietary fact sheets on a targeted population. By constructing a concrete food module for policymakers, aggregated and disaggregated food access and security indicators can be identified as points of reference or critical thresholds for the establishment of national and local strategies and the fulfillment of national security objectives. Therefore, this study aims to provide a practical policy tool to trace the effects of selected policy measures on the food baskets of different household income levels.

The remainder of the study is structured as follows. Section 1.2 delineates the methodology used to conduct the analysis and is comprised of three subsections. Subsection 1.2.1 presents the SAM for Pakistan, while Subsection 1.2.2 introduces the construction of the calorie intake matrix and the formulation of the food indicator. Lastly, Subsection 1.2.3 elaborates on the CGE model calibrated on the SAM database. Section 1.3 presents a series of policy scenarios designed to examine the behavior of the model and the transmission channels through which these policies affect food habits. The impact of these supply-side and redistributive policies on macroeconomic variables and food access and security, both in aggregate and disaggregate terms, is comparatively examined in Subsection 1.3.1. Section 1.4 presents the results of the sensitivity analysis, while Section 1.5 elucidates the conclusions drawn from the preceding sections.

1.2 The SAM-based CGE model for Pakistan

CGE models provide an appropriate quantitative framework for evaluating the impact of policy interventions on the circular flow of income in an economic system (Severini et al., 2018). In CGE models, the interdependencies between production activity, resource allocation, income distribution, and accumulation originate from demand and supply interactions across all markets, which in turn determine the equilibrium prices and quantities of factors and commodities (Shoven & Whalley, 1984). The behavior of the operators is susceptible to the adjustment of endogenous relative prices. From the perspective of households, the objective is to maximize utility, which depends on the budget constraint. From the perspective of producers, the objective is to choose inputs to minimize costs, subject to the production function.

The CGE system of linear and nonlinear simultaneous equations comprises endogenous and exogenous variables and parameters that delineate the interrelationships between economic agents. The compatibility of their optimizing choices is ensured by the implementation and refinement of powerful solution algorithms (Scarf, 1967). Some elements of market imperfections have been introduced into Walrasian CGE models to account for varying degrees of substitution between intermediate goods and primary factors, which are traditionally fixed per unit of output. Furthermore, foreign trade and associated factors, such as the limited substitution between domestically produced and imported goods (Armington, 1969), have been integrated. The presence of the public sector, which implies the introduction of a taxation system, interinstitutional transfers, rigidities in government deficit or surplus formation, and final demand formation, has also been included. In

this context, less orthodox CGE models place emphasis on the links between macroeconomic equilibrating mechanisms and microeconomic distributional implications (Taylor, 1990).

These models are commonly employed to evaluate the equilibrium benchmark that arises from the calibration process in comparison to the counterfactual scenario that emerges from the implemented policies. On the one hand, they reflect the magnitude of these measures in terms of changes in the main macroeconomic aggregates; on the other hand, they trace their transmission channels and highlight the operators involved. The contribution of CGE modeling ranges from the demand and supply sides (Severini et al., 2019; Socci et al., 2021) to primary and secondary income distribution shocks or policy actions (Ciaschini et al., 2012). Moreover, as they are founded upon SAM databases, they are capable of formalizing the behavior and decisions of detailed breakdowns of commodities, activities, and income earners (institutional sectors).

The static CGE model developed in this study describes the behavior of economic agents and their interdependencies in light of the structure of the SAM for Pakistan, which has been constructed for this purpose and integrated with information on food nutrients by household. In this regard, the present study represents a progress in the field of SAM-based CGE modeling, as it bridges the SAM with food data from the Food and Agriculture Organization (FAO, 2022) and explicitly defines the relationships between economic and food variables within the CGE framework. In particular, a matrix of calorie intake has been constructed in order to integrate the disaggregated data on households from the SAM with information on food intake. Furthermore, a food consumption indicator has been developed to link the two databases in the CGE model, thereby incorporating the food security dimension into the policy-making process.

1.2.1 The SAM for Pakistan

The impact analysis of economic and specific food security policies in Pakistan requires the construction of a database that can accurately reflect the structure of the economy and quantify the aggregate and disaggregated economic flows occurring between operators, in addition to the distribution of income between these operators and the food consumed. This database is represented by the SAM for Pakistan and is constructed on the basis of the most recent publicly available SAM for Pakistan by the International Food Policy Research Institute (IFPRI) (Debowicz et al., 2012). It represents an accounting scheme that relates a static picture of the circular flow of income within the economic system over a defined time frame. Depending on the analytical specifications of the study, the SAM may present multiple disaggregation levels. The structure of the aforementioned SAM is updated to include a comprehensive list of food products and a disaggregation of households, emphasizing their location (urban or rural) and, in the case of rural households, farm ownership and size. Figure 1 illustrates the structure of the SAM for Pakistan.

Figure 1. The SAM framework for Pakistan (expressed in billion rupees).

	Commodity $i = 1, \dots, 63$	Primary factors		Taxes on output	Institutional sectors				Taxes on income	Capital formation	Total
		Labor	Capital		Firms	Households $hh = 1, \dots, 16$	Government	Rest of the World			
Commodity $i = 1, \dots, 63$	Intermediate consumption					Final consumption	Final consumption	Exports		Gross investment	
Primary factors	Labor	Gross value added						Factor income from the RoW			
	Capital										
	Taxes on output										
Institutional sectors	Firms	Primary distribution of income			Taxes on output revenues	Secondary distribution of income				Taxes on income revenues	
	Households $hh = 1, \dots, 16$										
	Government										
	Rest of the World										
	Imports	Factor income to the RoW									
	Taxes on income					Taxes on income					
	Capital formation					Savings		Net lending / borrowing			
	Total										

Source: own elaboration.

The block of production is described by a symmetric product-by-product matrix, which provides a breakdown into 63 commodities and depicts the productive structure of the country.² The SAM also includes two primary factors, labor and capital, taxes on output and taxes on income. The institutional sectors include sixteen groups of households, firms, the government and the Rest of the World (RoW).³ The capital formation account closes the scheme. The SAM makes explicit the link between final demand and the production structure of the economy. It takes the form of a balanced square matrix, in which outflows are listed in the columns and the receipts are entered in the rows.

The matrix of intersectoral flows records transactions related to a composite product or service, obtained from the aggregation of domestic and foreign production. Each commodity in the row is characterized by the flows directed at intermediate consumption, final consumption by households, the government, and the Rest of the World, as well as gross fixed capital formation and changes in inventories. Along the column, commodity outflows are distinguished between domestic production, the remuneration of primary factors, imports, and payments for taxes on output. The primary factor rows encompass the generation of value added and the allocation of factor income from the Rest of the World. In contrast, the corresponding columns delineate the distribution of capital and labor remunerations to the domestic and foreign institutional sectors on the basis of their ownership.

² The disaggregation of commodities in the SAM for Pakistan is provided in Appendix A, Table A.1.

³ The classification of institutional sectors in the SAM for Pakistan is shown in Appendix A, Table A.2.

Inflows associated with firms pertain to the derivation of their main source of income, the gross operating surplus, in addition to any transfer received from other firms, households, the government, and the Rest of the World. The outlays made by firms are linked to taxation, transfers to other institutional sectors, and savings.

In the case of households, the associated rows and columns delineate the phases that culminate in the determination of the institutional sector's disposable income. The primary distribution of income to households, predominantly in the form of compensation of employees for labor services, is followed by the process of redistribution of resources among households themselves, from/to firms, the government, and the Rest of the World. The household column classifies the uses of income for final consumption, direct tax payments, transfers, and savings.

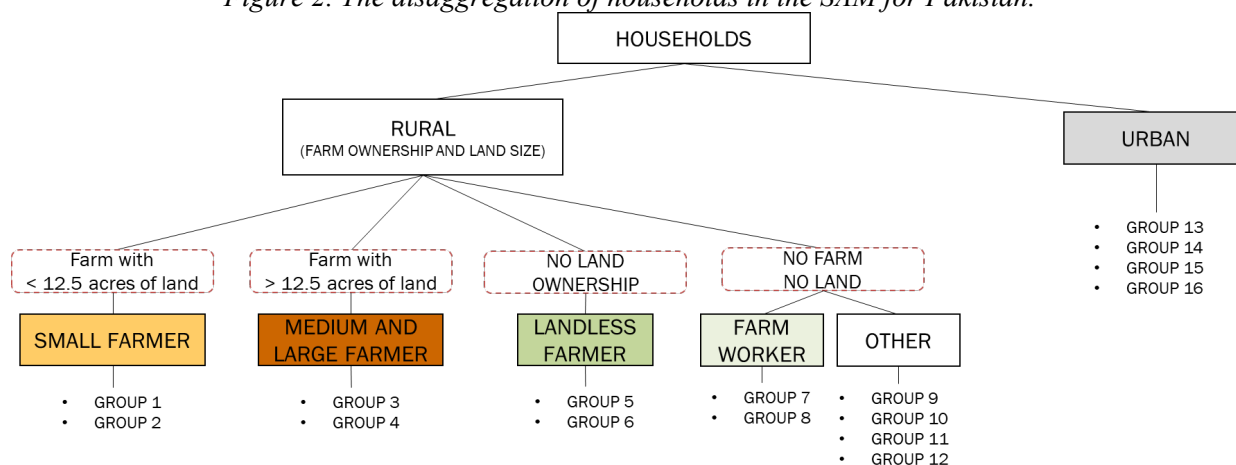
The government account records all transactions involving the central government. The primary source of revenue for this institutional sector is the tax system, which generates revenue from both direct and indirect taxes. In terms of expenditure, the government allocates revenue between current spending and transfers to various institutional sectors (i.e., households, firms, and the Rest of the World).

The Rest of the World inflows encompass import receipts, which include final goods and services, intermediate inputs, factor incomes from the domestic economy, and transfers from domestic institutional sectors. The RoW column includes purchases of domestic goods and services (i.e., exports), payments for factor incomes, and transfers to the domestic institutional sectors.

The capital formation row records receipts in the form of savings of domestic institutional sectors and the net lending or net borrowing position with respect to the Rest of the World. The column reports the final demand for investment that contributes to new capital formation and changes in inventories.

The disaggregation of households in the SAM for Pakistan results in a classification into sixteen per-capita income groups, as illustrated in Figure 2. This allows Pakistani policymakers to shape their strategies by identifying with greater accuracy their targets depending on the income and activity carried out.

Figure 2. The disaggregation of households in the SAM for Pakistan.



Source: elaboration on the SAM for Pakistan and Khan et al. (2018).

In particular, twelve of the sixteen household groups are situated in rural areas, while four are located in urban contexts. The rural households are classified into two categories based on two defining characteristics: farm ownership and land size. Households in rural areas that own a farm with an area of less than 12.5 acres are classified as small farmers. In contrast, rural households that own a farm with more than 12.5 acres of land are classified as medium and large farmers. The landless farmer subcategory comprises rural households that only own a farm but are not landowners. The farm worker category includes households that are employed on farms, as they are neither tenant farmers nor landowners. The other rural households are engaged in occupations other than agriculture and livestock.

The remaining four groups of households are identified as urban and are characterized by increasing per capita income, similarly to the rural classification. As shown in Table 1, the first subgroup has the lower per capita income compared to the others. For instance, it can be observed that the Pakistani population belonging to the HH1 (small farmer subgroup) earns 65,824 rupees per year, in contrast to the 142,820 rupees per year earned by the HH2 small farmer subgroup.

Table 1. Per capita income by Pakistani household group in thousand rupees.

<i>The household disaggregation</i>	<i>Code</i>	<i>Per capita income</i>
SMALL FARMER	HH1	65,824
SMALL FARMER	HH2	142,820
MEDIUM AND LARGE FARMER	HH3	57,692
MEDIUM AND LARGE FARMER	HH4	290,666
NO LAND OWNERSHIP - LANDLESS FARMER	HH5	57,646
NO LAND OWNERSHIP - LANDLESS FARMER	HH6	126,714
NO FARM AND NO LAND - FARM WORKER	HH7	37,739
NO FARM AND NO LAND - FARM WORKER	HH8	86,334
NO FARM AND NO LAND - OTHER	HH9	38,190
NO FARM AND NO LAND - OTHER	HH10	59,148
NO FARM AND NO LAND - OTHER	HH11	92,099
NO FARM AND NO LAND - OTHER	HH12	213,901
URBAN	HH13	46,037
URBAN	HH14	74,490
URBAN	HH15	116,026
URBAN	HH16	393,267

Source: elaboration based on the SAM for Pakistan.

1.2.2 The calorie intake matrix and the food indicator

The classification of households in the SAM for Pakistan serves as the foundation for developing an instrument, the calorie intake matrix, which can record baseline nutritional data and variations in calorie intake from food. The calorie intake matrix, shown in Table 2, provides a detailed view of food consumption patterns across the sixteen groups of Pakistani households. The data used to inform the matrix are per capita daily calories derived from FAO Food Balances (FAO, 2022). FAO considers 87 food items that do not exactly match the food commodity breakdown in the SAM for Pakistan, so the imputation process requires additional steps. In particular, it is possible to identify 49 FAO food items that can be univocally assigned to the 14 SAM

food subsets.⁴ The remaining food items from the FAO data set have been excluded from the analysis because they are not consumed according to the estimates set out in the FAO data.

Once the associations have been identified, the final step is to compute the total calories consumed by each group of households on an annual basis. The data on household group population, as provided by Khan et al. (2018), are multiplied by the number of calories consumed in the 14 SAM food subsets. This step involves the calculation of the total calories consumed by household group and food subset on a yearly basis, in coherence with the SAM time frame. The aforementioned matching procedure between FAO data and the SAM disaggregation of food commodities results in fourteen food consumption subsets, as illustrated in Table 2.

Table 2. The calorie intake matrix for Pakistan (billion calories).

Code	The household disaggregation	Sugarcane	All other crops	Other vegetables	Fruits & edible nuts	Poultry, domestic birds & eggs	Fishing	Meat & Meat Products	Milk & Dairy Products	Vegetable & animal oils & fats	Wheat Flour	IRRI Rice	Basmati Rice	Sugar	All other food	Average by group	Total
HH1	SMALL FARMER	3	109	47	90	40	6	84	534	484	1402	97	106	398	14	244	3414
HH2	SMALL FARMER	11	403	176	335	148	23	312	1983	1795	5204	362	394	1477	51	905	12675
HH3	MEDIUM AND LARGE FARMER	0	5	2	4	2	0	4	26	24	70	5	5	20	1	12	169
HH4	MEDIUM AND LARGE FARMER	2	76	33	63	28	4	58	371	336	974	68	74	277	10	169	2373
HH5	NO LAND OWNERSHIP - LANDLESS FARMER	2	87	38	72	32	5	67	426	386	1119	78	85	318	11	195	2726
HH6	NO LAND OWNERSHIP - LANDLESS FARMER	5	189	83	157	69	11	146	929	841	2438	170	184	692	24	424	5938
HH7	NO FARM AND NO LAND - FARM WORKER	5	164	72	136	60	9	127	807	730	2117	147	160	601	21	368	5157
HH8	NO FARM AND NO LAND - FARM WORKER	6	215	94	179	79	12	167	1058	958	2777	193	210	788	27	483	6763
HH9	NO FARM AND NO LAND - OTHER	9	326	143	271	120	18	253	1604	1453	4211	293	319	1195	41	733	10256
HH10	NO FARM AND NO LAND - OTHER	8	282	123	234	103	16	219	1387	1256	3640	253	275	1033	36	633	8866
HH11	NO FARM AND NO LAND - OTHER	7	236	103	196	86	13	182	1158	1048	3038	211	230	862	30	529	7400
HH12	NO FARM AND NO LAND - OTHER	5	164	71	136	60	9	127	805	728	2112	147	160	599	21	367	5143
HH13	URBAN	4	154	67	128	56	9	119	755	684	1983	138	150	563	19	345	4829
HH14	URBAN	6	229	100	190	84	13	177	1124	1017	2949	205	223	837	29	513	7182
HH15	URBAN	8	298	130	248	109	17	231	1466	1327	3847	267	291	1092	38	669	9370
HH16	URBAN	12	443	193	368	162	25	343	2176	1970	5711	397	432	1621	56	993	13909
Average by item		6	211	92	175	77	12	164	1038	940	2724	189	206	773	27		
Total		95	3379	1475	2808	1237	190	2617	16609	15038	43592	3031	3298	12373	428		

Source: elaboration from the SAM for Pakistan and FAO Food Balances.

The calorie intake matrix is composed of 16 rows, corresponding to the 16 household groups, and 14 columns, coinciding with the 14 SAM food subsets. The rows of the matrix display the breakdown of Pakistani households, whereas the columns are organized according to the categories of food items. In the rows of the

⁴ The 49 food items out of 87 considered by FAO Food Balances and the correspondence with the 14 food subsets obtained in the SAM for Pakistan are reported in Appendix B, Table B.1.

matrix, the data set reports calories consumed by each household group and for each different food item. In contrast, the columns indicate the calorie intake by food subset.⁵

A closer examination of the caloric consumption patterns observed in Pakistani households reveals that the most significant sources of calories are derived from wheat flour, vegetable and animal oils and fats, milk, and dairy products. Additionally, rice and sugar are nutrient-dense foods that serve a primary energetic function in Pakistani diets. The high yearly consumption of wheat flour indicates the necessity for targeted measures and particular attention with regard to its maintenance and improvement, resulting from different economic policies, across all income-level households.

The food indicator, derived from the calorie intake matrix, reports the total calories consumed by each group of Pakistani households. This is achieved by aggregating the energy derived from each food item, as outlined below:

$$FOOD_{hh} = \frac{\sum_j Calories_{j,hh}}{\sum_j Consumption_{j,hh}}$$

the subscript $j = 1, \dots, 14$ indicates food categories, whereas the subscript $hh = 1, \dots, 16$ refers to household groups. The indicator is calculated in the benchmark and varies in relation to the endogenous consumption component. As previously described, it captures the aggregated information on calories consumed, but it can also be disaggregated into its subsets to observe which food item drives global variations in the food basket.

1.2.3 The CGE model

The CGE model developed for Pakistan follows the structure of the SAM and formalizes the main relations between agents. This approach enables the tracing of the circular flow of income within the economy and the identification of the transmission mechanisms associated with policy simulations, including those pertaining to food security.⁶

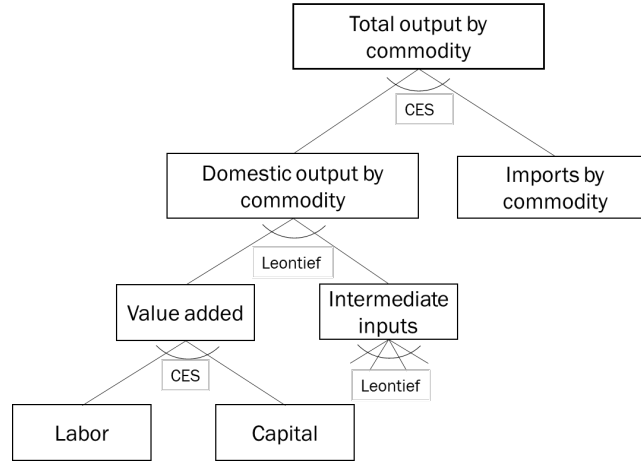
The production process is described by a multilevel nested function, whereby intermediate inputs and primary factors are combined to generate domestic output by commodity, as illustrated in Figure 3. Each nest identifies the subsequent level of aggregation and provides an overview of the multilevel nested framework of the technologies adopted. In the initial stage of the process, firms combine primary factors, namely labor and capital, to generate value added following a Constant Elasticity of Substitution (CES) functional form.

At the second level of nesting, intermediate inputs are combined with the labor-capital aggregate. This combination results in domestic production by commodity. The generation of domestic output is achieved through fixed-proportion inputs, as expressed by the Leontief production function, which denotes the complementarity between intermediate inputs and value added. Domestic production by commodity is merged with imports from the Rest of the World to determine the total output of the economy by means of a CES technology.

⁵ The calorie intake matrix expressed as the ratios of calories to household incomes is provided in Appendix B, Table B.2.

⁶ The complete model specification is provided in Appendix C.

Figure 3. The multilevel nested production function.



Source: own elaboration.

In consideration of this structure, it is possible to construct the associated cost function for each nest, which contains essentially the same information as the production function, by applying the principle of duality (Socci et al., 2023). Accordingly, the CES production function in coefficient form can be transformed into the CES cost function in coefficient form. The final price of total output by commodity P_i can be derived as follows:

$$P_i(1 - t_{out_i}) = [\beta_i^D P_{D,i}^{1-\sigma_D} + (1 - \beta_i^D) P_{M,i}^{1-\sigma_D}]^{\frac{1}{1-\sigma_D}} \quad (1)$$

The subscript $i = 1, \dots, 63$ refers to the Pakistani commodity, and t_{out_i} denotes the tax rate applied to the output of a given commodity. The parameter β_i^D is the share of domestic production in total production by commodity, and $P_{D,i}$ is the price of domestic goods and services. Thus, $(1 - \beta_i^D)$ indicates the share of imports in total production by commodity, while $P_{M,i}$ is the price of imports. The CES technology is applied to domestic production and imports, so the parameter of the elasticity of substitution σ_D differs from zero (Armington, 1969).⁷

The price of domestic goods $P_{D,i}$ is determined by the combination of the costs associated with primary factors and intermediate inputs:

$$P_{D,i} = \beta_i^{IF} P_{IF,i} + (1 - \beta_i^{IF}) P_{VA,i} \quad (2)$$

The variable $P_{IF,i}$ is the price of intermediate inputs, multiplied by β_i^{IF} that represents the share of intermediate inputs in domestic production. The variable $P_{VA,i}$ is the price of value added obtained from the combination of labor and capital, and $(1 - \beta_i^{IF})$ is the share of value added in domestic production.

The price of intermediate inputs is calculated by aggregating the average final prices of each good and service, considering their relative share in total costs for intermediate inputs:

⁷ In the model, the value of σ_D is set to 0.3 and all other parameters and shares are calibrated on the basis of the flows in the SAM.

$$P_{IF,i} = \sum_i \beta_i^{IN} P_i \quad (3)$$

The variable P_i is the final price of commodities, while the coefficient β_i^{IN} is the cost share of each intermediate input in total costs for intermediate inputs. The intermediate inputs are combined through a Leontief functional form.

The cost of value added is derived from the combination of the costs of factors of production – labor and capital – for each commodity, as follows:

$$P_{VA,i} = [\beta_i^{PF} PL^{1-\sigma_{PF}} + (1 - \beta_i^{PF}) PK^{1-\sigma_{PF}}]^{\frac{1}{1-\sigma_{PF}}} \quad (4)$$

The variable PL is the cost of labor, while the variable PK is the cost of capital. The parameters β_i^{PF} and $(1 - \beta_i^{PF})$ denote the respective shares of labor and capital employed in production processes in total value added cost, respectively. The elasticity of substitution between labor and capital σ_{PF} is assumed to be constant and equal to 1.88 (Lin & Raza, 2021).

The total supply of domestic and foreign goods and services must be equal to the total demand for intermediate consumption, final consumption by households and the government, and investment. In consideration of the fact that the matrix of intersectoral flows is symmetric, the market clearing condition can be written as follows when the equality $i = j$ is assumed:

$$\sum_i P_i Y_i = P_i \left(\sum_j B I_{i,j} + \sum_i \sum_{hh} C_{i,hh} + \sum_i G_{i,gov} + \sum_i I_i + \sum_i EX_i \right) \quad (5)$$

Thus, assuming the perfect competitiveness in all markets of goods and services, prices fluctuate in order to achieve the equilibrium between the left and right sides of the equation (5), clearing the markets of goods from excess demand or supply. Similarly, the market clearing condition is assumed to apply to the primary factors as well, whose prices fluctuate in order to balance their demand with the total supply, which is represented by institutional sector endowments:

$$\sum_{inst} (PL \cdot L_{inst}) = \sum_i (PL \cdot L_i) \quad (6)$$

$$\sum_{inst} (PK \cdot K_{inst}) = \sum_i (PK \cdot K_i) \quad (7)$$

The variables L_{inst} and K_{inst} indicate the total supply of labor and capital, respectively, corresponding to the endowments of institutional sectors. Contrarily, L_i and K_i represent the demand for labor and the demand for capital by production process, respectively.

On the demand side, the demand for goods for intermediate consumption $B I_i$ is determined endogenously by production processes. The demand for final consumption by commodity C_i is derived from the aggregation of the demand expressed by each household, which is assumed to maximize the utility function U_{hh} :

$$\max U_{hh} = \sum_i C_{i,hh} \quad (8)$$

The variable $C_{i,hh}$ represents consumption diversified by commodity and household. The utility function is expressed through a CES functional form, where the elasticity of substitution among between commodities is set equal to zero in order to inhibit substitution in terms of consumption across different goods. The solution to the maximization process allows for the determination of the levels of consumption and savings that are compatible with disposable income, according to the following constraint:

$$\text{disp_inc}_{hh} = \sum_i C_{i,hh} + S_{hh} \quad (9)$$

for $i = 1, \dots, 63$ goods and services in the economy. The summation $\sum_i C_{i,hh}$ is defined as the total consumption level of each group of households, while S_{hh} is the amount of savings.

The primary income of households pr_inc_{hh} is obtained by summing the remunerations of primary factors employed in the $i = 1, \dots, 63$ commodities:

$$\text{pr_inc}_{hh} = \varphi_{hh} \sum_i PLL_i + \vartheta_{hh} \sum_i PKK_i \quad (10)$$

The variables L_i and K_i represent the amount of labor and capital factors, respectively, used in the production process of each commodity. The quota φ_{hh} indicates the share of labor allocated to households as compensation of employees, whereas ϑ_{hh} represents the share of capital allocated to households as gross operating surplus. These shares are calculated with respect to factor ownership.

The secondary income of households sec_inc_{hh} is calculated by adding the transfers received to the primary income pr_inc_{hh} :

$$\text{sec_inc}_{hh} = \text{pr_inc}_{hh} + \sum_{inst} Tr_{hh,inst} \quad (11)$$

In equation (11) and in the equations presented below, the subscripts related to transfers indicate the direction of the flow in accordance with the matrix logic of the SAM. Thus, $Tr_{n,k}$ denotes transfers from the k^{th} institutional sector to the n^{th} institutional sector. The summation $\sum_{inst} Tr_{hh,inst}$ defines the incoming resources to households, and $inst \subseteq \{hh, fir, gov, row\}$ illustrates the set of institutional sectors. In particular, the subscript fir denotes corporations, the subscript gov indicates the government, and the subscript row identifies the Rest of the World.

The secondary income thus composed is allocated by households to payment of taxes, final consumption, transfers to other institutional sectors, and in a residual way to savings. This process leads to the determination of disposable income, denoted as disp_inc_{hh} :

$$\text{disp_inc}_{hh} = \text{sec_inc}_{hh} - t_redd_{hh} \text{pr_inc}_{hh} - \sum_{inst} Tr_{inst,hh} \quad (12)$$

In equation (12), the coefficient t_redd_{hh} is the implicit income tax rate by household group, pr_inc_{hh} is the tax base, which is differentiated by household group (i.e., the primary income). The summation $\sum_{inst} Tr_{inst,hh}$ represents outgoing transfers from households to the other institutional sectors.

The disposable income of firms is defined as the share of the remuneration of capital used in production processes and transfers received, net of direct taxes and outgoing transfers:

$$disp_inc_{fir} = \vartheta_{fir} \sum_i PK K_i + \sum_{inst} Tr_{fir,inst} - t_redd_{fir} PK K_{fir} - \sum_{inst} Tr_{inst,fir} \quad (13)$$

From the perspective of the government, the institutional sector is distinguished by a behavioral norm that diverges from the objective of maximizing the utility function. In contrast, the government employs a range of fiscal policies and measures that ultimately translate into either a surplus or a deficit. The disposable income of the government can be expressed as follows:

$$disp_inc_{gov} = G_{gov} + S_{gov} + OR_{gov} \quad (14)$$

The variable G_{gov} is defined as public expenditure, S_{gov} represents savings and OR_{gov} is the balance item that defines the amount of resources in surplus or deficit with respect to the sum of public expenditure and savings. Government expenditure is exogenous in real terms and endogenous in nominal terms.

The disposable income of the government is derived from the difference between tax levies – namely, direct taxes on household and corporate incomes and indirect taxes on output – transfers received from the other institutional sectors and transfers paid by the government:

$$\begin{aligned} disp_inc_{gov} = & \sum_{hh} t_redd_{hh} pr_inc_{hh} + \sum_{fir} t_redd_{fir} pr_inc_{fir} + \sum_i t_out_i P_i Y_i \\ & + \sum_{inst} Tr_{gov,inst} - \sum_{inst} Tr_{inst,gov} \end{aligned} \quad (15)$$

The income of the Rest of the World consists of its primary income, import revenues, and transfers received from domestic institutional sectors, less transfers paid to the domestic institutional sectors:

$$\begin{aligned} disp_inc_{row} = & \varphi_{row} \sum_i PL L_i + \vartheta_{row} \sum_i PK K_i + \sum_i P_{M,i} M_i + \sum_{inst} Tr_{row,inst} \\ & - \sum_{inst} Tr_{inst,row} \end{aligned} \quad (16)$$

The quota φ_{row} indicates the share of compensation of employees allocated to the Rest of the World, while ϑ_{row} represents the share of gross operating surplus allocated to the Rest of the World.

Ultimately, this model is savings-driven. The macroeconomic closure is ensured by the equilibrium between the flow of savings and the flow of the demand for investment:

$$\sum_{inst} S_{inst} = \sum_i I_i \quad (17)$$

1.3 Policy scenarios for food access and security

The static SAM-based CGE model for Pakistan is evaluated through the implementation of standard policy exercises that impact the supply side and the secondary distribution of income. The objective is to ascertain

the impact of alterations in the production structure and resource allocation across institutional sectors on both the overall economic performance, food access, and security. The selected policies enable an investigation of the behavior of the model when integrated with information on dietary requirements.

The shocks in question are standard, amounting to 1% of GDP, which corresponds to 180 billion rupees. In the context of the policy scenarios, the term ‘standard shock’ refers to a shock amounting to 1% of GDP, as calculated in the SAM database. The following three policy scenarios for food access and security are the subject of evaluation:

- The first scenario entails a 12% reduction in the output tax rate applicable to wheat milling and flour production.
- The second scenario considers a policy of transfers from the government to households. The distribution of these transfers is based on the computed shares of wheat flour consumption during the calibration procedure. In this scenario, all household groups receive transfers from the government, as wheat flour plays a central role in the food bundle across Pakistani regions, activities carried out, and income earned.
- The third scenario under examination operates on the redistribution side. This policy is characterized by a decrease in the tax rate on income for households, which represents an alternative channel for increasing the disposable income, thus influencing consumption and, in a residual manner, savings. The objective is to observe the impact on food assimilation in terms of caloric intake. The reduction is applied in a proportional manner to taxes on income paid by each household group, as calculated in the calibration procedure. It is noteworthy that this third policy affects household groups in a manner that differs from the previous two. Indeed, eight of the household groups in question (HH1, HH3, HH5, HH7, HH9, HH10, HH13, and HH14) are not subject to income tax charges. As previously shown in Table 1, the aforementioned groups exhibit lower per capita incomes in comparison to the other groups. As a result, this policy scenario increases the disposable income of taxpayers (HH2, HH4, HH6, HH8, HH11, HH12, HH15, and HH16). The decrease in the income tax rate yields a decline in tax revenues for the Pakistani government, with a loss of 180 billion rupees, which is equivalent to the policy amount.

1.3.1 Simulation results and comparison

The selection of an identical amount of resources allows for a comparison between the policy scenarios and the observation of the channels that they activate through the circular flow of income. The objective is to investigate the similarities and differences between supply-side and redistribution policies in the Pakistani economy in terms of changes in the main macroeconomic variables, household income, and food consumption. These effects are reported in Table 3.

The policies based on the reduction of tax rates, corresponding to Scenarios 1 and 3, as well as the policy on transfers, have a positive effect on private consumption. This is attributable to an increase in primary

incomes, as well as a reduction in the tax burden and an increase in transfers. The beneficial impact on private consumption is more pronounced in the case of the reduction in the output tax rate on wheat flour (+1.1%) and in the rise of transfers (+1.2%) than in the scenario that allows for a lower income tax burden.

Table 3. Impact on real macroeconomic variables, GDP deflator, and the multiplier in the three scenarios (percentage change from the benchmark).

<i>Real aggregate</i>	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>
GDP	0.9	1.0	0.3
Private consumption	1.1	1.2	0.5
SMALL FARMER (HH1)	2.1	2.1	0.1
SMALL FARMER (HH2)	1.2	1.3	0.2
MEDIUM AND LARGE FARMER (HH3)	2.4	2.4	0.1
MEDIUM AND LARGE FARMER (HH4)	0.8	0.9	0.3
NO LAND OWNERSHIP - LANDLESS FARMER (HH5)	2.1	2.2	0.1
NO LAND OWNERSHIP - LANDLESS FARMER (HH6)	1.4	1.4	0.8
NO FARM AND NO LAND - FARM WORKER (HH7)	2.1	2.2	0.1
NO FARM AND NO LAND - FARM WORKER (HH8)	1.4	1.5	0.4
NO FARM AND NO LAND – OTHER (HH9)	2.0	2.2	0.1
NO FARM AND NO LAND – OTHER (HH10)	1.6	1.8	0.1
NO FARM AND NO LAND – OTHER (HH11)	1.2	1.3	0.8
NO FARM AND NO LAND – OTHER (HH12)	0.6	0.7	1.4
URBAN (HH13)	1.7	1.9	0.1
URBAN (HH14)	1.3	1.5	0.1
URBAN (HH15)	1.1	1.2	0.8
URBAN (HH16)	0.6	0.7	0.4
Investment	1.6	1.7	-0.5
Export	0.0	-0.2	-0.1
Import	0.6	0.8	0.2
GDP deflator	-1.13	0.30	0.14
Multiplier	0.94	0.97	0.26

Source: CGE model estimates.

In particular, the reduction in the tax rate on wheat milling and flour has the effect of directly stimulating the production process and indirectly boosting the production of intermediate commodities. This, in turn, paves the way to increased demand for primary factors of production, as well as higher investments, which exhibit an increase of 1.6%. In Scenario 1, exports are not significantly impacted; however, in the second and third formulated policies, they experience a decrease, which is partly referable to the reduction in the competitiveness of domestic commodities, as evidenced by the rise in the GDP deflator. Conversely, post-

simulation imports exceed the benchmark levels in all scenarios, reflecting the necessity to meet the increase in final demand.

The impulse to final demand is observed across all groups of households in each policy scenario. However, this impulse is less pronounced in Scenario 3 (+0.5%), as only eight household groups are subject to income taxation. The uneven structure of income taxes gives rise to peculiar effects within the circular flow of income in the Pakistani system. Taxpayers demonstrate a greater incline towards increasing final consumption than non-taxpayers. Conversely, the demand for investments in the economy declines (-0.5%), indicating a deceleration in the economic activity. With regard to the impact on final consumption in Scenarios 1 and 2, it is relevant to highlight that lower per capita income groups (HH1, HH3, HH5, HH7, HH9, HH10, HH13, and HH14) tend to increase their consumption to a greater extent than higher per capita income groups. The described outcomes would suggest a favorable impact on calorie intake.

The aggregate effect on GDP is positive across all scenarios. The policy on transfers, corresponding to Scenario 2, generates the most substantial increase in real terms. However, the multiplier effect, defined as the ratio between the percentage variation in real GDP and the resources devoted to the policy measure, does not exceed unity. The policy based on the reduction in income tax rates demonstrates a lower multiplicative value due to the restricted tax base. Table 4 reports the changes in tax revenues.

Table 4. Impact on tax revenues in the three scenarios (percentage change from the benchmark).

<i>Tax revenue</i>	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>
Taxes on income	-0.13	0.41	-5.41
Taxes on output	-0.83	15.0	2.98

Source: CGE model estimates.

The 12% reduction in the output tax rate on wheat flour in Scenario 1, which corresponds to 1% of Pakistani GDP, has the effect of stimulating wheat flour production. This, in turn, leads to an increase in demand for intermediate inputs, imports, and factors of production in order to expand output. On the one hand, the Pakistani government's revenue from taxes on output declines by -0.83%. On the other hand, income tax revenues collected fall below the benchmark equilibrium, with a decrease of -0.13%.

Scenario 2, which is related to transfers from the government to households, is associated with a slight expansion in income tax revenues, given that transfers occur following the imposition of tax levies. On the contrary, taxes on output by commodity collected by the government rise by 15% as a result of increased disposable incomes and thus consumption, which in turn encourages production processes, thereby reinitiating the circular flow of income. Scenario 3 entails a decrease in income tax revenues by 5.41% as a direct impact of the policy that lowers the implicit tax rate on income for households. This effect on income tax levies is coupled with a 2.98% increase in taxes on output by commodity, given that rising disposable incomes allow for higher final demand, driving an acceleration in production processes.

From the food consumption perspective observed in Table 5, all three policies are effective in increasing the calories consumed by Pakistani households, but to different extents.

Table 5. Impact on real incomes and the $FOOD_{hh}$ indicator in the three scenarios (percentage change from the benchmark).

Households	Scenario 1		Scenario 2		Scenario 3	
	Real incomes	$FOOD_{hh}$	Real incomes	$FOOD_{hh}$	Real incomes	$FOOD_{hh}$
SMALL FARMER	1.29	2.13	2.15	2.15	0.09	0.09
SMALL FARMER	1.32	1.24	1.26	1.27	0.15	0.16
MEDIUM AND LARGE FARMER	1.25	2.40	2.40	2.39	0.11	0.10
MEDIUM AND LARGE FARMER	1.29	0.83	0.90	0.93	0.25	0.26
NO LAND OWNERSHIP - LANDLESS FARMER	1.28	2.15	2.18	2.17	0.10	0.10
NO LAND OWNERSHIP - LANDLESS FARMER	1.28	1.36	1.42	1.42	0.75	0.76
NO FARM AND NO LAND - FARM WORKER	1.14	2.12	2.25	2.24	0.11	0.11
NO FARM AND NO LAND - FARM WORKER	1.21	1.44	1.52	1.52	0.38	0.38
NO FARM AND NO LAND – OTHER	1.03	2.04	2.23	2.23	0.11	0.11
NO FARM AND NO LAND – OTHER	1.11	1.65	1.80	1.80	0.10	0.10
NO FARM AND NO LAND – OTHER	1.17	1.20	1.31	1.32	0.81	0.81
NO FARM AND NO LAND – OTHER	1.30	0.65	0.70	0.73	1.43	1.44
URBAN	1.07	1.75	1.95	1.95	0.11	0.11
URBAN	1.10	1.34	1.53	1.53	0.11	0.11
URBAN	1.17	1.07	1.22	1.23	0.75	0.75
URBAN	1.29	0.61	0.70	0.72	0.44	0.45
Total	1.25	1.36	1.11	1.47	0.47	0.38

Source: CGE model estimates.

In particular, there is a correlation between changes in calorie intake and alterations in real disposable incomes following the implementation of redistributive policies in Scenarios 2 and 3. The enhanced spending capacity of households gives rise to comparable shifts in food consumption patterns.

In Scenario 1, which entails a reduction in the output tax rate on wheat flour production, the consumption of food increases to a greater extent than real incomes for all low-income subgroups. Although in this case the rise in real incomes does not show distinctive differences across household groups, low-income subgroups express a considerably higher demand for calorie requirements with respect to higher-income households. In this sense, the supply-side policy demonstrates its potential to ensure food access and security, even in the absence of proper policies addressing income inequalities.

In contrast, the implementation of a policy of transfers based on flour consumption quotas calculated in the calibration procedure (Scenario 2) results in a notable increase in real incomes of low-income household subgroups. This is accompanied by a comparable increase in their food consumption. In addition to being effective in the field of food issues, this policy scenario is more equalizing than the other two, as it results in enhanced spending capacity for low-income households and a more modest increase in real incomes for upper-middle-income households. Therefore, Scenario 2 proposes that a redistributive policy that establishes

consumption quotas as a reference point for the allocation of resources, in place of minimum income thresholds, can have play a decisive role in ensuring food access and security.

The results of Scenario 3, which contemplate a reduction in the rate of taxes on income in proportion to the implicit tax rates calculated in the calibration procedure, diverge from the aforementioned policies in terms of both real incomes and calorie consumption. The increase in real disposable income is more pronounced among middle- and upper-income households than among low-income households, with a corresponding variation in nutrient assimilation.

1.4 Sensitivity analysis

The results obtained for the static SAM-based CGE model for Pakistan with information on the caloric intake must be validated with regard to their response to the exogenous parameters. In this manner, the robustness of the impacts on the macroeconomic aggregates can be confirmed. Therefore, a sensitivity analysis is conducted on the elasticity of substitution between labor and capital, denoted as σ_{PF} . The objective is to explore the impact of changes in the value of the elasticity of substitution between primary factors of production on their respective contributions to production processes and the transmission mechanisms of economic policies throughout the system.

The model is based on the assumption that labor and capital are combined through a CES technology to generate the value-added constraint, with the elasticity of substitution fixed at 1.88 according to econometric estimates (Lin & Raza, 2021). Upon decreasing and increasing this value by 10% and 20%, the model outcomes remain largely unaffected in comparison to the benchmark, as evidenced in Table 6, Table 7, and Table 8 for Scenarios 1, 2, and 3, respectively.

Table 6. Impact of the change in the elasticity of substitution σ_{PF} on real macroeconomic aggregates in Scenario 1 (percentage change from the benchmark).

<i>Aggregate</i>	<i>-20%</i>	<i>-10%</i>	<i>Benchmark</i>	<i>+10%</i>	<i>+20%</i>
GDP	1.0	1.0	0.9	1.2	0.4
Private consumption	1.1	1.1	1.1	1.5	0.7
Investment	1.7	1.6	1.6	1.6	1.0
Exports	-0.1	0.0	0.0	0.7	-1.4
Imports	0.7	0.7	0.6	1.6	0.4
GDP deflator	-1.02	-1.08	-1.13	-0.47	-0.50

Source: CGE model estimates.

Table 7. Impact of the change in the elasticity of substitution σ_{PF} on real macroeconomic aggregates in Scenario 2 (percentage change from the benchmark).

Aggregate	-20%	-10%	Benchmark	+10%	+20%
GDP	0.9	0.9	1.0	1.0	1.0
Private consumption	1.1	1.1	1.2	1.2	1.2
Investment	1.6	1.6	1.7	1.7	1.8
Exports	-0.2	-0.2	-0.2	-0.2	-0.2
Imports	0.8	0.8	0.8	0.9	0.9
GDP deflator	0.32	0.31	0.3	0.29	0.28

Source: CGE model estimates.

Table 8. Impact of the change in the elasticity of substitution σ_{PF} on real macroeconomic aggregates in Scenario 3 (percentage change from the benchmark).

Aggregate	-20%	-10%	Benchmark	+10%	+20%
GDP	0.2	0.3	0.3	0.3	0.3
Private consumption	0.4	0.5	0.5	0.5	0.5
Investment	-0.6	-0.6	-0.5	-0.5	-0.5
Exports	-0.1	-0.1	-0.1	-0.1	-0.1
Imports	0.1	0.1	0.2	0.2	0.2
GDP deflator	0.14	0.14	0.14	0.14	0.14

Source: CGE model estimates.

1.5 Conclusions

The Government of Pakistan is greatly concerned about the future implications of climate change and population growth on food security. In light of these concerns, the Government has explicitly identified the optimization of agricultural practices and crop differentiation as key targets for the consolidation of national security over the 2022-2026 period. The Government has not yet delineated the dedicated policies and resources that may be required to assess the current composition of the nutritional basket of households and analyze the impact of post-policy adjustments.

Therefore, this study aims to provide policymakers with reliable instruments that can assess the effect of economic policies from a perspective that departs from the conventional measures of primary and secondary income distribution. Specifically, the study seeks to examine the impact of economic policies on food access and security. To this end, the calorie intake matrix has been constructed, which conveys disaggregated and detailed information on the dietary habits of Pakistani households. The matrix is linked to a static CGE model for Pakistan, which has been calibrated on a SAM that integrates the household breakdown into 16 groups. The attempt is to incorporate nutritional accounting into national accounting, using statistical sources on food consumption patterns to provide public actors with a dual key to understanding the implications of their decisions and an assessment of the basic needs involved in policymaking.

The analysis thus investigates the direct, indirect, and induced impacts of three selected policy scenarios, represented by standard shocks, on macroeconomic variables and their implications for food access and security through a comprehensive indicator. The selection of standard shocks, amounting to 1% of

Pakistani GDP, is justified by the necessity of testing the model in operation for the first time. The mentioned policy scenarios affect the supply and the secondary distribution sides in order to explore alternative propagation channels to consumption, which in turn is related linearly to the food indicator. The effectiveness of these policies in stimulating food access and security is then examined. This approach offers a potential means of verifying the reliability of food results through mechanisms that affect income formation and redistribution, as opposed to fiscal policies that directly encourage private consumption.

The economic system, food access, and security benefit from the implementation of all three policies. Of these, the policy of transfers plays the most significant role in simultaneously improving access to food and the spending capacity of low-income households. This outcome would suggest a need for a redesign of the policies of transfers using the most consumed food quotas relative to other food commodities as the allocation method, with the aim of achieving equalizing impacts on real disposable incomes and directing resources towards a more substantial and nutrient-rich calorie intake.

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Appendix A

A.1. The classification of commodities in the SAM for Pakistan.

<i>Code</i>	<i>Definition</i>	<i>Code</i>	<i>Definition</i>
g1	Wheat	g34	Manufacture of all other textiles (synthetic fibers, yarns & fabrics; carpets, rugs, ropes & cordage, embroidery etc.)
g2	Paddy - IRRI	g35	Tanning of leather, manufacture of leather garments, fur garments, all footwear, luggage & saddlery
g3	Paddy - Basmati	g36	Sawmilling, chipping, shaping, treating of wood; and manufacture of wood products (panels, boards, plywood, veneer sheets, containers etc.)
g4	Raw Cotton	g37	Petroleum products incl. petroleum gases
g5	Sugarcane	g38	Fertilizers & Pesticides - Fertilizers & nitrogen compounds; and pesticides & agrochemical products
g6	Maize	g39	Chemicals (not including: fertilizers, pesticides - see FNP). Radioactive elements included here
g7	Oilseeds (sunflower, soyabean, mustard & rapeseed, linseed etc.)	g40	Cement, and all quarry-related products: lime, plaster, mixed concrete. Also included here: articles of fiber cement, concrete, plaster, mortars etc. for construction...
g8	All other crops (bajra, jowar, pulses, fodders, tobacco, flowers etc.)	g41	Baked construction products: ceramic tiles & flags, construction products of baked clay. Glass and glass products
g9	Potato	g42	Iron, steel and nonferrous metals
g10	Other vegetables	g43	Metal products (cutlery, buckets, etc.)
g11	Fruits & edible nuts (almond, pistachio etc.; groundnuts also included here).	g44	Domestic appliances and office machinery
g12	Cattle, sheep, goats etc. - including wool & hair, raw fur skin & hides, and animal husbandry services; but not raw milk - see MILK	g45	General and specialized machinery (e.g., for use in production processes)
g13	Raw milk	g46	Vehicles and transport equipment
g14	Poultry (& other domestic birds) - including eggs	g47	Paper, publishing, furniture
g15	Forestry (timber, logging & wild forest materials) and Hunting	g48	Electricity generation
g16	Fishing	g49	Electricity distribution
g17	Mining of crude oil	g50	Construction
g18	Mining of natural gas	g51	Wholesale & retail trade
g19	Mining of coal, lignite, peat. Coke oven products also included here (coke of coal, tar, other coke)	g52	Hotels & restaurants
g20	Other mining	g53	Transport, cargo-handling & storage
g21	Meat & Meat Products: slaughtering, prep. of meat products, processing of raw hides & skins, offal etc. (Rendering of edible fats excluded - see EDOIL).	g54	Telecomm, courier, post, cable TV providers, & internet service providers
g22	Milk, cream, ghee, butter, curd, cheese, ice-cream	g55	Finance (public and private financial sector inst.)
g23	Vegetable & animal oils & fats - may include non-edible products as well (waxes). Also, includes rendering & refining of edible fats (in meat processing).	g56	Business services
g24	Wheat Milling (Wheat Flour)	g57	Services of real estate agents and housing cooperative societies
g25	Rice Husking & Milling - IRRI	g58	Ownership of Dwellings
g26	Rice Husking & Milling - Basmati	g59	Public services other than health & education (public admin & defense, other)
g27	Sugar	g60	Public and private education services
g28	All other food, beverage and tobacco products	g61	Public and private health and social work services
g29	Cotton Ginning (lint)	g62	Services of domestic staff
g30	Cotton Spinning & Preparation of fibers (yarn) but may include other yarns of natural fibers (wool, silk)	g63	All other services (renting of machinery, sport recreation culture, membership org, other) as well as repair of M. Vehicles, personal services
g31	Cotton Weaving (cloth incl. cotton fabrics, terry toweling, weaving on khadi/handloom)		
g32	Knitted, crocheted textile articles		
g33	Wearing apparel (excluding articles of leather & fur; see LEAT)		

A.2. The classification of institutional sectors in the SAM for Pakistan.

<i>Institutional sector</i>	<i>Description</i>
Firms	Corporations
HH1	Rural small farmer (quartile 1)
HH2	Rural small farmer (quartile 234)
HH3	Rural medium+ farmer (quartile 1)
HH4	Rural medium+ farmer (quartile 234)
HH5	Rural landless farmer (quartile 1)
HH6	Rural landless farmer (quartile 234)
HH7	Rural farm worker (quartile 1)
HH8	Rural farm worker (quartile 234)
HH9	Rural non-farm (quartile 1)
HH10	Rural non-farm (quartile 2)
HH11	Rural non-farm (quartile 3)
HH12	Rural non-farm (quartile 4)
HH13	Urban (quartile 1)
HH14	Urban (quartile 2)
HH15	Urban (quartile 3)
HH16	Urban (quartile 4)
Government	Central government
Rest of the World	External institutional sectors

Appendix B

B.1. Correspondence between food items from FAO and food items in the SAM for Pakistan.

Number	FAO food item	SAM food item		Number	FAO food item	SAM food item	
		Code	Description			Code	Description
1	Wheat and products	g24	Wheat Flour	28	Tomatoes and products	g10	Other vegetables
2	Rice and products	g25 g26	IRRI Rice Basmati Rice	29	Onions	g10	Other vegetables
3	Barley and products	g8	All other crops	30	Vegetables, Other	g10	Other vegetables
4	Millet and products	g8	All other crops	31	Oranges, Mandarins	g11	Fruits & edible nuts
5	Sorghum and products	g8	All other crops	32	Bananas	g11	Fruits & edible nuts
6	Cereals, Other	g8	All other crops	33	Apples and products	g11	Fruits & edible nuts
7	Potatoes and products	g10	Other vegetables	34	Dates	g11	Fruits & edible nuts
8	Roots, Other	g10	Other vegetables	35	Grapes and products (excl wine)	g11	Fruits & edible nuts
9	Sugar cane	g5	Sugarcane	36	Fruits, Other	g11	Fruits & edible nuts
10	Sugar non-centrifugal	g27	Sugar	37	Tea (including mate)	g28	All other food
11	Sugar (Raw Equivalent)	g27	Sugar	38	Pimento	g10	Other vegetables
12	Sweeteners, Other	g28	All other food	39	Spices, Other	g28	All other food
13	Beans	g8	All other crops	40	Bovine Meat	g21	Meat & Meat Products
14	Peas	g8	All other crops	41	Mutton & Goat Meat	g21	Meat & Meat Products
15	Pulses, Other and products	g8	All other crops	42	Poultry Meat	g14	Poultry, domestic birds & eggs
16	Nuts and products	g11	Fruits & edible nuts	43	Offals, Edible	g21	Meat & Meat Products
17	Groundnuts	g11	Fruits & edible nuts	44	Butter, Ghee	g22	Milk & Dairy Products
18	Coconuts - Incl Copra	g11	Fruits & edible nuts	45	Fats, Animals, Raw	g23	Vegetable & animal oils & fats
19	Soyabean Oil	g23	Vegetable & animal oils & fats	46	Eggs	g14	Poultry, domestic birds & eggs
20	Groundnut Oil	g23	Vegetable & animal oils & fats	47	Milk - Excluding Butter	g22	Milk & Dairy Products
21	Sunflower seed Oil	g23	Vegetable & animal oils & fats	48	Freshwater Fish	g16	Fishing
22	Rape and Mustard Oil	g23	Vegetable & animal oils & fats	49	Pelagic Fish	g16	Fishing
23	Cottonseed Oil	g23	Vegetable & animal oils & fats				
24	Palm kernel Oil	g23	Vegetable & animal oils & fats				
25	Palm Oil	g23	Vegetable & animal oils & fats				
26	Rice bran Oil	g23	Vegetable & animal oils & fats				
27	Oil crops Oil, Other	g23	Vegetable & animal oils & fats				

B.2. The calorie intake matrix for Pakistan (ratio of calories to household income).

Code	The household disaggregation	Sugarcane	All other crops	Other vegetables	Fruits & edible nuts	Poultry, domestic birds & eggs	Fishing	Meat & Meat Products	Milk & Dairy Products	Vegetable & animal oils & fats	Wheat Flour	IRRI Rice	Basmati Rice	Sugar	All other food
HH1	SMALL FARMER	0.011	0.39	0.17	0.33	0.14	0.02	0.31	1.94	1.75	5.09	0.35	0.38	1.44	0.05
HH2	SMALL FARMER	0.005	0.18	0.08	0.15	0.07	0.01	0.14	0.89	0.80	2.33	0.16	0.18	0.66	0.02
HH3	MEDIUM AND LARGE FARMER	0.011	0.38	0.17	0.32	0.14	0.02	0.30	1.87	1.70	4.92	0.34	0.37	1.40	0.05
HH4	MEDIUM AND LARGE FARMER	0.002	0.09	0.04	0.07	0.03	0.00	0.07	0.43	0.39	1.14	0.08	0.09	0.32	0.01
HH5	NO LAND OWNERSHIP - LANDLESS FARMER	0.013	0.45	0.19	0.37	0.16	0.03	0.35	2.19	1.99	5.76	0.40	0.44	1.63	0.06
HH6	NO LAND OWNERSHIP - LANDLESS FARMER	0.006	0.20	0.09	0.17	0.07	0.01	0.15	0.98	0.89	2.57	0.18	0.19	0.73	0.03
HH7	NO FARM AND NO LAND - FARM WORKER	0.019	0.69	0.30	0.57	0.25	0.04	0.53	3.38	3.06	8.86	0.62	0.67	2.52	0.09
HH8	NO FARM AND NO LAND - FARM WORKER	0.008	0.30	0.13	0.25	0.11	0.02	0.23	1.46	1.33	3.84	0.27	0.29	1.09	0.04
HH9	NO FARM AND NO LAND - OTHER	0.019	0.68	0.30	0.56	0.25	0.04	0.53	3.33	3.02	8.74	0.61	0.66	2.48	0.09
HH10	NO FARM AND NO LAND - OTHER	0.012	0.44	0.19	0.36	0.16	0.02	0.34	2.15	1.95	5.64	0.39	0.43	1.60	0.06
HH11	NO FARM AND NO LAND - OTHER	0.008	0.28	0.12	0.23	0.10	0.02	0.21	1.36	1.23	3.58	0.25	0.27	1.02	0.04
HH12	NO FARM AND NO LAND - OTHER	0.003	0.12	0.05	0.10	0.04	0.01	0.09	0.58	0.52	1.52	0.11	0.12	0.43	0.01
HH13	URBAN	0.016	0.57	0.25	0.47	0.21	0.03	0.44	2.78	2.52	7.30	0.51	0.55	2.07	0.07
HH14	URBAN	0.010	0.35	0.15	0.29	0.13	0.02	0.27	1.71	1.55	4.49	0.31	0.34	1.27	0.04
HH15	URBAN	0.006	0.22	0.10	0.18	0.08	0.01	0.17	1.07	0.97	2.81	0.20	0.21	0.80	0.03
HH16	URBAN	0.002	0.06	0.03	0.05	0.02	0.00	0.05	0.31	0.28	0.82	0.06	0.06	0.23	0.01

Appendix C

Sets

i	Commodities
$inst$	Institutional sectors
hh	Households
fir	Firms
gov	Government
row	Rest of the World

Parameters

b_i^D	Share of domestic production by commodity in total production
β_i^D	Share of domestic production by commodity in total production in the cost function
ρ_D	Exponent of the CES production function linked to σ_D
σ_D	Elasticity of substitution between domestic and imported commodities
t_{out_i}	Implicit tax rate on output by commodity
pmw_i	Price of imported commodities
exr	Nominal exchange rate
b_i^{IF}	Share of intermediate inputs in domestic output by commodity
β_i^{IF}	Share of intermediate inputs in domestic output by commodity in the cost function
ρ_{IF}	Exponent of the CES production function linked to σ_{IF}
σ_{IF}	Elasticity of substitution between intermediate inputs and value added in domestic production (equal to zero)
b_i^{IN}	Share of intermediate input in total intermediate inputs by commodity
β_i^{IN}	Share of intermediate input in total intermediate inputs by commodity in the cost function
b_i^{PF}	Share of labor factor in total value added by commodity
β_i^{PF}	Share of labor factor in total value added by commodity in the cost function
σ_{PF}	Elasticity of substitution between labor and capital
φ_{inst}	Share of compensation of employees by institutional sector
ϑ_{inst}	Share of gross operating surplus by institutional sector
$t_{redd_{inst}}$	Implicit tax rate on income paid by institutional sector
$Tr_{inst,gov}$	Transfers paid by the government to the other institutional sectors
$Tr_{inst,row}$	Transfers paid by the Rest of the World to the other institutional sectors
χ_{is}^U	Share of consumption in disposable income by institutional sector
σ_U	Elasticity of substitution between consumption and savings
$\delta_{is,i}^C$	Share of consumption of the i^{th} commodity in the consumption bundle by institutional sector
σ_C	Elasticity of substitution between commodities in the consumption bundle
δ_i^I	Share of the demand for investment by commodity in total gross investment
σ_I	Elasticity of substitution between commodities in the investment bundle
δ_i^E	Share of the demand for export by commodity in total exports
σ_E	Elasticity of substitution between commodities in the Rest of the World export bundle

Variables

Y_i	Total output by commodity
P_i	Price of commodities
$Y_{D,i}$	Quantity of domestic output by commodity
$P_{M,i}$	Price of imports
M_i	Quantity of imports

$P_{D,i}$	Price of domestic output by commodity
BI_i	Demand for intermediate inputs by commodity
VA_i	Demand for value added by commodity
$P_{IF,i}$	Price of intermediate inputs by commodity
$P_{VA,i}$	Price of value added by commodity
PL	Price of labor
PK	Price of capital
L_i	Labor demand by commodity
K_i	Capital demand by commodity
pr_inc_{inst}	Primary income by institutional sector
L_{inst}	Labor endowment by institutional sector
K_{inst}	Capital endowment by institutional sector
sec_inc_{inst}	Secondary income by institutional sector
$disp_inc_i$	Disposable income by institutional sector
$Tr_{inst,inst}$	Transfers between institutional sectors (households and firms, and from households and firms to the government and the Rest of the World)
U_{inst}	Utility by institutional sector
C_{inst}	Consumption by institutional sector
S_{inst}	Saving by institutional sector
Pu_{inst}	Price index of utility by institutional sector
Pc_{inst}	Price index of consumption by institutional sector
$C_{i,inst}$	Quantity consumed by commodity and by institutional sector
PI	Price index of investment
I_i	Demand for investment by commodity
G_{gov}	Public expenditure of the government
EX_i	Export demand by commodity

Equations

Production block

$$Y_i = \left[b_i^D (Y_{D,i})^{\rho_D} + (1 - b_i^D) (M_i)^{\rho_D} \right]^{\frac{1}{\rho_D}}$$

$$P_i (1 - t_{out_i}) = \left[\beta_i^D P_{D,i}^{1-\sigma_D} + (1 - \beta_i^D) P_{M,i}^{1-\sigma_D} \right]^{\frac{1}{1-\sigma_D}}$$

$$Y_{D,i} = b_i^D Y_i \left(\frac{P_i}{P_{D,i}} \right)^{\sigma_D}$$

$$P_{M,i} = \frac{pmw_i}{exr}$$

$$M_i = (1 - b_i^D) Y_i \left(\frac{P_i}{P_{M,i}} \right)^{\sigma_D}$$

$$Y_{D,i} = \left[b_i^{IF} (BI_i)^{\rho_{IF}} + (1 - b_i^{IF}) (VA_i)^{\rho_{IF}} \right]^{\frac{1}{\rho_{IF}}}$$

$$P_{D,i} = \beta_i^{IF} P_{IF,i} + (1 - \beta_i^{IF}) P_{VA,i}$$

$$BI_i = b_i^{IF} Y_{D,i} \left(\frac{P_{D,i}}{P_{IF,i}} \right)$$

$$VA_i = (1 - b_i^{IF}) Y_{D,i} \left(\frac{P_{D,i}}{P_{VA,i}} \right)$$

$$P_{IF,i} = \sum_i \beta_i^{IN} P_i$$

$$P_{VA,i} = [\beta_i^{PF} PL^{1-\sigma_{PF}} + (1 - \beta_i^{PF}) PK^{1-\sigma_{PF}}]^{\frac{1}{1-\sigma_{PF}}}$$

$$L_i = b_i^{PF} VA_i \left(\frac{P_{VA,i}}{PL} \right)^{\sigma_{PF}}$$

$$K_i = (1 - b_i^{PF}) VA_i \left(\frac{P_{VA,i}}{PK} \right)^{\sigma_{PF}}$$

Primary income, secondary income and disposable incomes

$$pr_inc_{inst} = \varphi_{inst} \sum_i PLL_i + \vartheta_{inst} \sum_i PKK_i$$

$$sec_inc_{inst} = pr_inc_{inst} + \sum_{inst} Tr_{inst,inst}$$

$$disp_inc_{hh} = sec_inc_{hh} - t_redd_{hh} pr_inc_{hh} - \sum_{inst} Tr_{inst,hh}$$

$$disp_inc_{fir} = \vartheta_{fir} \sum_i PKK_i + \sum_{inst} Tr_{fir,inst} - t_redd_{fir} PKK_{fir} - \sum_{inst} Tr_{inst,fir}$$

$$disp_inc_{gov} = \sum_{hh} t_redd_{hh} pr_inc_{hh} + \sum_{fir} t_redd_{fir} pr_inc_{fir} + \sum_i t_out_i P_i Y_i + \sum_{inst} Tr_{gov,inst} - \sum_{inst} Tr_{inst,gov}$$

$$disp_inc_{row} = \varphi_{row} \sum_i PL L_i + \vartheta_{row} \sum_i PKK_i + \sum_i P_{M,i} M_i + \sum_{inst} Tr_{row,inst} - \sum_{inst} Tr_{inst,row}$$

Consumption block

$$U_{inst} = \sum_i C_{i,inst}$$

$$Pu_{inst} = \left[\chi_{inst}^U PC_{inst}^{(1-\sigma_U)} + (1 - \chi_{inst}^U) PI^{(1-\sigma_U)} \right]^{\frac{1}{1-\sigma_U}}$$

$$C_{inst} = \chi_{inst}^U U_{inst} \left(\frac{Pu_{inst}}{PC_{inst}} \right)^{\sigma_U}$$

$$S_{inst} = (1 - \chi_{inst}^U) U_{inst} \left(\frac{Pu_{inst}}{PI} \right)^{\sigma_U}$$

$$PC_{inst} = \left(\sum_i \delta_{inst,i}^C P_i^{1-\sigma_C} \right)^{\frac{1}{1-\sigma_C}}$$

$$C_{i,inst} = \delta_{inst,i}^C U_{inst} \left(\frac{PC_{inst}}{P_i} \right)^{\sigma_C}$$

$$PI = \left(\sum_i \delta_i^I P_i^{1-\sigma_I} \right)^{\frac{1}{1-\sigma_I}}$$

$$I_i = \delta_i^I I \left(\frac{PI}{P_i} \right)^{\sigma_I}$$

$$EX_i = \delta_i^E disp_inc_{row} \left(\frac{pmw_i}{P_i} \right)^{\sigma_E}$$

Market clearing conditions

$$\sum_{inst} (PL \cdot L_{inst}) = \sum_i (PL \cdot L_i)$$

$$\sum_{inst} (PK \cdot K_{inst}) = \sum_i (PK \cdot K_i)$$

For $i = j$,

$$\sum_i P_i Y_i = P_i \left(\sum_j BI_{i,j} + \sum_i \sum_{hh} C_{i,hh} + \sum_i G_{i,gov} + \sum_i I_i + \sum_i EX_i \right)$$

$$\sum_{inst} S_{inst} = \sum_i I_i$$

Chapter 2

Tools and policy actions to reconcile economic targets and emission abatement

Abstract

The 28th Conference of the Parties acknowledged the shortfall in efforts to limit global warming to 1.5°C, as outlined by the 21st Conference of the Parties targets. The resulting Declaration calls for ambitious measures, including the tripling of renewable energy usage and the phasing out of coal in power generation. Countries are encouraged to develop and deploy new technologies to curb emissions. Given the pivotal role of energy input in production, although it is one of the largest contributors to CO₂ emissions, producers are faced with the decision of whether to persist with fossil inputs (thereby provoking emissions) or to change the use of the input through the abatement technology. From this perspective, endogenizing the choice between the fossil energy input and the associated abatement technology cost in the economy may be a viable way to promote the energy transition.

Therefore, this study presents a static Computable General Equilibrium model based on a Social Accounting Matrix that integrates the cost of CO₂ abatement technology into the production cost function, with the objective of reducing CO₂ emissions from fossil-powered plants without compromising economic performance. This study focuses on China, which is responsible for approximately one-third of global CO₂ emissions and is the world's largest energy consumer. However, this approach may represent a best practice that can be extended to the investigation of environmental policies for other countries.

Keywords: Environmental Accounts, Social Accounting, CGE, Environmental Impact, Emission Control

JEL classification codes: E01, E16, C68, Q58

2.1 Progress in the institutional commitment to environmental protection

Since the first Earth Summit in 1972 brought environmental action to global attention, intergovernmental panels have been engaged in an intense debate on the effectiveness of environmental policy instruments in addressing carbon intensity through agreements on sustainable transition pathways. In particular, the Conference of the Parties (COP) serves as the executive body of the Intergovernmental Panel on Climate Change (IPCC), which provides the best available science for implementing environmental policies and mitigation measures. The COP has raised awareness of the necessity for countries to contribute at all stages of their economic and social development.

The most successful conference to date is COP21, held in Paris in 2015. It resulted in limiting the planet's temperature rise to 1.5°C compared to pre-industrial levels (UNFCCC, 2015). Starting in 2020, the signatories of the Paris Agreement established mandatory Nationally Determined Contributions (NDCs), which represent the domestic policy actions to achieve the goal of keeping global warming below 2°C. These contributions are to be updated every five years. Parties may voluntarily provide estimates of the long-term effects of the NDCs to assess the effectiveness of future measures. COP21 promoted several initiatives, including the Technology Mechanism, to encourage research projects for the creation and transfer of technologies for the reduction of Greenhouse Gas (GHG) emissions. Additionally, COP21 prioritizes the availability and transparency of information through the Enhanced Transparency Framework (ETF), which is an integrated communication system. The global stocktake ensures the dissemination of policy settings and periodic monitoring of overall results.

In December 2023, the United Arab Emirates assumed the presidency of COP28, which conducted the inaugural global stocktake to monitor progress towards the commitments set forth in COP21. The global stocktake expressed concern that the average surface temperature of the planet has increased by 1.1°C due to human-caused emissions (IPCC, 2023), despite the optimistic expectations regarding the implementation of the NDCs. The actions taken have not yielded the anticipated outcomes with respect to the objectives established in COP21. The Conference recognizes that disparities between countries have hindered the pursuit of these objectives. Even the allocated financial resources were inadequate to bridge these gaps. COP28 acknowledges the outcomes and updates the principal steps towards the long-term objective of net zero. The participating countries have committed to achieve ambitious targets, including tripling the amount of energy derived from renewable sources and doubling energy efficiency by 2030. Furthermore, the declaration calls for a reduction in the use of fossil fuels and the phasing out of unabated coal power in the energy sector (UNFCCC, 2023). However, no deadline is specified. In order to achieve these goals, countries are encouraged to develop and deploy low- or zero-emission technologies, such as nuclear, carbon capture and storage, and renewable technologies.

In 2023, global CO₂ emissions increased by 1.1%, with energy combustion emissions accounting for 90% of the overall growth. As reported by the IEA (2024), coal was the primary source of fossil fuel-related CO₂ emissions. Fossil fuels remain a significant source of energy for both emerging and advanced economies, serving as the primary fuel for power generation, heavy industry (including steel and iron processing, as well

as cement production), and transportation. In the years following COVID-19, energy combustion resulted in an approximate increase of 850 million tons (Mt) in total carbon emissions. As previously indicated, coal was the primary contributor, accounting for approximately 70% of this increase, with emissions increasing by 900 Mt. There was a slight increase in emissions from natural gas, while those from oil remained modestly below their levels in 2019.

The adoption of CO₂ abatement technologies may harm the performance of economic systems. The economic literature suggests that there exists a trade-off between economic and environmental objectives (Wesseh & Lin, 2016; Du & Yi, 2022). In accordance with the demands of COP28, immediate action must be taken to curtail the environmental impact of production systems by upgrading fossil fuel-powered installations. These installations must minimize waste and harmful substances during the production process. Consequently, producers must consider alternative options, such as a compensating fiscal burden or the implementation of abatement equipment. Given that the energy input is fundamental to the production process and generates CO₂ emissions, producers are faced with the choice between continuing to use fossil inputs (and thus, provoking emissions) or changing the utilization of the input through the implementation of the abatement technology. In any case, the exploitation of fossil energy input gives rise to an environmental cost that can be attributed to either the abatement cost or the burden resulting from the payment of an emission-proportionate tax.

The objective of this investigation is to incorporate the decision between continuing to use fossil energy inputs and the associated costs for abatement technology into the Chinese economy, with the aim of evaluating the efficacy of fiscal policies designed to reduce carbon emissions as an intermediate target. The cost of energy encompasses not only the cost of fossil energy sources but also the cost of determining whether to pay to emit or adopt CO₂ abatement technologies.

This study presents the construction of a static Computable General Equilibrium (CGE) model in which the modeling contribution is to integrate the cost of CO₂ emissions and abatement technology into the production cost function in order to reduce CO₂ emissions from fossil-powered installations without compromising the performance of the economic system. The CO₂ abatement technology is applied to four fossil energy inputs (coal, gas, oil, and coke) and contributes to the formation of the environmentally extended value added. As the application is made for China, this work represents a dual effort: the construction of the environmental Social Accounting Matrix (SAM) and the elaboration of the CGE model.

The remainder of this work is organized as follows. Section 2.2 presents an overview of China's policies aimed at addressing environmental issues. Section 2.3 provides a description of the SAM database, which has been structured for the purpose of calibrating the CGE model. Section 2.4 illustrates the SAM-based CGE model for China by entering the details of the nested production cost function, the behavioral equations, the market-clearing conditions, and the macro closures. Section 2.5 examines the most widely used policy instruments to mitigate the socioeconomic impacts of pollution from CO₂ emissions and presents the four policy scenarios envisaged. Subsections 2.5.1, 2.5.2, 2.5.3, and 2.5.4 discuss the main aggregated and disaggregated results of the four CO₂ mitigation scenarios. Section 2.6 conducts the sensitivity analysis, while Section 2.7 concludes.

2.2 China's policies for environmental protection

China is responsible for approximately one third of global CO₂ emissions and is the world's largest energy consumer (Crippa et al., 2024). About twenty years after the Rio Earth Summit and the Kyoto Protocol, the country signed and adopted the Paris Agreement, the legally binding treaty under the United Nations Framework Convention on Climate Change (UNFCCC) that complements the previous documents. The declaration aims at limiting global warming to 1.5°C compared to pre-industrial levels and promotes the implementation of feasible plans to reach the nationally determined contributions.

As of 2024, parties to the Paris Agreement are required to provide transparent reports on their progress in order to receive suggestions for refocusing or improving the actions taken. With regard to the nationally determined contributions, China has pledged to reduce carbon dioxide emissions per unit of Gross Domestic Product (GDP) by 18% by 2025 in comparison to 2020 levels. This is to be followed by a peak in emissions by 2030 and carbon neutrality by 2060. These objectives are set forth in the "1+N" climate policy framework, which comprises two principal documents: "Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementations of the New Development Philosophy" and "The Action Plan for Carbon Dioxide Peaking Before 2030".

In addition to the "1+N" climate policy package, the 2021-2025 Five-Year Plan (FYP) establishes targets for the reduction of carbon and energy intensity by 18% and 13.5%, respectively, by 2025 with respect to 2020 levels. The objective is to achieve a reduction of greenhouse gas emissions by 4% and an increase in forest cover to 24.1% by 2025. An additional goal is to increase the share of non-fossil energy sources in the energy mix to approximately 20%. The 2021-2025 FYP represents the fourteenth national policy statement of the People's Republic of China, and it reflects an effort to integrate the socioeconomic and the environmental dimensions. The plan was announced during the National People's Congress in March 2021 and represents an extension of the previous Five-Year Plan, which spanned the period from 2016 to 2020. The plan delineates the country's strategic priorities and goals, which include fostering innovation, boosting domestic consumption, improving the quality of life for citizens, and addressing environmental issues. Additionally, the plan aims to reinforce China's global leadership in strategic industries, including artificial intelligence, biotechnology, and clean energy. Key objectives include increasing research and development spending, expanding digital infrastructure, reducing carbon emissions, enhancing healthcare, and strengthening the social safety net.

China has recently taken further steps to regulate CO₂ emissions under a market-regulated basis. The International Carbon Action Partnership (ICAP) report from March 2023 provides an update on the current status of improvements to the Chinese Emission Trading System (ETS). The Chinese national ETS entered into operation in 2021 with the pilot experiment of the Shenzhen carbon market and is currently one of the 28 ETSs in force as of January 2023. The Ministry of Ecology and Environment is the government agency responsible for making decisions in this field, with the objective of reducing the total national emissions of CO₂ in the power industry by 44%. In 2022, the average price in the ETS market was 55.30 ¥/tCO₂. Furthermore, the country is contemplating the expansion of the ETS framework to encompass additional

production activities, including petrochemicals, chemicals, building materials, steel, nonferrous metals, paper, and domestic aviation (ICAP, 2023).

These statements emphasize the necessity of timely action with regard to carbon adaptation and mitigation, as agreed upon at the COP. China's contribution to global coal-fired power generation increased by 10 percentage points between 2015 and 2022. Given that energy is responsible for approximately 90% of China's GHG emissions, there is the need to design sector-specific policy instruments to intervene in the energy sector. In order to achieve carbon neutrality by 2060, China must intensify its efforts to reduce CO₂ emissions from fossil energy sources. The diversification of energy sources and the implementation of CO₂ abatement technologies such as Carbon Capture, Utilization and Storage (CCUS) must be at the forefront of this transformation. CCUS is defined as the process of removing CO₂ emissions from fossil fuel-fired industrial plants without interrupting operations or directly from the atmosphere for storage onshore or offshore (IEA, 2023). China produces more than half the world's coal-fired power generation, steel and cement, but has less than 5% of the world's CCUS projects currently under development (IEA, 2023).

2.3 The environmental SAM for China

The calibration of the model entails identifying the values of the parameters and quotas that would reproduce the demand and supply mechanisms, thereby enabling the structure of the economy and behavioral interactions to emerge. CGEs can formalize the functioning of markets for goods and factors, as well as the behavioral rules of operators, when supported by a purposefully structured database, the SAM. CGE models can exploit the advantages of SAMs, which are based on national accounts data, and trace the entire circular flow of income from the generation of value added to the primary and secondary distribution and use of disposable income for consumption and savings. The SAM is an accounting scheme that describes the picture of the circularity of income within the economic system over a specified time frame and can be organized at different levels of disaggregation (Stone, 1961). In this manner, it allows the development of models to study the impact of policies on industrial interdependencies, production, primary factors and institutional sectors, as well as on the primary and secondary distribution of income, tax and transfer systems, accumulation, and external transactions and positions (Pyatt and Round, 1977).

The core information of the environmental SAM for China is the symmetric Input-Output (IO) table, which encompasses 149 industries. This detailed disaggregation is provided in the Chinese Environmentally Extended Input-Output (CEEIO) database, in which each production activity is associated with the total carbon emissions expressed in physical terms (Liang et al., 2016; Tian et al., 2021).⁸ The additional data necessary to tie production with income distribution, redistribution, use and accumulation in the Chinese SAM are derived from the China Statistical Yearbooks published by the National Bureau of Statistics (NBS) of China. Figure 1 provides a graphical representation of the location of the flows reported in the SAM, which are expressed in 100 million Yuan.

⁸ The classification of the 149 industries is provided in Appendix A, Table A.1.

Figure 1. The scheme of the environmental SAM for China (100 million Yuan).

	INDUSTRIES i=1,...,149	LABOR	CAPITAL		TAXES		PRIVATE INSTITUTIONAL SECTORS	PUBLIC INSTITUTIONAL SECTOR	CAPITAL FORMATION	REST OF THE WORLD	TOTAL	
			NON-ABAT	ABAT	OUTPUT	CARBON						
INDUSTRIES i=1,...,149	Intermediate consumption						Private final consumption	Public final consumption	Gross investments	Exports		
LABOR	Gross value added										Factor income from RoW	
CAPITAL		NON-ABAT	ABAT									
TAXES		OUTPUT	CARBON									
PRIVATE INSTITUTIONAL SECTORS	Primary distribution of income					Secondary distribution of income			Current transfers from RoW			
PUBLIC INSTITUTIONAL SECTOR						Tax revenues						
CAPITAL FORMATION						Private savings	Public savings	Net lending / borrowing				
REST OF THE WORLD	Imports	Factor income to RoW				Current transfers to RoW						
TOTAL												

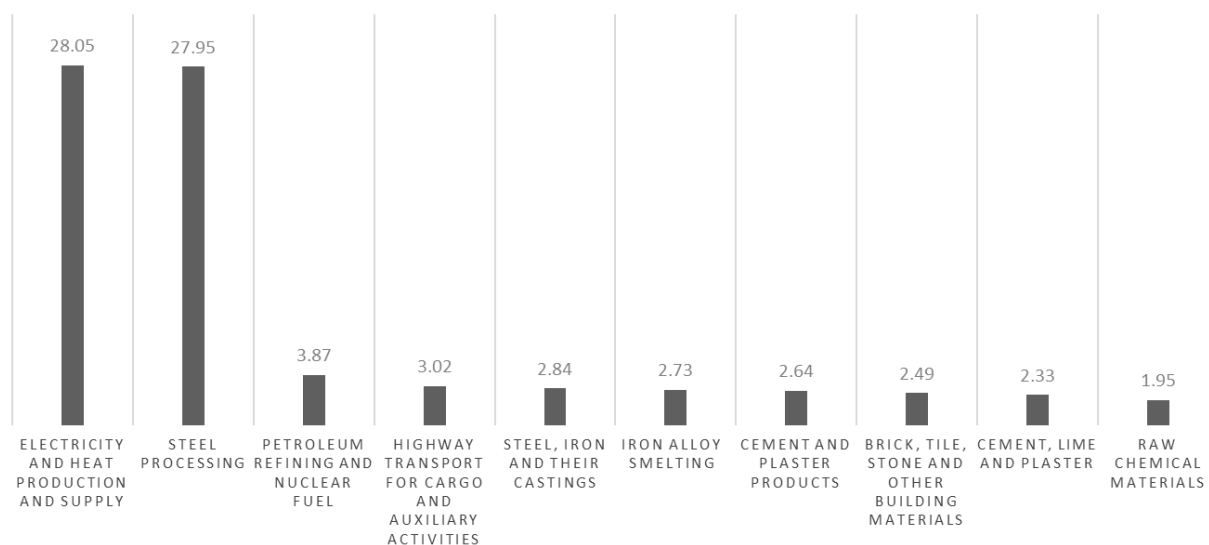
Source: own elaboration.

The SAM obtained provides a comprehensive and detailed overview of the economic structure of the country, encompassing 149 production activities and six primary factors (labor, abatement capital for coal, gas, oil and coke, and non-abatement capital). The sum of the five flows of abatement and non-abatement capital is equal to the original capital flow by industry. The database incorporates abatement capital as part of the capital endowment. Four industries in the CEEIO are identified as sources of fossil fuels.⁹ The abatement equipment is exclusively directed towards the mitigation of fossil energy-related CO₂ emissions. The corresponding flows of gross operating surplus from the abatement capital accrue to the institutional sectors in proportion to their ownership: these flows are imputed proportionately to the share of gross operating surplus from non-abatement capital. The SAM includes four private institutional sectors (nonfinancial corporations, financial corporations, rural and urban households), one public institutional sector (the government), and the Rest of the World (RoW). The capital formation account records gross fixed investments and changes in inventories.

The tax system encompasses taxes on output, the carbon tax and taxes on income. In particular, the carbon tax by industry is integrated in the database as a share in taxes on output. It is computed by multiplying the tons of CO₂ emissions by industry at the average price of carbon emissions in the Chinese ETS market in 2022 - 55.30 ¥/tCO₂ (ICAP, 2023). Figure 2 depicts the largest CO₂ emitting industries in the SAM for China.

⁹ The four fossil energy inputs, electricity, and their alias are listed in Appendix A, Table A.2.

Figure 2. The ten largest CO₂ emitting industries in the SAM for China (% share in total CO₂ emissions).



Source: own elaboration based on the SAM for China.

As indicated by the database, Electricity and heat production and supply is the largest CO₂ emitting industry in China, responsible for 28.05% of the total CO₂ emissions generated by the production processes. Energy-related emissions in the electricity industry are driven by coal. The electricity and heat production and supply industry in China is significantly dependent on fossil fuels, particularly coal, gas, oil, and coke. This is the primary reason why the energy industry is the focus of international attention with regard to the introduction of new policy instruments that allow for the mitigation of carbon emissions without inducing an unfavorable contraction of the economic systems.

2.4 The SAM-based CGE model for emission abatement

The SAM-based CGE model for China represents a tool for testing fiscal policies and observing the disaggregated impacts on the most affected activities, institutional sectors, carbon abatement capabilities, and CO₂ emission reduction. It may serve as a best practice to be developed in other countries. In order to achieve their environmental goals, policymakers require support in exploring the most appropriate instruments and assessing the aggregate and disaggregated economic impacts of targeted measures. This can be accomplished by using models that combine a general equilibrium analysis with multisectoral facets (Severini et al., 2019).

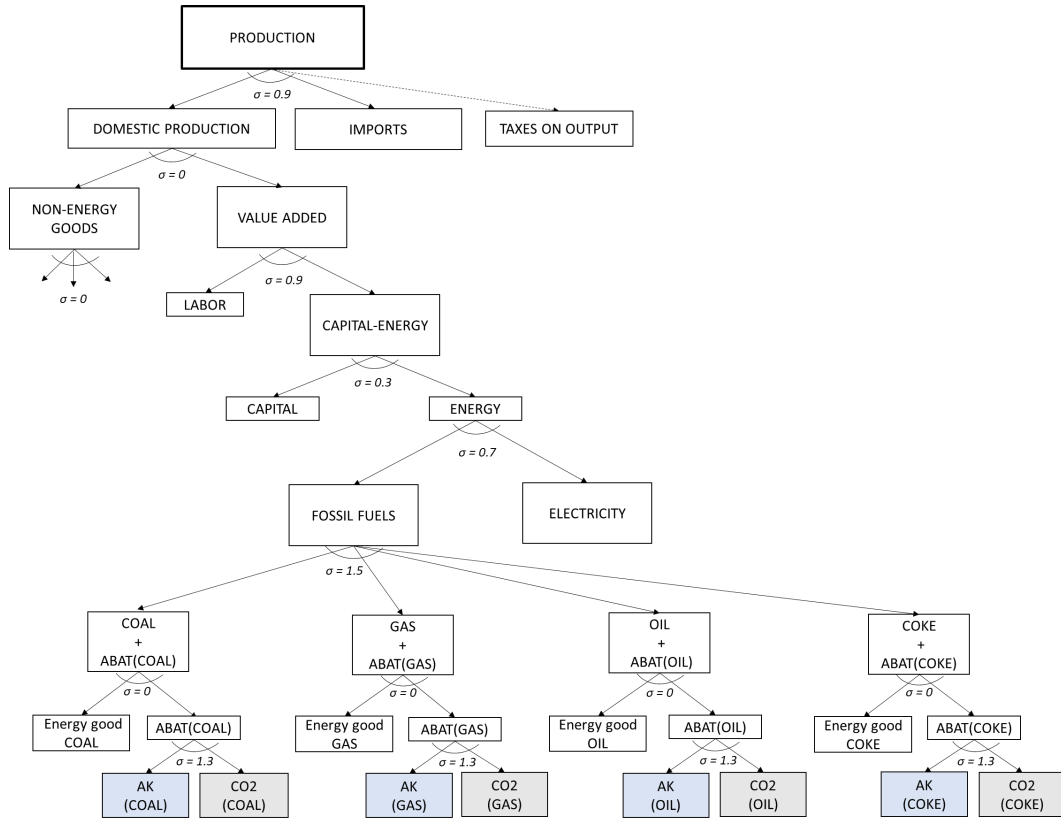
The advantages of adopting this framework include the capacity to comprehend the facts and the ability of the economy to absorb policy recommendations and exogenous shocks, which enables decision-makers to make more informed choices. Furthermore, multisectoral general equilibrium models enable the identification of the connections between prices, quantities, and the underlying driving forces, thereby providing insight into the functioning of the economy and its potential response to external contingencies and changes (Socci et al., 2021). Additionally, they can effectively assist in the design and communication of policies by making them accessible to stakeholders and the general public.

From a technical standpoint, these models can also detect potential unintended effects and trade-offs. Analysts and scholars have widely used environmental CGE models to assess the direct, indirect, and induced impacts of economic and green policies (Bergman, 2005; Böhringer and Rutherford, 2010; Ciaschini et al., 2012). These models can express the interrelationships between production, distribution, redistribution, consumption, and accumulation, and the response of the economic structure to the pressing social issue of environmental degradation by testing mitigation and adaptation policies (Babatunde et al., 2017). Indeed, CGE models calibrated on the SAM allow for an emphasis on the multi-input and multi-output structure of the economy under consideration (Deriu et al., 2022). They offer a means to observe how the economy would appear if different sets of policies or external conditions were in place – the counterfactual scenarios – in comparison to the benchmark equilibrium.

The implementation and refinement of powerful solution algorithms for CGE models over time has ensured the compatibility of the optimizing choices of the various actors (Scarf, 1967). Households seek to maximize utility, given the budgetary constraint, whereas firms aim to minimize the costs associated with production processes. In this regard, the set of operators involved has expanded over time to include public administrations and the Rest of the World. The modeling formulation for labor and commodity markets has begun incorporating certain forms of distortions and imperfect competition to enhance realism and accommodate the developments proposed by the structuralist theory (Taylor, 1990; Hoffman, 2003; Kitwiwattanachai et al., 2010).

This study develops a static CGE model for China calibrated on the environmental SAM with the objective of endogenizing the cost of CO₂ abatement technology into the production cost function in substitution for the cost of carbon emissions. This modeling effort aims at providing policy instruments that can reduce CO₂ emissions from fossil-powered plants while avoiding any adverse effects on the performance of the economic system. The carbon abatement technology is implemented for the four fossil energy inputs (coal, gas, oil, and coke) and contributes to the formation of the environmentally extended value added. Figure 3 depicts the multilevel production cost function in the model.

Figure 3. The structure of the nested production cost function.



Source: own elaboration.

The lowest level of the nest in Figure 3 defines the abatement cost as a function of CO₂ emissions and the expenditure on abatement technology through a Constant Elasticity of Substitution (CES) functional form.¹⁰ Therefore, CO₂ emissions, as valued at the 2022 average ETS price, enter production processes in substitution with the abatement technology. In the case of coal, the abatement cost (the node designated as “ABAT(coal)” in Figure 3) takes the following form:

$$P_{coal,i}^{ABAT} = \left[\delta_{co,i} P_{coal}^{CARB(1-\sigma_{ac})} + (1 - \delta_{co,i}) P_{coal}^{AK(1-\sigma_{ac})} \right]^{\frac{1}{(1-\sigma_{ac})}} \quad (1)$$

The subscript $i = 1, \dots, 149$ denotes the industries. The parameter $\delta_{co,i}$ is the share of coal carbon emission cost in the total abatement cost, and it multiplies the price of CO₂ from coal, P_{coal}^{CARB} . The complement to one of the abovementioned share $(1 - \delta_{co,i})$ represents the relative share of the abatement technology cost, while P_{coal}^{AK} is the price of the abatement capital for coal. The two weighted prices represent the node of the cost function that is uniquely associated with each energy good, as they quantify the specific environmental impact in terms of CO₂ emissions. To align to the literature on the calibration of production cost functions in the abatement sector, the model assumes that the two inputs are substitutable, so the elasticity σ_{ac} takes the value of 1.3 (Kiuila & Rutherford, 2013).

¹⁰ The details of the SAM-based CGE model for China, including sets, parameters, variables, and equations, are provided in Appendix B.

The abatement cost is aggregated with the cost of the associated fossil energy source, with an elasticity of substitution equal to zero. With regard to coal,

$$P_{coal,i}^{ENV} = \beta_{co,i}P_{coal,i} + (1 - \beta_{co,i})P_{coal,i}^{ABAT} \quad (2)$$

The quota $\beta_{co,i}$ is the share of the cost of coal in the total fossil energy cost, whereas $(1 - \beta_{co,i})$ is the share of the abatement cost. The quotas refer to the cost for coal and its environmental impact, respectively. This aggregated cost, which is applied to all fossil energy sources in the formation of their respective prices, is denoted as $P_{coal,i}^{ENV}$ for coal.

In the subsequent nesting level, the costs for fossil energy inputs are combined as follows:

$$P_i^{FOSSIL} = \left[\alpha_{co,i}P_{coal,i}^{ENV(1-\sigma_f)} + \alpha_{gas,i}P_{gas,i}^{ENV(1-\sigma_f)} + \alpha_{oil,i}P_{oil,i}^{ENV(1-\sigma_f)} + \alpha_{ck,i}P_{coke,i}^{ENV(1-\sigma_f)} \right]^{\frac{1}{(1-\sigma_f)}} \quad (3)$$

for each $i = 1, \dots, 149$ industry in the economy. The coefficients $\alpha_{co,i}$, $\alpha_{gas,i}$, $\alpha_{oil,i}$, and $\alpha_{ck,i}$ indicate, respectively, the shares of coal, gas, oil and coke in the total cost for fossil fuels by industry. The variables $P_{coal,i}^{ENV}$, $P_{gas,i}^{ENV}$, $P_{oil,i}^{ENV}$, and $P_{coke,i}^{ENV}$ are the prices of coal, gas, oil, and coke by industry. Fossil fuels are assumed to be substitutes, with an elasticity of substitution σ_f of 1.5 (Li et al., 2019).

The energy cost emerges from the combination of the cost of fossil fuels and the cost of electricity as follows:

$$P_i^{EN} = \left[\beta_{el,i}P_{elec,i}^{(1-\sigma_{re})} + (1 - \beta_{el,i})P_i^{FOSSIL(1-\sigma_{re})} \right]^{\frac{1}{(1-\sigma_{re})}} \quad (4)$$

The coefficient $\beta_{el,i}$ is the share of the cost of electricity in the total cost for energy, while $(1 - \beta_{el,i})$ is the share of the cost of fossil fuels in the total cost of energy. They assign the respective weights to the prices of electricity $P_{elec,i}$ and fossil fuels P_i^{FOSSIL} . The elasticity of substitution between electricity and the fossil energy sources σ_{re} is equal to 0.7 (Li et al., 2019).

The upper level of the nested production cost function allows for complementarity between the energy cost and non-abatement capital:

$$P_i^{KE} = \left[\gamma_{k,i}PK^{(1-\sigma_{cap})} + (1 - \gamma_{k,i})P_i^{EN(1-\sigma_{cap})} \right]^{\frac{1}{(1-\sigma_{cap})}} \quad (5)$$

The quota $\gamma_{k,i}$ represents the share of non-abatement capital cost in the total cost for energy and non-abatement capital. The complement to one of this proportion $(1 - \gamma_{k,i})$ is multiplied by the energy aggregate price. The variables PK and P_i^{EN} are the prices of non-abatement capital and energy aggregate, respectively. The elasticity of substitution σ_{cap} is set to 0.3 (Li et al., 2019).

The environmentally extended value-added cost is derived from the combination of the non-abatement capital and energy costs, along with the labor costs:

$$P_i^{VA} = \left[\eta_{lab,i}PL^{(1-\sigma_{kl})} + (1 - \eta_{lab,i})P_i^{KE(1-\sigma_{kl})} \right]^{\frac{1}{(1-\sigma_{kl})}} \quad (6)$$

The parameter $\eta_{lab,i}$ identifies the share of labor costs in total value-added costs, which is linked to the price of labor PL . The remaining quota $(1 - \eta_{lab,i})$ represents the share of the non-abatement capital and energy bundle to value added, multiplied by the price of the non-abatement capital and energy aggregate cost, P_i^{KE} . The elasticity of substitution σ_{kl} is equal to 0.9 (Li et al., 2019).

By combining the average prices of non-energy intermediate goods, taking into account the respective shares on the overall cost for non-energy intermediate inputs, the price of non-energy intermediate inputs that participate in domestic production is determined as:

$$P_i^{NE} = \sum_i \beta_{ne,i} P_i \quad (7)$$

for each intermediate input except for the fossil source intermediate inputs. They combine through the Leontief technology.

The price of domestically produced output by industry, defined as P_i^{DOM} , is obtained by summing the costs of the environmentally extended value added and intermediate non-energy inputs, as illustrated by equation (8):

$$P_i^{DOM} = \beta_{int,i} P_i^{NE} + (1 - \beta_{int,i}) P_i^{VA} \quad (8)$$

The variable P_i^{NE} is the price of non-energy intermediate inputs multiplied by $\beta_{int,i}$, which corresponds to the share of non-energy intermediate inputs in domestic production. The variable P_i^{VA} is the price of the environmentally extended value added by industry, while the parameter $(1 - \beta_{int,i})$ represents the share of value added in domestic production. Value added and non-energy intermediate inputs are used in fixed proportions in production processes (Leontief technology).

The function of total production costs is therefore given by the following equation:

$$(1 - r_{out_i}) P_i = \left[\mu_{dom,i} P_i^{DOM(1-\sigma_{ar})} + (1 - \mu_{dom,i}) P_i^M(1-\sigma_{ar}) \right]^{\frac{1}{(1-\sigma_{ar})}} \quad (9)$$

The variable P_i is the final price of goods and services in the economy and r_{out_i} expresses the tax rate on output by industry. The coefficient $\mu_{dom,i}$ is the share of domestic production in total production, multiplied by the price of domestically produced output, P_i^{DOM} . The remaining quota $(1 - \mu_{dom,i})$ indicates the share of imports that support internal production in total production, and P_i^M is the price of imports. Domestic production and imports combine to obtain total production following a CES technology, with the value of the elasticity of substitution σ_{ar} equal to 0.9 (Zhang et al., 2021). It is assumed that domestic and imported goods are imperfect substitutes (Armington, 1969). Table 1 below summarizes the elasticities of substitution in the nested production cost function of the CGE model, their associated values, and references from the literature.

Table 1. The elasticity coefficients in the production cost function.

Elasticity	Value	Reference	Description
σ_{ac}	1.3	Kiuila and Rutherford (2013)	Elasticity of substitution between abatement capital and CO ₂ emissions
σ_f	1.5	Li et al. (2019)	Elasticity of substitution between the fossil energy goods
σ_{re}	0.7	Li et al. (2019)	Elasticity of substitution between the fossil fuel composite and electricity
σ_{cap}	0.3	Li et al. (2019)	Elasticity of substitution between the energy composite and non-abatement capital
σ_{kl}	0.9	Li et al. (2019)	Elasticity of substitution between the capital-energy composite and labor
σ_{ar}	0.9	Zhang et al. (2021)	Elasticity of substitution between domestically produced and imported goods under Armington assumption

Source: own elaboration.

The SAM-based CGE model describes the behavior of the economic operators. Households aim to maximize their utility U^{hh} subject to the constraint represented by their budget, the disposable income $disp_inc^{hh}$, as indicated by equations (10) and (11):

$$\max_{\sum_i C_i^{hh}} U^{hh} = \sum_i C_i^{hh} \quad (10)$$

The superscript hh denotes the set of households (it includes rural and urban households), whereas the summation $\sum_i C_i^{hh}$ identifies households' total consumption. The utility function uses a Leontief-type form to ensure that perfect complementarity between diverse types of goods consumed is maintained when relative prices fluctuate. The budget constraint, which is represented by households' disposable income, can be expressed as follows:

$$\begin{aligned} Ydisp^{hh} = & \varphi_{hh} \cdot \sum_i L_i + \vartheta_{hh,c} \cdot \sum_i K_{i,c} - tinc_{hh} \left(\varphi_{hh} \cdot \sum_i L_i + \vartheta_{hh,c} \cdot \sum_i K_{i,c} \right) \\ & + \sum_{priv} \left(\varphi_{priv} \sum_i L_i + \vartheta_{priv,c} \sum_i K_{i,c} \right) tr_{priv,hh} + Tr_{gov,hh} + Tr_{row,hh} \quad (11) \\ & - \sum_{inst} \left(\varphi_{hh} \sum_i L_i + \vartheta_{hh,c} \sum_i K_{i,c} \right) tr_{hh,inst} \end{aligned}$$

In equation (11) and in the equations presented below, the subscripts for transfers describe the direction of the flow. Thus, $Tr_{n,k}$ denotes transfers from the n^{th} institutional sector to the k^{th} institutional sector, while $tr_{n,k}$ represents the implicit transfer rate of the flows from the n^{th} institutional sector to the k^{th} institutional sector. The disposable income arises from the mechanisms of allocation, distribution and redistribution of resources generated in the economic system. These mechanisms include the remuneration of factors of production, which accrue to the institutional sectors based on their initial endowment, as well as taxes and transfers between

institutional sectors. In the case of equation (11) for households, the subscript *inst* represents the set of all institutional sectors. The subscript *priv* denotes the set of the private institutional sectors in the Chinese SAM – nonfinancial, financial corporations and households. The subscript *c* specifies the set of capital, with $c = \{abat, noabat\}$, *abat* denotes the abatement capital, while *noabat* indicates the non-abatement capital. The parameter φ_{hh} is the share of the compensation of employees distributed to urban and rural households, while $\vartheta_{hh,c}$ is the share of gross operating surplus attributed to urban and rural households depending on their endowments of abatement and non-abatement capital. The primary income of households ($\varphi_{hh} \cdot \sum_i L_i + \vartheta_{hh,c} \cdot \sum_i K_{i,c}$) represents the income tax base – taxes on household income are levied at the implicit tax rate $tinc_{hh}$. The implicit transfer rate $tr_{priv, hh}$ identifies the transfers from the private institutional sectors to households; it depends on the private institutional sectors' primary incomes. The term $Tr_{gov, hh}$ identifies transfers from the government to households and $Tr_{row, hh}$ indicates transfers from the Rest of the World to households. These two flows are considered as fixed in the model. The outgoing transfers from households to the other institutional sectors are identified as a function of households' primary income. The implicit transfer rate $tr_{hh, inst}$ represents the proportion of primary income of households that is used for transfers to the other institutional sectors.

From the expenditure side, the disposable income of households is defined as the sum of final consumption and savings:

$$Ydisp^{hh} = C^{hh} + S^{hh} \quad (12)$$

The disposable income of nonfinancial and financial corporations, whose identifying set is *corp*, is determined according to equation (13):

$$\begin{aligned} Ydisp^{corp} = & \vartheta_{corp,c} \cdot \sum_i K_{i,c} - tinc_{corp} \left(\vartheta_{corp,c} \cdot \sum_i K_{i,c} \right) \\ & + \sum_{inst} \left(\varphi_{inst} \cdot \sum_i L_i + \vartheta_{inst,c} \cdot \sum_i K_{i,c} \right) tr_{inst, corp} + Tr_{gov, corp} \\ & + Tr_{row, corp} - \sum_{corp} \left(\vartheta_{corp,c} \cdot \sum_i K_{i,c} \right) tr_{corp, inst} \end{aligned} \quad (13)$$

Corporations receive a share $\vartheta_{corp,c}$ of gross operating surplus by type of capital *c* as primary income, on which they pay income taxes at the implicit tax rate $tinc_{corp}$. In addition, they receive transfers from households and other corporations depending on the primary incomes of these institutional sectors, at the implicit transfer rate $tr_{inst, corp}$; transfers from the government and the Rest of the World, indicated respectively as $Tr_{gov, corp}$ and $Tr_{row, corp}$. They pay transfers to the other institutional sectors at the implicit transfer rate $tr_{corp, inst}$.

From the expenditure approach, the disposable income of corporations corresponds to the level of investment, given that they do not express demand for final consumption:

$$Ydisp^{corp} = S^{corp} \quad (14)$$

The disposable income of the government from the income approach is illustrated in equation (15):

$$\begin{aligned}
Ydisp^{gov} = & \vartheta_{gov,c} \cdot \sum_i K_{i,c} \\
& + \sum_i r_{out_i} P_i Q_i + tinc_{priv} \left(\varphi_{priv} \cdot \sum_i L_i + \vartheta_{priv,c} \cdot \sum_i K_{i,c} \right) \\
& + \left(\varphi_{priv} \cdot \sum_i L_i + \vartheta_{priv,c} \cdot \sum_i K_{i,c} \right) tr_{priv,gov} + Tr_{row,gov} - Tr_{gov,inst}
\end{aligned} \tag{15}$$

The government collects a share of gross operating surplus by type of capital owned $\vartheta_{gov,c} \cdot \sum_i K_{i,c}$, indirect taxes on output $\sum_i r_{out_i} P_i Q_i$, income taxes from private institutional sectors $tinc_{priv}(\varphi_{priv} \cdot \sum_i L_i + \vartheta_{priv,c} \cdot \sum_i K_{i,c})$, transfers from private institutional sectors $(\varphi_{priv} \cdot \sum_i L_i + \vartheta_{priv,c} \cdot \sum_i K_{i,c})tr_{priv,gov}$, and transfers from the Rest of the World, $Tr_{row,gov}$. Government outflows include transfers to the institutional sectors, indicated as $Tr_{gov,inst}$.

The government does not operate as a maximizing agent. On the contrary, the public institutional sector implements fiscal policies and measures that result in either a deficit ($S^{gov} < 0$) or a surplus ($S^{gov} > 0$). The government deficit or surplus is determined residually as follows:

$$S^{gov} = Ydisp^{gov} - G \tag{16}$$

The government deficit or surplus is obtained as the difference between government revenues and the level of public expenditure G .

The closure condition on the Rest of the World states that the level of the net lending or borrowing position of the economy towards the RoW stems from the difference between expenditures X and revenues $Ydisp^{row}$:

$$S^{row} = X - Ydisp^{row} \tag{17}$$

The variable X represents the value of total exports to the Rest of the World and the variable S^{row} is the current account balance, which registers the level of net lending or borrowing. In particular, foreign demand, as identified by exports, is a function of the endogenous domestic prices of goods, the exogenous foreign prices of goods, the exogenous income of the Rest of the World, and the exogenous nominal exchange rate. The variable $Ydisp^{row}$ records the transactions occurring between the domestic economy and the Rest of the World, leading to the revenues of the latter, as specified in equation (18):

$$\begin{aligned}
Ydisp^{row} = & \varphi_{row} \cdot \sum_i L_i + \vartheta_{row,c} \cdot \sum_i K_{i,c} + \sum_i M_i \\
& + \sum_{priv} \left(\varphi_{priv} \cdot \sum_i L_i + \vartheta_{priv,c} \cdot \sum_i K_{i,c} \right) tr_{priv,row} + Tr_{gov,row} \\
& - Tr_{row,inst}
\end{aligned} \tag{18}$$

The quotas φ_{row} and $\vartheta_{row,c}$ indicate the respective shares of compensation of employees and gross operating surplus distributed to the Rest of the World. The variable $\sum_i M_i = \sum_i P_i^M Q_i^M$ defines the value of total imports. The quota $tr_{priv,row}$ represents the implicit transfer rate from private domestic institutional sectors to the Rest

of the World; $Tr_{gov,row}$ are transfers from the government to the Rest of the World, while $Tr_{row,inst}$ are transfers paid by the Rest of the World to the domestic institutional sectors.

The market-clearing conditions of this model are grounded in the Walrasian tradition. The equilibrium described by equations (19)-(21) is achieved through the mediation of relative prices, which act as a coordinating mechanism between the market forces of supply and demand in the goods and factor markets. The total supply of domestic and foreign goods and services must be equal to the total demand for intermediate consumption (comprising energy and non-energy intermediate inputs), private and public consumption, gross investments, and exports, as expressed in equation (19). Given that the intersectoral flow matrix is symmetric, when $i = j$, the market-clearing condition for goods and services is given by:

$$P_i Q_i = P_i \cdot \left(\sum_j Int_{i,j} + \sum_i C_i + \sum_i G_i + \sum_i I_i + \sum_i X_i \right) \quad (19)$$

The aggregate labor supply by the institutional sectors is equal to the aggregate labor demand by industry, as specified in equation (20):

$$\sum_{inst} L^{inst} = \sum_i L_i \quad (20)$$

Similarly, the aggregate capital supply by type of capital c by the institutional sectors is equal to the aggregate capital demand by industry and by type of capital:

$$\sum_{inst} K_c^{inst} = \sum_i K_{i,c} \quad (21)$$

The macro closure of the model imposes the equality between the flows of savings and investments:

$$\sum_{inst} S^{inst} = \sum_i I_i \quad (22)$$

The aggregate savings of the institutional sectors must be equal to the total demand for investment.

2.5 Policy scenarios for emission abatement

The tools available to reduce the environmental footprint of production systems vary in cost and implementation time, but they share the objective of overcoming the traditional trade-off between positive economic performance and CO₂ mitigation. In the context of economic theory, it is argued that compensating for pollutant emissions is incompatible with the cost-minimizing setup of firms. Indeed, the market solution entails internalizing the ecological damage through the implementation of a Pigouvian tax. Producers are thus responsible for bearing the additional costs associated with addressing the unintended consequences of their production processes, in order to equate the marginal social cost (Pigou, 1932). However, the introduction of

a Pigouvian tax gives rise to at least two key considerations. Firstly, the quantification of environmental degradation represents a significant challenge. Secondly, the process of cost internalization results in a shift in the tax burden from the producer to the consumer, with the ultimate impact reflected in final prices and, therefore, charged on the consumer.

The application of shadow pricing can prove a useful tool for the valuation of pollutants, as it enables policymakers to integrate the environmental costs associated with human activities into their decision-making processes (Drèze & Stern, 1990; Färe et al., 1993). The practice of attributing a monetary value to harmful substances is based on the assumption that society would bear the costs related to these substances if they were not subject to regulation. The incorporation of environmental costs attributable to pollution into economic decision-making processes may serve to incentivize individuals and organizations to reduce their pollution levels. Nevertheless, this approach has limitations. The accuracy of shadow prices is conditioned by the quality and completeness of the data used to assess the environmental costs of pollution. Moreover, the degree of effectiveness of shadow pricing is influenced by the prevailing political and legislative environment and the extent to which individuals and organizations are willing to take into account environmental costs. While shadow pricing can be an effective tool for valuing pollutants, it should be employed in concert with other policy instruments, such as regulations and incentives, to achieve the desired environmental outcomes (Perman et al., 2003).

The Chinese government has set the objective of reducing carbon intensity by 18% within the 2021-2025 Five-Year Plan. Carbon intensity is defined as the amount of CO₂ emissions per unit of GDP (IEA, 2021). The static CGE model developed in this study aims to contribute to the ongoing debate regarding the valuation of pollutants, with a particular focus on CO₂ emissions from production processes. It also aims to facilitate the modeling integration and testing of new policy instruments that are directed at a dual objective, namely, reconciling environmental protection and favorable economic performance. Four scenarios have been devised to assess the capacity of the economic system to reduce CO₂ emissions without adversely affecting the positive macroeconomic performance in any of the five years covered by the FYP. These scenarios employ two environmental policy instruments: the carbon tax, which China has not yet adopted, and the abatement technology, which represents the capital device used in the production process to prevent pollution (Guerriero, 2020). The environmental target under consideration is a reduction in carbon intensity by 3.60% over a one-year period. In particular, the scenarios that are the subject of this analysis are the following four:

- Scenario 1: doubling of the carbon tax, which this model assumes to be the 2022 average ETS price (55.30 ¥/tCO₂).
- Scenario 2: increase in the demand for abatement capital in the Electricity and heat production and supply industry.
- Scenario 3: combination of Scenario 1 and 2. Scenario 3 doubles the carbon tax and increases the demand for abatement capital in the Electricity and heat production and supply industry.
- Scenario 4: combination of Scenario 3 and carbon tax revenue recycling to households.

2.5.1 Scenario 1: simulation results

The focus of Scenario 1 is the implementation of a carbon tax, which is designed to redirect resources from environmentally damaging activities that impose a disproportionate cost on society relative to their benefits. It is one of the market-based fiscal policy instruments used for environmental preservation, the implementation of which can serve to mitigate the degree of distortion caused by other taxes. This market-based instrument entails a reduction in demand for goods produced through polluting processes and presents a significant challenge to the production sphere, as it acts as a disincentive to production.

In particular, Scenario 1 proposes to double the carbon tax, which in the context of the Chinese economy is represented by the average ETS price in 2022. The average 2022 ETS price, applied to the value of CO₂ emissions in the SAM for China, increases from 55.30 ¥/tCO₂ to 110.60 ¥/tCO₂. Table 2 illustrates the results of Scenario 1, which aims to reduce CO₂ emissions as an intermediate objective over the course of the year. Table 2 presents the percentage change of real macroeconomic aggregates, the GDP deflator, CO₂ emissions, and carbon intensity in comparison to the benchmark.

Table 2. Scenario 1 – changes in real macroeconomic aggregates, GDP deflator, and CO₂ emissions (percentage change from the benchmark).

<i>Aggregate</i>	<i>% change</i>
Real GDP	-1.03
Private consumption	-1.29
Investment	-1.40
Exports	-0.81
Imports	-1.41
GDP deflator	0.57
CO ₂ emissions	-1.59
Carbon intensity	-0.31
Average CO ₂ intensity annual target	-3.60

Source: CGE model estimates.

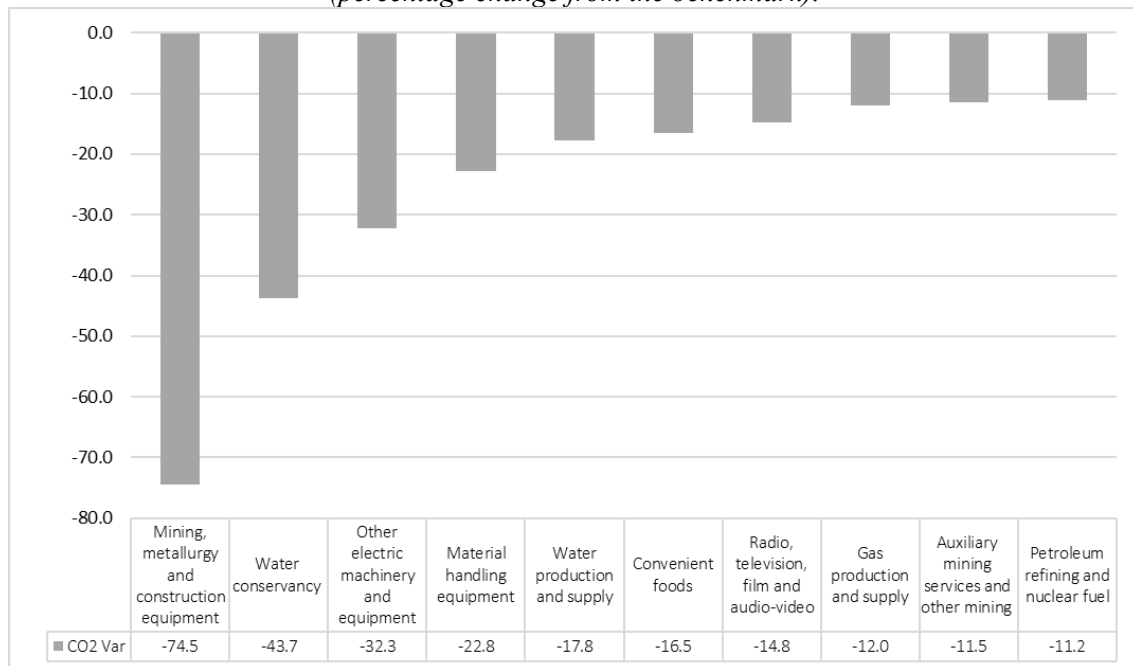
From a macroeconomic perspective, the effect of doubling the carbon tax on GDP is negative. The implementation of a double carbon tax acts as a disincentive to production, resulting in a decline in imports (-1.41%) and subsequently impacting the generation of value added. This results in a reduction in the allocation of primary income, which in turn leads to a decrease in disposable income and a reduction in the level of private consumption (-1.29%). The adverse impact on private consumption can be attributed to both the reduction in disposable income and the shift in the tax burden from corporations to households. This shift is brought about by the rising final prices that result from the doubling of the carbon tax as part of taxes on production. The deterioration in competitiveness, as evidenced by the rise in the price level in the country (0.57% of the GDP deflator), is responsible for the decline in foreign demand, as reflected by a reduction in

exports (-0.81%). The elevated production costs drive a contraction of production that triggers the decline in consumption, and are simultaneously linked to the sharp drop in final demand for investment (-1.40%).

As indicated by the effects on the macroaggregates illustrated in Table 2, the implementation of the carbon tax comes at a cost, and the choice of the carbon metric is a crucial consideration when the policymaker seeks to measure the environmental impacts of the policy instrument in place. In this case, the alterations in CO₂ emissions from production and consumption processes lead to a sharp decline from the benchmark carbon emissions, with a negative change of -1.59%. The carbon intensity, defined as the ratio between CO₂ emissions from production and consumption and GDP, decreases by -0.31%. However, this reduction is inadequate to attain the yearly average CO₂ intensity annual target, which is set at -3.60% and, above all, is originated from a deterioration of the economic performance. Indeed, it is important to note that these favorable environmental outcomes stem from the contraction of the economic system.

The carbon tax functions as a deterrent to production and the reduction in CO₂ emissions is as large as the production activities decelerate their production and reduce demand for polluting intermediates. Figure 4 shows the ranking of the ten industries that experience the most substantial reduction in CO₂ emissions in Scenario 1.

Figure 4. Scenario 1 – the ten best industrial performances in terms of CO₂ reduction (percentage change from the benchmark).



Source: CGE model estimates.

As illustrated in Figure 4, the Mining, metallurgy, and construction equipment industry is the foremost contributor to the reduction of CO₂ emissions from its production processes. A reduction of 74.5% in CO₂ emissions is observed in comparison to the benchmark equilibrium. The production of this industry is closely related to the power generation and the heavy industry (e.g., steel and cement production), which encompass the most carbon-intensive sectors and are ranked among the ten most polluting industries (see Figure 1). This

environmental outcome for the Mining and metallurgy sector is also partially attributable to a reduction in CO₂ emissions in Auxiliary mining services and other mining. The third industry with the best environmental performance is Other electric machinery and equipment, which is another industry with close ties to the activities of electricity generation and supply. The interdependencies between sectors exert an impact on the intensity and magnitude of CO₂ emission reduction.

The ten industries with the lowest CO₂ emissions are all associated with the intensive use of fossil energy sources, both directly through absorption in their production processes and indirectly through the activation of other production processes. This indicates that in the case of Scenario 1, the primary driver of environmental protection is the reduction in production, which subsequently leads to a decline in carbon emissions.

2.5.2 Scenario 2: simulation results

Scenario 2 consists of an increase in demand for abatement technologies within the electricity industry, which is responsible for the highest level of CO₂ emissions from fossil energy combustion across the entire production system (28.05%, as estimated in the SAM). Indeed, fossil fuels remain the primary source of energy generation in both advanced and emerging economies. The Chinese government has allocated 180 billion yuan for the implementation of Carbon Capture and Storage (CCUS) technologies in the energy sector by 2060 (IEA, 2021, p. 75). To examine the short-term effects of integrating a CCUS technology, its deployment is simulated over a one-year period. The CCUS technology is treated as a carbon abatement cost, which may be defined as the cost of the device used to prevent pollution during production processes. The abatement technology may be conceived of as a provisional short-term instrument designed to encourage the transition to renewable energy sources. The resources committed to the increased demand for abatement technologies by the Chinese government represent 0.2% of the country's GDP. Table 3 illustrates the impact of the higher demand for abatement technologies on the macroeconomic aggregates, the GDP deflator, CO₂ emissions, and carbon intensity.

Table 3. Scenario 2 – changes in real macroeconomic aggregates, GDP deflator, and CO₂ emissions (percentage change from the benchmark).

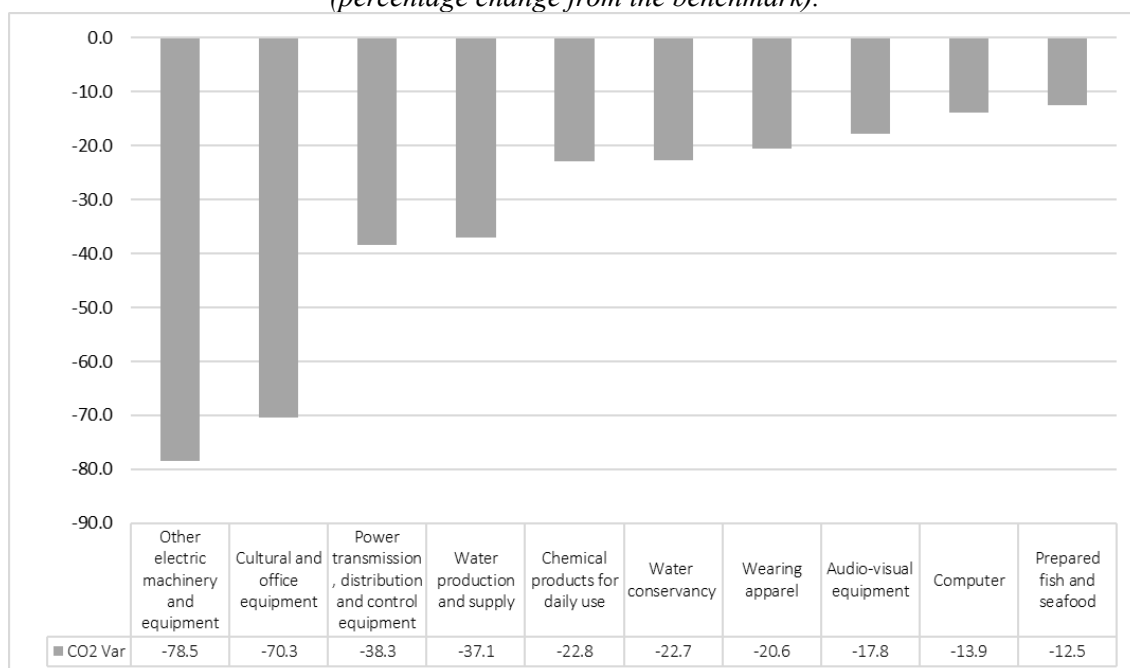
<i>Aggregate</i>	<i>% change</i>
Real GDP	0.47
Private consumption	0.27
Investment	0.63
Exports	-0.06
Imports	-0.57
GDP deflator	0.03
CO ₂ emissions	-2.57
Carbon intensity	-2.83
Average CO ₂ intensity annual target	-3.60

Source: CGE model estimates.

This scenario is based on a planned policy of the Chinese government. In comparison to Scenario 1, which involves the doubling of the carbon tax, the impact of the higher demand for abatement technology devices on real GDP is positive, with an estimated increase of 0.47%. This response can be primarily attributable to the stimulation of production interdependencies that are activated to produce the abatement technology devices, as evidenced by the increase in investment of 0.63% in relation to the benchmark equilibrium. The stimulus to economic activity gives rise to an increase in primary incomes, which in turn generates additional demand for final consumption and investments, thereby reinitiating the circular flow of income. In point of fact, the objective of this policy is not to expand production capacity, which is not a viable option in the short term. Rather, the objective is to promote improvements in production processes and generate positive effects on the system in the immediate term.

Technologies that can act in this regard include equipment that can reduce the environmental impact of existing production installations. In this instance, the system appears to mitigate the trade-off between economic performance and environmental outcomes. Thus, the rise in demand for abatement technology devices in the Electricity and heat production and supply yields a favorable environmental and economic response: the surge in GDP is accompanied by a reduction in CO₂ emissions, with the carbon intensity approaching the annual target at a greater rate than that observed in Scenario 1. The overall reduction in CO₂ emissions from production and consumption per unit of GDP is -2.83%. Figure 5 displays the disaggregated impact on carbon emission reduction, presented as a ranking of the ten industries with the most substantial reductions in CO₂ emissions.

Figure 5. Scenario 2 – the ten best industrial performances in terms of CO₂ reduction (percentage change from the benchmark).



Source: CGE model estimates.

As the demand for abatement technologies in China’s electricity industry increases, Other electric machinery and equipment emerges as the industry with the greatest potential for CO₂ abatement, with an estimated decrease in carbon emissions from its production processes of -78.5%. This environmental outcome is more pronounced than in Scenario 1 due to the fact that Scenario 2 simulates a demand-side policy that aims to foster production rather than discourage it, and simultaneously promotes a fair balance between the economic activity and pollution by changing the use of fossil source absorption. In comparison to the disaggregated impacts observed in Scenario 1 (see Figure 4), Power transmission, distribution, and control equipment is coupled with the Other electric machinery and equipment as an essential industry related to the Electricity and heat production and supply. The Power transmission, distribution, and control equipment industry encompasses the production and distribution of various components of electric grids, including transformers and voltage regulators. Such components can facilitate the expansion of electric capacity and the management of electric flows. It can thus be argued that this industry may serve as a principal contributor to the reduction of carbon emissions.

2.5.3 Scenario 3: simulation results

Scenario 3 simultaneously doubles the carbon tax and increases the demand for abatement technologies in the Electricity and heat production and supply industry. This scenario proposes a combination of Scenarios 1 and 2, which is to be implemented in the electricity industry. The total resources committed to Scenario 3 amount to 0.9% of China’s GDP. In this scenario, the substitution between the costs of carbon taxation and carbon emission abatement plays a pivotal role in guiding the system’s reaction to potential energy transition

capabilities. In other words, it sheds light on the system's capacity to reduce pollution and, consequently, its potential for adapting the utilization of fossil energy sources and transitioning from fossil fuels to renewables over the longer term. Table 4 presents a summary of the outcomes for selected economic aggregates, the GDP deflator, CO₂ emissions, and carbon intensity in percentage change relative to the benchmark.

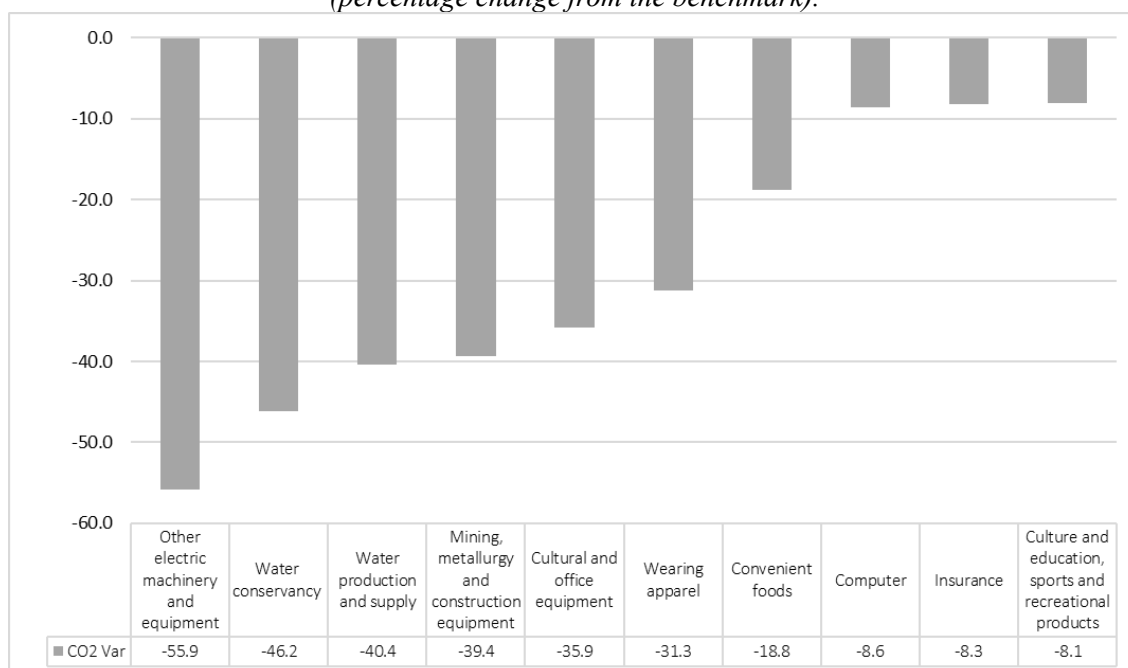
Table 4. Scenario 3 – changes in real macroeconomic aggregates, GDP deflator, and CO₂ emissions (percentage change from the benchmark).

<i>Aggregate</i>	<i>% change</i>
Real GDP	-0.01
Private consumption	-0.71
Investment	-0.18
Exports	0.01
Imports	-1.88
GDP deflator	0.12
CO ₂ emissions	-2.87
Carbon intensity	-2.09
Average CO ₂ intensity annual target	-3.60

Source: CGE model estimates.

The increased demand for abatement technologies in the electricity industry, in conjunction with the carbon tax, exerts a less restrictive influence on real GDP than the carbon tax alone scenario. In contrast to the decline in real GDP of -1.03% observed in Scenario 1, the reduction in real GDP remains at -0.01% in Scenario 3. As a matter of fact, the negative impact on the components of GDP is less pronounced, with the exception of imports, which decline by -1.88% compared to -1.41% in Scenario 1. Despite the fact that the production system is discouraged by the carbon tax, the demand for abatement technology appears to mitigate the contractionary economic and distributional effects of the doubling of the carbon tax and allows for improved environmental performance in comparison to the implementation of the carbon tax in isolation. Indeed, CO₂ emissions are reduced by -2.87%, and more significantly, the carbon intensity is found to be reduced by -2.09%, which is considerably closer to the average annual target than in Scenario 1. The rise in the demand for abatement technology devices, coupled with the doubling of carbon taxation in the electricity industry, does not accommodate the dual target of the economic and environmental performances. However, it provides the opportunity to outline prospective strategies for achieving a balance between the two instruments, thereby reconciling the two objectives, depending on the policy action and direction that the policymaker intends to pursue. Figure 6 depicts the ranking of the ten industries that experience the most prominent reduction in CO₂ emissions in Scenario 3.

Figure 6. Scenario 3 – the ten best industrial performances in terms of CO₂ reduction (percentage change from the benchmark).



Source: CGE model estimates.

As illustrated in Figure 6, the magnitude of the contraction in carbon emissions in this scenario with respect to the benchmark equilibrium is attenuated and can be placed in between the carbon emission reduction rankings of Scenarios 1 and 2. In accordance with the findings of the preceding scenario, the industry of Other electric machinery and equipment is once again identified as the primary contributor to carbon emission reduction, with a CO₂ reduction of -55.9% relative to the benchmark equilibrium. Conversely, other industries exhibit an improvement in this combined scenario, including those related to water conservancy and water production and supply. It is noteworthy that the Mining, metallurgy and construction equipment industry is the sole heavy sector industry to retain its position in the ranking.

2.5.4 Scenario 4: simulation results

Scenario 4 suggests a combination of the carbon taxation instrument and the increase in demand for abatement technology devices in the electricity industry, coupled with the recycling of carbon tax revenues to bolster household disposable income through public transfers. The total resources allocated to this policy mix amount to 1.7% of the country's GDP. This scenario would act on the supply side, the demand side, and the redistribution side with the objective of fostering environmentally compatible production processes and sustaining household purchasing power in light of the shift in the burden of the carbon tax through final prices, and the rising price effect that follows the production stimulus. The recycling of the carbon tax revenue would serve to offset, at least partially, the adverse effects on households' disposable incomes of the two mentioned mechanisms. Table 5 records the impact of the policy on the main real macroeconomic aggregates, the GDP deflator, CO₂ emissions, and carbon intensity.

Table 5. Scenario 4 – changes in real macroeconomic aggregates, GDP deflator, and CO₂ emissions (percentage change from the benchmark).

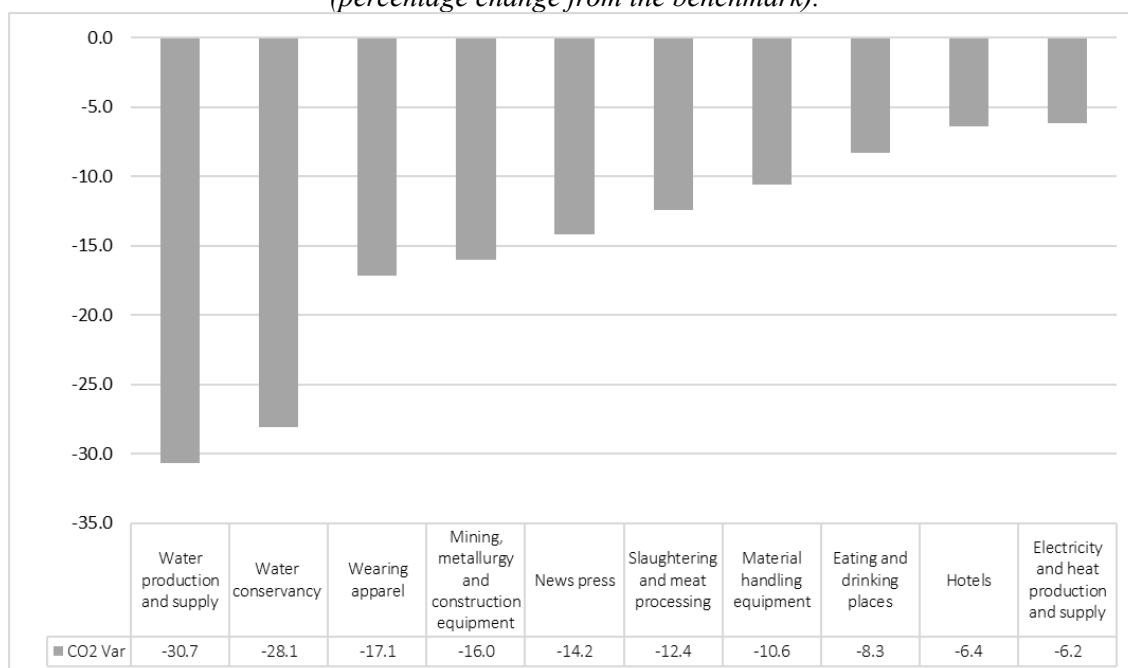
<i>Aggregate</i>	<i>% change</i>
Real GDP	1.57
Private consumption	1.70
Investment	1.32
Exports	0.91
Imports	-0.80
GDP deflator	0.13
CO ₂ emissions	-1.29
Carbon intensity	-2.94
Average CO ₂ intensity annual target	-3.60

Source: CGE model estimates.

As shown in Table 5, this scenario yields favorable outcomes for the Chinese economy. The demand components that contribute to the increase of GDP by 1.57% are private consumption (+1.70%), investment (+1.32%), and exports (+0.91%). Despite the rise in domestic prices, exports remain relatively unaffected. In addition to the positive macroeconomic effects, this scenario is also highly beneficial from an environmental standpoint. Carbon emissions decline by 1.29% in comparison to the benchmark equilibrium, but more significantly, carbon intensity is reduced by 2.94%. In light of the evolving international landscape on carbon mitigation and adaptation, it seems that, in the short term, the option of the abatement cost in substitution of the compensating carbon tax, while supporting households' purchasing power, represents an appropriate policy action for achieving the dual goal of sustained economic performance and mitigated environmental impact of production processes. Therefore, the combination of the three instruments – the carbon tax, the abatement technologies in the electricity industry, and the recycling of the carbon tax revenue – appears to be the most effective policy mix for emission abatement without compromising production and the economic performance.

Figure 7 presents the disaggregated impacts of Scenario 4 on carbon reduction, illustrating the ten most effective industrial performances in terms of carbon emission contraction. The ranking demonstrates that the two industries with the most significant carbon emission reduction are Water production and supply and Water conservancy. The extent of CO₂ reduction is less pronounced than in the preceding three scenarios, with a ranking that ranges from -30.7% to -6.2%. This is due to the fact that, in Scenario 4, households' consumption receives a further stimulus from public transfers, thereby restimulating production processes, electricity absorption, and thus carbon emission generation, with the associated abatement cost. It is noteworthy that, in contrast to the other three scenarios, the electricity industry is positioned last in the ranking of the best-performing industries in terms of CO₂ emission contraction.

Figure 7. Scenario 4 – the ten best industrial performances in terms of CO₂ reduction (percentage change from the benchmark).



Source: CGE model estimates.

2.6 Sensitivity analysis

The static SAM-based CGE model for China requires validation regarding its response to the exogenous parameters derived from the literature. This will enable the consistency of the impacts of the various fiscal and environmental instruments on the macroeconomic aggregates, with a view to ensuring their validation. A sensitivity analysis is therefore conducted on the elasticity of substitution between the abatement technology and CO₂ emissions. This is done in order to ascertain the extent to which alterations in the value of their substitution possibility influence the respective contribution to production processes and the transmission mechanisms of economic policies throughout the system. The model postulates that the abatement technology and CO₂ emissions combine through a CES technology to create the environmental constraint for each fossil energy source, with a related elasticity of substitution of 1.3 (Kiuila & Rutherford, 2013). A reduction or increase of 10% or 20% in this value has no significant impact on the model outcomes in comparison to the benchmark, as evidenced in Tables 6-9. The effects of the four policy scenarios remain consistent throughout the four sensitivity experiments, indicating that the results are reliable. Modifications to the elasticity of substitution between CO₂ emissions and the abatement technology do not yield a substantial change in the Chinese technology.

Table 6. Scenario 1 – Impact of the change in the elasticity of substitution between abatement technology and CO₂ on real macroeconomic aggregates (percentage change from the benchmark).

Aggregate	-20%	-10%	Benchmark	+10%	+20%
Real GDP	-1.0259	-1.0259	-1.0259	-1.0258	-1.0258
Private consumption	-1.2851	-1.2851	-1.2850	-1.2850	-1.2850
Investment	-1.3983	-1.3983	-1.3983	-1.3983	-1.3983
Exports	-0.8119	-0.8119	-0.8119	-0.8119	-0.8119
Imports	-1.4062	-1.4063	-1.4063	-1.4063	-1.4063

Source: CGE model estimates.

Table 7. Scenario 2 – Impact of the change in the elasticity of substitution between abatement technology and CO₂ on real macroeconomic aggregates (percentage change from the benchmark).

Aggregate	-20%	-10%	Benchmark	+10%	+20%
Real GDP	0.4713	0.4713	0.4713	0.4713	0.4713
Private consumption	0.2655	0.2655	0.2655	0.2655	0.2655
Investment	0.6261	0.6261	0.6261	0.6261	0.6261
Exports	-0.0602	-0.0602	-0.0602	-0.0602	-0.0602
Imports	-0.5668	-0.5668	-0.5668	-0.5668	-0.5668

Source: CGE model estimates.

Table 8. Scenario 3 – Impact of the change in the elasticity of substitution between abatement technology and CO₂ on real macroeconomic aggregates (percentage change from the benchmark).

Aggregate	-20%	-10%	Benchmark	+10%	+20%
Real GDP	-0.0146	-0.0146	-0.0146	-0.0146	-0.0146
Private consumption	-0.7070	-0.7070	-0.7070	-0.7069	-0.7069
Investment	-0.1819	-0.1819	-0.1819	-0.1819	-0.1819
Exports	0.0050	0.0051	0.0051	0.0051	0.0051
Imports	-1.8756	-1.8756	-1.8756	-1.8756	-1.8756

Source: CGE model estimates.

Table 9. Scenario 4 – Impact of the change in the elasticity of substitution between abatement technology and CO₂ on real macroeconomic aggregates (percentage change from the benchmark).

Aggregate	-20%	-10%	Benchmark	+10%	+20%
Real GDP	1.5743	1.5743	1.5743	1.5743	1.5743
Private consumption	1.7034	1.7034	1.7034	1.7034	1.7034
Investment	1.3197	1.3197	1.3197	1.3197	1.3197
Exports	0.9133	0.9134	0.9133	0.9134	0.9134
Imports	-0.8009	-0.8009	-0.8009	-0.8009	-0.8009

Source: CGE model estimates.

2.7 Conclusions

The latest report from the International Energy Agency on CO₂ emissions indicates that carbon emissions increased by 1.1% in 2023. Of this increase, 90% can be attributed to fossil energy combustion processes. In light of the prevailing environmental circumstances, there is an urgent necessity for prompt alterations in traditional production paradigms to pave the way for a gradual transition from fossil fuels to renewable resources in energy combustion for electricity generation. It was observed by COP28 that the ambitious actions initially announced by the governments of the participating countries at COP21 – and subsequently updated through the Nationally Determined Contributions – have yet to be fully implemented or are only partially completed.

This study is primarily concerned with China, which is the world's largest energy producer and the country with the highest levels of CO₂ emissions. In 2023, China was responsible for 34% of global CO₂ emissions. The policy question that is raised is whether it is possible to achieve compatibility between carbon mitigation and economic objectives. To this end, this study constructs an environmental SAM for China, calibrates a CGE model on this database, and endogenizes the costs of carbon abatement and CO₂ emissions into the production cost function.

The SAM-based CGE model for China serves as a tool for evaluating fiscal policies and observing the aggregated and disaggregated impacts on the most affected economic activities, institutional sectors, carbon abatement capabilities, and CO₂ emission reduction. With regard to the abatement cost within the model, the production costs associated with fossil energy sources are a function of the carbon tax in substitution for the expenditure on the abatement technology. Producers may opt to utilize fossil fuel sources, thereby increasing CO₂ emissions and consequently incurring an emission-proportionate tax, or alternatively, they may choose to bear the costs associated with the implementation of abatement technology.

Given the pivotal role of energy across all production processes, and the prevalence of fossil sources for energy absorption in both advanced and emerging economies, producers are confronted with a critical decision: whether to maintain the use of fossil inputs, which inevitably leads to emissions, or to alter the utilization of the fossil source through the implementation of the abatement technology. In any case, the exploitation of fossil energy input gives rise to an environmental cost that can be attributed to either the abatement cost or the burden resulting from the payment of an emission-proportionate tax.

The results highlight the significance of adopting a multisectoral approach for the design and assessment of sectoral policy measures. This is exemplified by the promotion of CO₂ abatement technology deployment in the electricity industry, which can be conceived as a substitute for carbon taxation. An increase in demand for abatement technology gives rise to interdependencies in production, thereby mitigating the adverse effects of a combined carbon tax on the economic system. When the costs associated with abatement and carbon emissions are accompanied by the recycling of carbon tax revenue, the system demonstrates a certain ability to overcome the traditional trade-off between economic and environmental objectives.

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Appendix A

A.1. The industries in the CEEIO table for China.

<i>Code</i>	<i>Definition</i>	<i>Code</i>	<i>Definition</i>
a1	Crop cultivation	a76	Other special equipment
a2	Forestry	a77	Automobile vehicle
a3	Livestock and livestock products	a78	Auto parts and accessories
a4	Fishery	a79	Railroad transport equipment
a5	Technical services for agriculture	a80	Ship building
a6	Coal mining and processing	a81	Other transport machinery
a7	Crude petroleum and natural gas	a82	Generators
a8	Ferrous metal ore mining	a83	Power transmission, distribution and control equipment
a9	Non-ferrous metal ore mining	a84	Cable and electrical materials
a10	Non-metallic minerals mining	a85	Battery
a11	Auxiliary mining services and other mining	a86	Household appliances
a12	Grain mill products	a87	Other electric machinery and equipment
a13	Feeding stuff production	a88	Computer
a14	Vegetable oil and forage	a89	Communication equipment
a15	Sugar refining	a90	Radar and broadcasting equipment
a16	Slaughtering and meat processing	a91	Audio-visual equipment
a17	Prepared fish and seafood	a92	Electronic elements and devices
a18	Other food processing	a93	Other electronic equipment
a19	Convenient foods	a94	Instruments, meters and other measuring equipment
a20	Liquid milk and dairy products	a95	Other manufacturing products
a21	Spices and fermentation products	a96	Scrap and waste recycling products
a22	Other food manufacturing	a97	Metal products, machinery and equipment repairs
a23	Wines, spirits and liquors	a98	Electricity and heat production and supply
a24	Non-alcoholic beverage	a99	Gas production and supply
a25	Tea	a100	Water production and supply
a26	Tobacco products	a101	Building construction
a27	Cotton textiles	a102	Civil engineering construction
a28	Woolen textiles	a103	Construction installation
a29	Hemp textiles	a104	Construction decoration and other construction services
a30	Knitted mills	a105	Wholesale
a31	Finished textile products	a106	Retail
a32	Wearing apparel	a107	Railway transport for passengers
a33	Leather, furs, down and related products	a108	Railway transport for cargo and auxiliary activities
a34	Footwear	a109	Urban public transport and highway transport for passengers
a35	Sawmills, fibreboard, and products of wood, bamboo, cane, palm, straw, etc.	a110	Highway transport for cargo and auxiliary activities
a36	Furniture	a111	Water transport for passengers
a37	Paper and paper products	a112	Water transport for cargo and auxiliary activities
a38	Printing and record medium reproduction	a113	Air transport for passengers
a39	Arts and crafts	a114	Air transport for cargo and auxiliary activities
a40	Culture and education, sports and recreational products	a115	Pipeline transport
a41	Petroleum refining and nuclear fuel	a116	Multimodal transport and transport agents
a42	Coking	a117	Handling and warehousing
a43	Raw chemical materials	a118	Post
a44	Chemical fertilizers	a119	Hotels
a45	Chemical pesticides	a120	Eating and drinking places
a46	Chemicals for painting, dying and others	a121	Telecommunication
a47	Synthetic chemicals	a122	Broadcasting, television and satellite transmission services
a48	Chemicals for special usages	a123	The Internet and related services
a49	Chemical products for daily use	a124	Software services
a50	Medical and pharmaceutical products	a125	Information technology services
a51	Chemical fibers	a126	Finance
a52	Rubber products	a127	Capital market services
a53	Plastic products	a128	Insurance
a54	Cement, lime and plaster	a129	Real estate
a55	Cement and plaster products	a130	Leasehold
a56	Brick, tile, stone and other building materials	a131	Business services
a57	Glass and glass products	a132	Scientific research and experiment
a58	Ceramic products	a133	Special technical services
a59	Fireproof products	a134	Science & technology promotion and application services
a60	Other non-metallic mineral products	a135	Water conservancy
a61	Steel, iron and their castings	a136	Ecological protection and environmental governance
a62	Steel processing	a137	Public infrastructure management
a63	Iron alloy smelting	a138	Residential services
a64	Nonferrous metal smelting	a139	Other social services
a65	Nonferrous metal processing	a140	Education services
a66	Metal products	a141	Health services
a67	Boiler, engines and turbine	a142	Social work
a68	Metalworking machinery	a143	News press
a69	Material handling equipment	a144	Radio, television, film and audio-video
a70	Pump, valve, compressor and similar machinery	a145	Culture and arts
a71	Cultural and office equipment	a146	Sports
a72	Other general equipment	a147	Recreational services
a73	Mining, metallurgy and construction equipment	a148	Social security
a74	Chemical engineering, wood and non-metallic processing equipment	a149	Public administration and social organization
a75	Cultivation, forestry, animal husbandry and fishery machinery		

A.2. The energy goods and their alias in the model.

<i>Code</i>	<i>CEEIO Definition</i>	<i>Alias in the model</i>
a6	Coal mining and processing	Coal
a7	Crude petroleum and natural gas	Gas
a41	Petroleum refining and nuclear fuel	Oil
a42	Coking	Coke
a98	Electricity and heat production and supply	Electricity

Appendix B

Sets

<i>i</i>	Industry
<i>c</i>	Type of capital (abatement and non-abatement capital)
<i>abat</i>	Abatement capital
<i>noabat</i>	Non-abatement capital
<i>int</i>	Intermediate goods
<i>ne</i>	Non-energy inputs
<i>fossil</i>	Fossil fuels (coal, gas, oil, coke)
<i>inst</i>	Institutional sectors
<i>priv</i>	Private institutional sectors (nonfinancial, financial corporations, and households)
<i>hh</i>	Households
<i>corp</i>	Financial and nonfinancial corporations
<i>gov</i>	Government
<i>row</i>	Rest of the World

Parameters

$\mu_{dom,i}$	Share of domestic output in total output in the cost function
μ_i^Q	Share of domestic output in total output
σ_{ar}	Elasticity of substitution between domestic output and imports
ρ_{ar}	Exponent of the CES function under the Armington assumption
$r_{out,i}$	Tax rate on output by industry
p^W	World price
nex	Nominal exchange rate
$\beta_{int,i}$	Share of non-energy intermediate inputs in domestic output by industry in the cost function
$\beta_{ne,i}$	Share of non-energy intermediate inputs in total demand for intermediate inputs by industry in the cost function
$\eta_{lab,i}$	Share of labor in total environmentally extended value added by industry in the cost function
σ_{kl}	Elasticity of substitution between labor and the environmentally extended value added
$\gamma_{k,i}$	Share of non-abatement capital in the total cost for energy and non-abatement capital by industry in the cost function
σ_{cap}	Elasticity of substitution between non-abatement capital and the energy aggregate
$\beta_{el,i}$	Share of electricity in total cost for energy by industry in the cost function
σ_{re}	Elasticity of substitution between electricity and the fossil energy sources
$\alpha_{co,i}$	Share of coal in the total cost of fossil fuels by industry in the cost function
$\alpha_{gas,i}$	Share of gas in the total cost of fossil fuels by industry in the cost function
$\alpha_{oil,i}$	Share of oil in the total cost of fossil fuels by industry in the cost function
$\alpha_{ck,i}$	Share of coke in the total cost of fossil fuels by industry in the cost function
σ_f	Elasticity of substitution between fossil fuels
$\beta_{co,i}$	Share of coal input in the total cost of coal input and abatement cost by industry in the cost function
$\beta_{gas,i}$	Share of gas input in the total cost of gas input and abatement cost by industry in the cost function
$\beta_{oil,i}$	Share of oil input in the total cost of oil input and abatement cost by industry in the cost function
$\beta_{ck,i}$	Share of coke input in the total cost of coke input and abatement cost by industry in the cost function
$\delta_{co,i}$	Share of CO ₂ emissions from coal in the total abatement cost of coal by industry in the cost function

$\delta_{gas,i}$	Share of CO ₂ emissions from gas in the total abatement cost of gas by industry in the cost function
$\delta_{oil,i}$	Share of CO ₂ emissions from oil in the total abatement cost of oil by industry in the cost function
$\delta_{ck,i}$	Share of CO ₂ emissions from coke in the total abatement cost of coke by industry in the cost function
σ_{ac}	Elasticity of substitution between CO ₂ emissions and abatement capital
φ_{inst}	Share of compensation of employees by institutional sector
$\vartheta_{inst,c}$	Share of gross operating surplus by institutional sector and type of capital
$tinc_{inst}$	Implicit tax rate on income paid by institutional sector
$tr_{inst,inst}$	Implicit transfer rate from one institutional sector to another institutional sector
$Tr_{gov,inst}$	Transfers from the government to the institutional sectors
$Tr_{row,inst}$	Transfers from the Rest of the World to the institutional sectors
χ_{inst}^U	Share of consumption in disposable income by institutional sector
σ_U	Elasticity of substitution between consumption and savings
$\delta_{inst,i}^C$	Share of consumption of the i^{th} good in the consumption bundle by institutional sector
σ_C	Elasticity of substitution in the consumption bundle
δ_i^I	Share of the demand for investment by good in total gross investment
σ_I	Elasticity of substitution in the investment bundle
δ_i^E	Share of the demand for export by good in total exports
σ_E	Elasticity of substitution in the Rest of the World export bundle

Variables

P_i	Price of output by industry
Q_i	Quantity of output by industry
P_i^{DOM}	Price of domestic output by industry
Q_i^{DOM}	Quantity of domestic output by industry
P_i^M	Price of imports by industry
Q_i^M	Quantity of imports by industry
$tout_i$	Taxes on output by industry
P_i^{NE}	Price of non-energy intermediate inputs by industry
P_i^{VA}	Price of the environmentally extended value added by industry
PL	Price of labor
L_i	Labor demand by industry
P_i^{KE}	Price of the non-abatement capital and energy aggregate by industry
$K_{i,c}$	Capital demand by industry and by type of capital
PK	Price of the non-abatement capital
P_i^{EN}	Price of the non-abatement capital and energy aggregate by industry
$P_{elec,i}$	Price of electricity by industry
P_i^{FOSSIL}	Price of fossil energy sources by industry
$P_{coal,i}^{ENV}$	Price of coal by industry (including the abatement cost)
$P_{gas,i}^{ENV}$	Price of gas by industry (including the abatement cost)
$P_{oil,i}^{ENV}$	Price of oil by industry (including the abatement cost)
$P_{coke,i}^{ENV}$	Price of coke by industry (including the abatement cost)
$P_{coal,i}$	Price of the coal input by industry
$P_{gas,i}$	Price of the gas input by industry
$P_{oil,i}$	Price of the oil input by industry
$P_{coke,i}$	Price of the coke input by industry

$P_{coal,i}^{ABAT}$	Price of carbon abatement associated with coal by industry
$P_{gas,i}^{ABAT}$	Price of carbon abatement associated with gas by industry
$P_{oil,i}^{ABAT}$	Price of carbon abatement associated with oil by industry
$P_{coke,i}^{ABAT}$	Price of carbon abatement associated with coke by industry
P_{coal}^{CARB}	Price of CO ₂ emissions from coal
P_{coal}^{AK}	Price of abatement capital for coal
P_{gas}^{CARB}	Price of CO ₂ emissions from gas
P_{gas}^{AK}	Price of abatement capital for gas
P_{oil}^{CARB}	Price of CO ₂ emissions from oil
P_{oil}^{AK}	Price of abatement capital for oil
P_{coke}^{CARB}	Price of CO ₂ emissions from coke
P_{coke}^{AK}	Price of abatement capital for coke
$Y^{prim\ inst}$	Primary income by institutional sector
$Y^{disp\ inst}$	Disposable income by institutional sector
L^{inst}	Labor endowment by institutional sector
K_c^{inst}	Capital endowment by institutional sector and by type of capital
U^{inst}	Utility by institutional sector
C^{inst}	Consumption by institutional sector
S^{inst}	Saving by institutional sector
Pu_{inst}	Price index of utility by institutional sector
Pc_{inst}	Price index of consumption by institutional sector
C_i^{is}	Quantity consumed by good and by institutional sector
PI	Price index of investment
I_i	Demand for investment
X_i	Demand for export

Equations

Production block

$$Q_i = \left[\mu_i^Q (Q_i^{DOM})^{\rho_{ar}} + (1 - \mu_i^Q) (Q_i^M)^{\rho_{ar}} \right]^{\frac{1}{\rho_{ar}}}$$

$$(1 - r_{out,i}) P_i = \left[\mu_{dom,i} P_i^{DOM(1-\sigma_{ar})} + (1 - \mu_{dom,i}) P_i^{M(1-\sigma_{ar})} \right]^{\frac{1}{(1-\sigma_{ar})}}$$

$$Q_i^{DOM} = \mu_i^Q Q_i \left(\frac{P_i}{P_i^{DOM}} \right)^{\sigma_{ar}}$$

$$P_i^M = \frac{P^W}{exr}$$

$$Q_i^M = (1 - \mu_i^Q) Q_i \left(\frac{P_i}{P_i^M} \right)^{\sigma_{ar}}$$

$$P_i^{DOM} = \beta_{int,i} P_i^{NE} + (1 - \beta_{int,i}) P_i^{VA}$$

$$P_i^{NE} = \sum_i \beta_{ne,i} P_i \quad ne \rightarrow \forall int \neq \{coal, oil, gas, coke, electricity\}$$

$$P_i^{VA} = \left[\eta_{lab,i} PL^{(1-\sigma_{kl})} + (1 - \eta_{lab,i}) P_i^{KE(1-\sigma_{kl})} \right]^{\frac{1}{(1-\sigma_{kl})}}$$

$$P_i^{KE} = \left[\gamma_{k,i} PK^{(1-\sigma_{cap})} + (1 - \gamma_{k,i}) P_i^{EN(1-\sigma_{cap})} \right]^{\frac{1}{(1-\sigma_{cap})}}$$

$$P_i^{EN} = \left[\beta_{el,i} P_{elec,i}^{(1-\sigma_{re})} + (1 - \beta_{el,i}) P_i^{FOSSIL(1-\sigma_{re})} \right]^{\frac{1}{(1-\sigma_{re})}}$$

$$P_i^{FOSSIL} = \left[\alpha_{co,i} P_{coal,i}^{ENV(1-\sigma_f)} + \alpha_{gas,i} P_{gas,i}^{ENV(1-\sigma_f)} + \alpha_{oil,i} P_{oil,i}^{ENV(1-\sigma_f)} + \alpha_{ck,i} P_{coke,i}^{ENV(1-\sigma_f)} \right]^{\frac{1}{(1-\sigma_f)}}$$

$$P_{coal,i}^{ENV} = \beta_{co,i} P_{coal,i} + (1 - \beta_{co,i}) P_{coal,i}^{ABAT}$$

$$P_{gas,i}^{ENV} = \beta_{gas,i} P_{gas,i} + (1 - \beta_{gas,i}) P_{gas,i}^{ABAT}$$

$$P_{oil,i}^{ENV} = \beta_{oil,i} P_{oil,i} + (1 - \beta_{oil,i}) P_{oil,i}^{ABAT}$$

$$P_{coke,i}^{ENV} = \beta_{ck,i} P_{coke,i} + (1 - \beta_{ck,i}) P_{coke,i}^{ABAT}$$

$$P_{coal,i}^{ABAT} = \left[\delta_{co,i} P_{coal}^{CARB(1-\sigma_{ac})} + (1 - \delta_{co,i}) P_{coal}^{AK(1-\sigma_{ac})} \right]^{\frac{1}{(1-\sigma_{ac})}}$$

$$P_{gas,i}^{ABAT} = \left[\delta_{gas,i} P_{gas}^{CARB(1-\sigma_{ac})} + (1 - \delta_{gas,i}) P_{gas}^{AK(1-\sigma_{ac})} \right]^{\frac{1}{(1-\sigma_{ac})}}$$

$$P_{oil,i}^{ABAT} = \left[\delta_{oil,i} P_{oil}^{CARB(1-\sigma_{ac})} + (1 - \delta_{oil,i}) P_{oil}^{AK(1-\sigma_{ac})} \right]^{\frac{1}{(1-\sigma_{ac})}}$$

$$P_{coke,i}^{ABAT} = \left[\delta_{ck,i} P_{coke}^{CARB(1-\sigma_{ac})} + (1 - \delta_{ck,i}) P_{coke}^{AK(1-\sigma_{ac})} \right]^{\frac{1}{(1-\sigma_{ac})}}$$

Primary income and disposable incomes

$$Y_{prim}^{inst} = \varphi_{inst} \cdot \sum_i L_i + \vartheta_{inst,c} \cdot \sum_i K_{i,c}$$

$$Y_{disp}^{hh} = Y_{prim}^{hh} - tinc_{hh}(Y_{prim}^{hh}) + \sum_{priv} (Y_{prim}^{priv}) tr_{priv,hh} + Tr_{gov,hh} + Tr_{row,hh} - \sum_{inst} (Y_{prim}^{hh}) tr_{hh,inst}$$

$$Y_{disp}^{corp} = Y_{prim}^{corp} - tinc_{corp}(Y_{prim}^{corp}) + \sum_{inst} (Y_{prim}^{inst}) tr_{inst,corp} + Tr_{gov,corp} + Tr_{row,corp} - \sum_{corp} (Y_{prim}^{corp}) tr_{corp,inst}$$

$$Ydisp^{gov} = Yprim^{gov} + \sum_i r_{out_i} P_i Q_i + tinc_{priv}(Yprim^{priv}) + (Yprim^{priv})tr_{priv,gov} + Tr_{row,gov} - Tr_{gov,inst}$$

$$Ydisp^{row} = Yprim^{row} + \sum_i M_i + \sum_{priv} (Yprim^{priv})tr_{priv,row} + Tr_{gov,row} - Tr_{row,inst}$$

Consumption block

$$U^{inst} = \sum_i C_i^{inst}$$

$$P u_{inst} = \left[\chi_{inst}^U P C_{inst}^{(1-\sigma_U)} + (1 - \chi_{inst}^U) P I^{(1-\sigma_U)} \right]^{\frac{1}{1-\sigma_U}}$$

$$C^{inst} = \chi_{inst}^U U^{inst} \left(\frac{P u_{inst}}{P C_{inst}} \right)^{\sigma_U}$$

$$S^{inst} = (1 - \chi_{inst}^U) U^{inst} \left(\frac{P u_{inst}}{P I} \right)^{\sigma_U}$$

$$P C_{inst} = \left(\sum_i \delta_{inst,i}^C P_i^{1-\sigma_C} \right)^{\frac{1}{1-\sigma_C}}$$

$$C_i^{inst} = \delta_{inst,i}^C U^{inst} \left(\frac{P C_{inst}}{P_i} \right)^{\sigma_C}$$

$$P I = \left(\sum_i \delta_i^I P_i^{1-\sigma_I} \right)^{\frac{1}{1-\sigma_I}}$$

$$I_i = \delta_i^I I \left(\frac{P I}{P_i} \right)^{\sigma_I}$$

$$X_i = \delta_i^E Y d^{row} \left(\frac{P^W}{P_i} \right)^{\sigma_E}$$

Market clearing conditions

$$\sum_{inst} L^{inst} = \sum_i L_i$$

$$\sum_{inst} K_c^{inst} = \sum_i K_{i,c}$$

For $i = j$,

$$P_i Q_i = P_i \cdot \left(\sum_j Int_{i,j} + \sum_i C_i + \sum_i G_i + \sum_i I_i + \sum_i X_i \right)$$

$$\sum_{inst} S^{inst} = \sum_i I_i$$

Chapter 3

Degree of monopoly and price formation in a multisectoral CGE model

Abstract

Computable General Equilibrium (CGE) models based on Social Accounting Matrices (SAMs) represent a best practice for policy analysts seeking to inform policy decisions. They constitute a powerful tool for the quantification of economic implications deriving from the introduction of shocks on the supply side, the demand side, and the income distribution.

While structuralist approaches to CGE modeling introduce forms of rigidity in selected primary factor markets and in macroeconomic closures, the assumption of perfect competition in the markets of commodities remains a persistent feature even in the latest generation of models. From this perspective, the introduction of a new modeling solution that incorporates varying degrees of monopoly in selected commodity markets would facilitate a more realistic impact analysis of policy measures.

In accordance with this line of inquiry, this study explores the effects of an ascending degree of monopoly power across all commodity markets within a SAM-based CGE model for Italy. The theoretical exercise is structured through the incorporation of a mark-up, which ranges from zero (representing the perfect competition scenario) to 0.4 (corresponding to the high degree of monopoly scenario) and includes an intermediate degree of monopoly. Specifically, the hypothesis of an increasing monopoly degree is coupled with a standard demand shock scenario to determine the impact of reduced competitiveness in commodity markets on the effectiveness of economic policies in generation, distribution, and redistribution of income in both aggregated and disaggregated terms.

Keywords: Social Accounting Matrix, Computable General Equilibrium, Monopoly Pricing, Fiscal policy

JEL classification codes: C68, D58, E16, E62

3.1 The European and national regulatory frameworks on competition

The Treaty on the Functioning of the European Union (TFEU)¹¹ is concerned with regulating competition in European Union (EU) countries to promote the proper functioning of the internal market, as specified in Article 3 of the TFEU regarding the areas of competence of European lawmaking. The EU is committed to periodically monitoring the internal market to prevent the emergence of conditions of competition that could distort the free movement of goods and services within the EU, with a view to protecting the interests of consumers.

In particular, Title VII, in Chapter I, is exclusively dedicated to the issue of restriction and distortion of competition within the European Union. A variety of actions may be considered as falling within the scope of those intended to restrict competition. These include, for example, the fixing of sales and purchase prices, whether directly or indirectly, as well as the control of production, technological progress and investment. Other practices that distort competition include the partitioning of the market among a small group of players and the imposition of additional clauses unrelated to the subject matter of the contract, which are designed to benefit specific contractors.

Article 102 of the TFEU establishes the regulatory framework for the prevention and correction of abuses of dominant positions. Such abuses are defined as the imposition of unfair purchase or selling prices, the discontinuation of production, the circumscribing of markets, or the prevention of technical development. Additionally, they encompass the application of disparate terms to different contractors. State aid is subject to periodic monitoring to ensure compliance with the aforementioned provisions.

In Italy, the European legislative provisions on competition were initially transposed by Law No. 99/2009, which introduced the adoption of an annual market and competition law into Italian legislation at Article 47. The law's primary objectives are threefold: the elimination of regulatory impediments, whether of a regulatory or administrative nature, to market opening; the fostering of competition; and the guaranteeing of consumer protection. However, the obligation introduced by Law No. 99/2009 remained unfulfilled until 2017, when Law No. 124/2017 passed the first annual law for market and competition. This law encompasses a range of areas, including car insurance, supplementary pension funds, telephone operators, the energy sector, fuels, pharmaceuticals, and transportation.

In the years following 2017, the annual law for market and competition was not fulfilled until it was revitalized by the National Recovery and Resilience Plan (NRRP). The NRRP represents an economic policy instrument endorsed by the EU with the objective of providing support to member states in their efforts to recover from the economic and social repercussions of the COVID-19 pandemic. Each EU member state is given the opportunity to devise its own plan, delineating the manner in which funding provided by the Next Generation EU (NGEU) program can be used to address specific challenges and contribute to the process of recovery and transformation.

The NRRP identifies the stimulation of competition as a key measure for economic recovery, growth, and innovation. The Italian NRRP, for instance, includes the approval of the annual law for market and

¹¹ The consolidated version as of September 2024 is available at http://data.europa.eu/eli/treaty/tfeu_2016/2024-09-01

competition among the ‘enabling’ reforms.¹² The legislation must include measures that are conducive to the effective implementation of the Plan itself, as well as the removal of administrative, regulatory, and procedural impediments that influence economic activities and the quality of products and services provided to citizens and businesses.

In this context, it is of crucial importance to gain a comprehensive understanding of the structure and distinctive characteristics of the markets in question. This understanding is essential for the development and assessment of targeted policies that are specifically tailored to the requirements of highly regulated markets. This study therefore aims at incorporating a form of market imperfection based on mark-up pricing into a Computable General Equilibrium (CGE) model calibrated on a Social Accounting Matrix (SAM) for Italy as a measure of departure from the perfectly competitive equilibrium (Roson, 2006).

The incorporation of imperfect competition into CGE models represents a significant advancement in both theoretical and empirical terms. From a theoretical perspective, it addresses the limitations of the traditional approach, providing a more comprehensive and realistic depiction of market structures. From an empirical viewpoint, it enhances the model’s ability to evaluate economic policies accurately, thereby contributing to more informed and effective policymaking. This integration is essential for improving both the theoretical rigor and practical applicability of CGE models in economic analysis, policy design, and implementation.

The remainder of this study is organized as follows. Section 3.2 provides an examination of the theory of imperfect competition in partial and general equilibrium models, emphasizing the implications and pivotal aspects of considering this theoretical and methodological advancement. Section 3.3 provides a detailed description of the database, which is represented by the SAM for Italy, and the CGE model, illustrating the characteristics of the production function, the behavioral relations, the market-clearing conditions and the macroeconomic closures. Section 3.4 is dedicated to the formalization of the mark-up hypothesis within the SAM-based CGE model. Section 3.5 is dedicated to the theoretical scenarios: Subsections 3.5.1 and 3.5.2 report the main results of the scenarios proposed for testing the functioning of the mark-up hypothesis. Section 3.6 presents the sensitivity analysis of the model, while Section 3.7 concludes.

3.2 The theory of imperfect competition

The introduction of imperfect competition into CGE modeling represents an evolving research field. It has notable theoretical and technical implications concerning product differentiation and the strategic behavior of firms. Indeed, the competitive structure of production may be highly fragmented. Industries can interact in a combination of strategic frameworks, including oligopoly and monopolistic competition. Oligopoly raises among a few selected sectors that adopt a strategic behavior (Flaig et al., 2013; Mathouraparsad, 2016). In

¹² <https://www.governo.it/en/approfondimento/nrrp-reforms/19324#:~:text=The%20NRRP's%20enabling%20reforms%20include,of%20intervention%20or%20economic%20activities.>

contrast, monopolistic competition does not impede market entry, and economic operators sell heterogeneous products. In this case, the ability to move freely and make optimal quantity choices allows firms to reach a break-even equilibrium. Furthermore, in the context of imperfect competition in commodity markets, the composition of costs and economies of scale enter the debate. These aspects relate to the differentiation of products and inputs. In an open system, differentiation also refers to imports and exports. Differentiation takes a tree-like shape to describe distinct nests of prices, goods, intermediate inputs, and primary factors. Therefore, differentiation by production stage is combined with differentiation by geographic origin (Armington, 1969). Finally, the mark-up equation is derived from the resolution of the cost-minimization problem. The profit margin is a relevant transmission channel for exogenous shocks, considering that it is affected by market shares, competitors' expected behavior and anticipated demand elasticity (Bajo-Rubio & Gómez-Plana, 2005).

During the Seventies and the Eighties, international economics theorists advanced the proposition that the removal of trade barriers would permit firms to reduce production costs and increase product variety (Krugman, 1989). The study of imperfect competition in an open economy marks a fundamental departure from the traditional comparative advantage model based on constant returns to scale. In continuity with the idea of establishing a logical link between the theory of industrial organization and internal economies of scale (Helpman, 1981), the initial multisectoral and multi-commodity models for a small open economy were developed (Harris, 1984; De Melo & Robinson, 1989). Firms produce goods and services, with a share of their output destined for final consumer markets and another destined for use as intermediate inputs in production processes. In this setting, the mechanism of pricing is twofold. In certain instances, firms impose variable costs based on their expected demand curve that coincides with the actual demand curve in the short term. In other instances, firms adopt the collusive price hypothesis, which posits that the final price is equal to the import price, including customs duties. In both cases, the number of production lines emerges as a further variable.

Alternative modeling solutions may reflect a crowding-out effect between national and foreign production. For example, domestic differentiation for intermediate inputs is based on the Armington assumption (Hertel & Swaminathan, 1996). Within the boundaries of a country, a technical component produced in one region is in direct competition with another component obtained in another administrative unit, with the determining factor being the region of origin. In contrast, at the international level, domestic goods are homogeneous and compete with composite imported goods, which are derived from an aggregation process of the types produced in the foreign country.

In the context of a zero-profit assumption, the mark-up can be considered a relevant transmission mechanism for an exogenous disturbance or policy. The mark-up may be reduced in two ways: firstly, by an increase in the expected elasticity of demand; and secondly, by a contraction in the collusive price, which is in turn induced by a decrease in the price of competitive imports. Consequently, efforts are made to integrate the price elasticity of demand into the mark-up, utilizing the resulting construct as a corrective instrument for the equilibrium price determined by the market-clearing condition. This correction is implemented in select production activities where the perfect competition assumption is deemed implausible.

On the demand side of the economy, consumers maximize the utility function that incorporates multiple varieties of goods linked through a Spence-type generalization of a Constant Elasticity of Substitution (CES) aggregation (Spence, 1976). Furthermore, the utility function can be expanded to encompass the preference for composite imported goods, which are obtained by combining the region-specific product types of trading partners. This occurs when firms are subject to domestic and foreign competition and interact by changing the quantity produced (Harrison et al., 1997). A sole value for the elasticities of substitution associated with products and their varieties is selected to condense preferences into a single analytical structure and enable comparison with results under constant returns to scale. While the increase in overall welfare under increasing returns to scale is observable, the focus is on the advantage to firms of production cycle rationalization.

More recent contributions show that the Cournot oligopoly is adaptable to strategic quantity adjustment behaviors (De Santis, 2002). This market regime serves as the foundation for determining the inverse value of the price elasticity of demand and formalizing perfect substitutability with a CES technology. A distinguishing feature is that the number of firms is an endogenous variable that can influence the mark-up in an inversely proportional relation (Li et al., 2013). Two distinct profit margins are set up, one for domestic products and another for exports. Both remunerate the fixed costs incurred by firms for physical capital, investments in research and development, and marketing activities to design goods that are qualitatively more aligned with consumers' tastes than those produced by competitors.

The generic mark-up function is based on the findings of the studies conducted on the Uruguay Round (Blake et al., 1999). However, the mark-up function does not take into account the parameter of expected competitors' reactions in response to changes in output. The number of firms in a sector may influence the magnitude of the difference between the price charged and marginal costs, which in turn affects the income distribution and has the potential to exert pro-competition or anti-competition effects. If the demand for a given variety of goods increases under monopolistic competition, the industry may experience a massive entry of new firms. On the one hand, this mechanism boosts competition dynamics, while on the other hand, it will induce a decline in the mark-up with a subsequent increase in efficiency. Pro-competitive effects are beneficial in terms of reducing the price of imported goods. In this circumstance, domestic firms experience an increase in the price elasticity of demand for products, which prompts them to reduce the mark-up in order to stimulate the purchase of domestic goods.

In this perspective, integrating imperfect competition into a CGE model is crucial for achieving significant advancements in both theoretical and practical terms. From a theoretical standpoint, incorporating imperfect competition helps to overcome the well-known limitations of the Walrasian model. CGE models traditionally rely on the assumption of perfect competition, which implies that firms are price-takers and markets always clear without any friction. However, a considerable number of commodity markets exhibit traits of imperfect competition, with firms having a certain degree of market power that enables them to set prices above marginal costs and exert influence over the market conditions. By modeling these imperfections,

CGE models can more accurately represent the strategic interactions among firms, the presence of economies of scale, and the impacts of product differentiation.

This shift towards a more nuanced representation of the market structure strengthens the theoretical foundations of CGE models, making them more robust and closer to the observed behavior of the economy. From a practical standpoint, incorporating imperfect competition into CGE models allows for more realistic assessments of economic policies. When markets are imperfectly competitive, the responses of firms and consumers to policy changes can diverge significantly from those predicted under perfect competition. This realism is crucial for the formulation of effective and targeted policy measures.

3.3 The SAM-based CGE model for Italy

The CGE model addresses economic policy analysis (Scrieciu, 2007; Socci et al., 2021), with the objective of evaluating the impact of policies on the supply side, the demand side, and the income distribution (Severini et al., 2020; Deriu et al., 2021). The model is developed through a system of simultaneous linear and nonlinear equations (Scarf, 1967), which provide a framework for the analysis of the set of commodity and factor markets in the economy, and their interplay across the circular flow of income. Additionally, the model incorporates the processes of utility optimization by consumers, subject to the income constraint, and profit maximization by firms compatibly with the production function. The vector of prices ensures that the equilibrium between the demand and supply of all markets is maintained.

The objective of CGE models is to analyze the effects that exogenous perturbations can have on resource allocation, efficiency, collective well-being, as well as the formation and redistribution of income among the institutional sectors (Socci et al., 2022). The formalization and resolution of a CGE model requires a series of steps, beginning with the selection of the model and functional forms and concluding with parameter and variable specifications. This process is anchored in the assumption that the system is in equilibrium and that the economic system's response is derived from this equilibrium (Shoven & Whalley, 1984). Consequently, the model allows for a comparison between the initial equilibrium (the benchmark equilibrium) and its counterfactual, derived from new policies influencing the price and quantity formation of each aggregate. This enables the provision of information on impacts in nominal and real terms. In particular, the model follows the SAM framework to replicate the production structure and the institutional sectors' behavior.

The SAM represents the transactions between activities, primary factors of production, and institutional sectors across the economic system. In formal terms, it is an instrument of analysis that completes the flows of the Input-Output (IO) tables or Supply and Use tables to provide a comprehensive representation of the circular flow of income, from income generation and primary distribution to redistribution, use, and accumulation (Socci, 2003).

The SAM for Italy provides a matrix representation of all transactions between different production activities, the use of primary factors by production activities, the distribution of income associated with factors of production among institutional sectors, transactions between institutional sectors, the use of disposable

income, and capital formation (Stone, 1951). In addition, the SAM provides detailed information on the system of direct and indirect taxes levied on activities and institutional sectors and collected by the government. The fundamental data sources to construct the SAM for Italy are provided by the Italian National Institute of Statistics (*Istituto Nazionale di Statistica*, Istat). These are the Supply and Use tables¹³ and the institutional sector accounts.¹⁴

The economic flows recorded in each row of the SAM represent the receipts of the operator named in the row. Conversely, the flows recorded in each column indicate the outflows of the operator named in the column. The main principle of accounting reconciliation is that the total value of each row must be equal to the total value of the corresponding column. This ensures that the economic balance for each account is accurately reported. Accordingly, the SAM is the most suitable accounting framework for depicting the complex interdependencies that underpin the economic system. The SAM for Italy is structured according to the scheme in Figure 1.

Figure 1. The SAM framework for Italy (expressed in million euros).

	Commodity	Activity	Net taxes on commodities	Compensation of employees						Mixed income and Gross operating surplus	Taxes less subsidies on activities	Institutional sectors					Capital formation	Total
				Low skills		Medium skills		High skills				Financial corporations	Nonfinancial corporations	Households and NPISHs	Government	Rest of the World		
				male	female	male	female	male	female									
Commodity		Intermediate consumption									Final consumption	Final consumption	Exports	Gross fixed investment and changes in inventories				
Activity	Domestic production																	
Net taxes on commodities	Net taxes on commodities																	
Compensation of employees	Low skills	male	Gross value added											Factor income from the Rest of the World				
		female																
	Medium skills	male																
	female																	
High skills	male																	
	female																	
Mixed income and Gross operating surplus																		
Taxes less subsidies on activities																		
Institutional sectors	Financial corporations			Primary distribution of income							Secondary distribution of income (current taxes on income, wealth, ...; social contributions; social benefits; other current transfers)							
	Nonfinancial corporations																	
	Households and NPISHs																	
	Government			Net taxes on commodities revenues														
	Rest of the World	Imports												Factor income to the Rest of the World				
Capital formation												Savings	Net lending / borrowing					
Total																		

Source: own elaboration.

The SAM scheme for Italy records the flows between different operators or accounts at distinct phases of the circular flow of income. The national structure includes 63 commodities and 63 production activities.¹⁵ Value

¹³ <https://www.istat.it/tavole-di-dati/il-sistema-di-tavole-input-output-anni-2015-2020/>

¹⁴ <http://dati.istat.it/>

¹⁵ The classification of the 63 commodities and the 63 production activities are shown in Appendix A, Tables A.1 and A.2.

added encompasses two factors of production, capital and labor. Labor is disaggregated by skill (low, medium, and high) and gender (male and female), with a total of six categories. The disaggregation of labor by skill and gender is achieved through integration of the SAM database with the EUROSTAT database.¹⁶ The low-skilled workers are defined as individuals holding a lower-secondary school degree or less, the medium-skilled workers are those who have obtained an upper-secondary school degree, and the high-skilled workers are those who have completed the tertiary level of education.

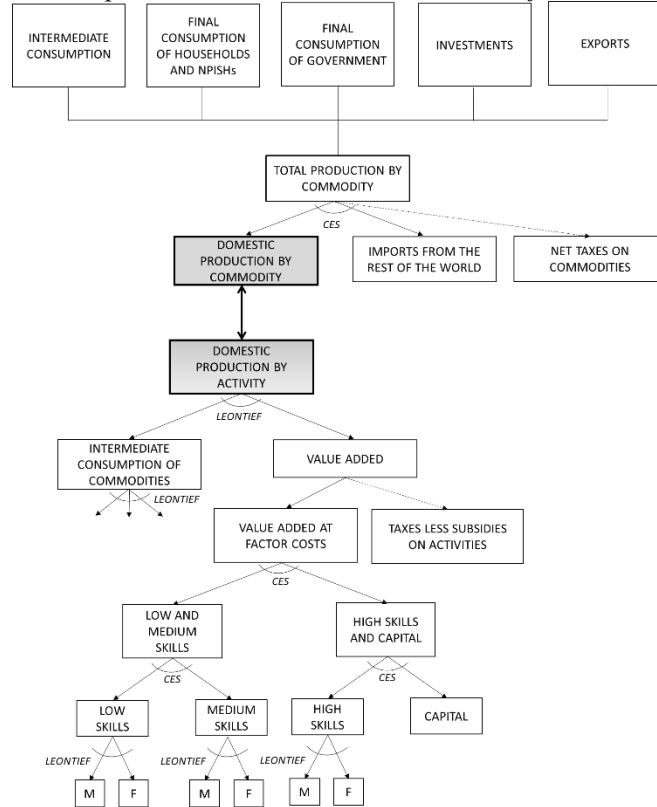
There are four private institutional sectors (financial and nonfinancial corporations, households and non-profit institutions serving households, NPISHs), six public institutional sectors referred to as government (central administration, pension funds, regions, provinces, municipalities and other local and central government), and the Rest of the World (RoW). The capital formation account records gross fixed capital formation and changes in inventories.

In addition, there are three principal categories of taxation: net taxes on commodities, taxes on less subsidies on activities, and taxes on income. In particular, net taxes on commodities are classified into 14 types, taxes less subsidies on activities are distinguished into 13 types, and taxes on income are divided into 20 different types. The primary distribution of income is a function of income from labor and capital to the institutional sectors that collect it based on their ownership. The secondary distribution of income is linked to taxes and transfers between institutional sectors. The use of income translates into consumption and savings. Savings accommodate capital accumulation, highlighting the circularity.

The production cost function and the components of demand in the Italian economic system are illustrated in Figure 2.

¹⁶ https://ec.europa.eu/eurostat/databrowser/view/LFSA_ERGAED/default/table?lang=en

Figure 2. The production and demand structures of the CGE model.



Source: own elaboration.

The initial nesting stage delineates the formation of total production and the generation of relative prices that are differentiated by product type.¹⁷ Total production is obtained by combining domestic production with imports from the Rest of the World, under the assumption of imperfect substitutability between domestic and imported goods (Armington, 1969). The dual cost function is structured as follows:

$$(1 - tq_{i,t,out})P_i = \left[\delta_i^Q P_{dom,i}^{(1-\sigma_Q)} + (1 - \delta_i^Q) Pm_i^{(1-\sigma_Q)} \right]^{\frac{1}{1-\sigma_Q}} \quad (1)$$

The subscript $i = 1, \dots, 63$ indicates commodities. The variable P_i represents the price of goods by commodity type, $tq_{i,t,out}$ is the tax rate on commodities, $P_{dom,i}$ is the price of domestic goods, and Pm_i is the price of imports. The coefficient δ_i^Q is the share of domestic commodities in total production by type of commodity, while σ_Q is the elasticity of substitution between domestic and imported goods. These elasticities of substitution are differentiated by commodity, following Ciaschini et al. (2012).

The subsequent stage of nesting involves a transition from domestic production by commodity to domestic production by activity. This transition is evidenced by the link in the make-and-use structure of the SAM. Indeed, the production of each type of commodity can be observed from two distinct perspectives, as it can be produced by different production activities, according to the definitions of primary and secondary production. Domestic production by activity is derived by aggregating value added and intermediate goods. In particular, the price of domestic production by activity is expressed as follows:

¹⁷ The full technical specifications of the SAM-based CGE model are provided in Appendix B.

$$(1 - tq_{j,t_act})P_{dom,j} = [\delta_j^D Pbi_j^{(1-\sigma_D)} + (1 - \delta_j^D)Pva_j^{(1-\sigma_D)}]^{1-\sigma_D} \quad (2)$$

The subscript $j = 1, \dots, 63$ denotes production activities. The variable Pbi_j is the price of intermediate inputs by activity, tq_{j,t_act} represents the tax rate on activities, and Pva_j is the price of value added by activity. The coefficient δ_j^D is the share of intermediate inputs in domestic production, whereas σ_D is the elasticity of substitution between intermediate inputs and value added, which is equal to zero (Leontief technology).

The aggregate for intermediate inputs is derived from the combination of the various types of domestic and imported intermediate commodities. The associated dual of the production cost function by activity is as follows:

$$Pbi_j = \sum_i \left(\delta_{i,j}^{BI} P_i^{(1-\sigma_{BI})} \right)^{\frac{1}{1-\sigma_{BI}}} \quad (3)$$

The variable P_i represents the average price of goods generated by the market-clearing condition. The coefficient $\delta_{i,j}^{BI}$ is the cost share of each intermediate input in total costs for intermediate inputs, while σ_{BI} is the elasticity of substitution between intermediate inputs, which is set equal to zero, in accordance with the Leontief-type technology assumption.

The value added is derived from the combination of the primary factors, namely labor and capital. In this model, the labor factor is disaggregated by skill and gender. The price of value added by activity is determined by the following combination:

$$Pva_j = \left[\delta_j^v \cdot PLMS_j^{(1-\sigma_v)} + (1 - \delta_j^v) \cdot PHSK_j^{(1-\sigma_v)} \right]^{\frac{1}{1-\sigma_v}} \quad (4)$$

The variables $PLMS_j$ and $PHSK_j$ represent, respectively, the price of labor for the low/medium-skilled aggregate and the price of high-skilled labor and capital aggregate. The coefficient δ_j^v represents the proportion of the low/medium-skilled aggregate cost in total value added by activity, while σ_v is the elasticity of substitution between the two cost aggregates for low/medium-skilled labor and high-skilled/capital labor. This value is calibrated at 0.67.

The aggregate of low- and medium-skilled labor by activity is derived from the combination of two aggregates: the low-skilled and the medium-skilled categories of labor. This combination takes the following form:

$$PLMS_j = \left[\delta_j^{LMS} \cdot PLS_j^{(1-\sigma_{LMS})} + (1 - \delta_j^{LMS}) \cdot PMS_j^{(1-\sigma_{LMS})} \right]^{\frac{1}{1-\sigma_{LMS}}} \quad (5)$$

The variables PLS_j and PMS_j represent the prices of labor in the low-skilled and in the medium-skilled aggregates, respectively. The quota δ_j^{LMS} is the proportion of the low-skilled labor by activity in the total low/medium-skilled labor factor cost. The coefficient σ_{LMS} represents the elasticity of substitution between the low-skilled and the medium-skilled labor.

Similarly, the aggregation of high-skilled labor and capital by activity can be expressed as follows:

$$PHSK_j = \left[\delta_j^{HSK} \cdot PHS_j^{(1-\sigma_{HSK})} + (1 - \delta_j^{HSK}) \cdot PK^{(1-\sigma_{HSK})} \right]^{\frac{1}{1-\sigma_{HSK}}} \quad (6)$$

In equation (6), the variables PHS_j and PK denote the price of the high-skilled labor aggregate by activity and the price of capital, respectively. The quota δ_j^{HSK} is the proportion of high-skilled labor in the total high-skilled labor and capital aggregate cost by activity, while σ_{HSK} is the elasticity of substitution between the high-skilled labor and capital.

The value of each of the three aggregates related to the labor factor (the low-skilled, the medium-skilled, and the high-skilled categories) is obtained through the combination of male and female labor:

$$PLS_j = \left[\delta_j^{LS} \cdot PFLS^{(1-\sigma_{LS})} + (1 - \delta_j^{LS}) \cdot PMLS^{(1-\sigma_{LS})} \right]^{\frac{1}{1-\sigma_{LS}}} \quad (7)$$

The variables $PFLS$ and $PMLS$ represent the prices of female labor and male labor, respectively, within the context of the low-skilled aggregate. The share δ_j^{LS} is the proportion of female labor in the low-skilled labor aggregate cost by activity, while σ_{LS} is the elasticity of substitution between male and female labor in the low-skilled labor aggregate. This value is set at zero.

The values for the medium-skilled and high-skilled labor aggregates are obtained in a similar manner, as illustrated in equations (8) and (9):

$$PMS_j = \left[\delta_j^{MS} \cdot PFMS^{(1-\sigma_{MS})} + (1 - \delta_j^{MS}) \cdot PMMS^{(1-\sigma_{MS})} \right]^{\frac{1}{1-\sigma_{MS}}} \quad (8)$$

$$PHS_j = \left[\delta_j^{HS} \cdot PFHS^{(1-\sigma_{HS})} + (1 - \delta_j^{HS}) \cdot PMHS^{(1-\sigma_{HS})} \right]^{\frac{1}{1-\sigma_{HS}}} \quad (9)$$

This SAM-based CGE model for Italy incorporates the role of an additional institution, the trade union, which engages in negotiations with firms over the price of labor by skill and gender ($PFLS$, $PMLS$, $PFMS$, $PFMS$, $PFHS$, and $PMHS$), according to the ‘right-to-manage’ modeling approach (Pissarides, 1998). In particular, workers are organized in trade unions and negotiate the nominal wage with firms. Trade unions seek to maximize their utility function, while firms aim to maximize their profits by selecting the level of employment given the bargained wage. Therefore, the labor market is not perfectly competitive. The nominal wage rigidity gives rise to the formation of involuntary unemployment. The wage-setting functions for the prices of labor by skill and gender are the outcomes of the maximization of the Nash function, which includes the objective functions of the firms and the trade unions, weighted by the respective bargaining powers (Böhringer et al., 2005). The resulting wage-setting functions are expressed as follows:

$$PFLS = \frac{u_{FLS} \cdot b_{FLS} \cdot \eta_{FLS}}{1 - \eta_{FLS} \cdot u_{FLS}} \quad (10a)$$

$$PMLS = \frac{u_{MLS} \cdot b_{MLS} \cdot \eta_{MLS}}{1 - \eta_{MLS} \cdot u_{MLS}} \quad (10b)$$

$$PFMS = \frac{u_{FMS} \cdot b_{FMS} \cdot \eta_{FMS}}{1 - \eta_{FMS} \cdot u_{FMS}} \quad (10c)$$

$$PMMS = \frac{u_{MMS} \cdot b_{MMS} \cdot \eta_{MMS}}{1 - \eta_{MMS} \cdot u_{MMS}} \quad (10d)$$

$$PFHS = \frac{u_{FHS} \cdot b_{FHS} \cdot \eta_{FHS}}{1 - \eta_{FHS} \cdot u_{FHS}} \quad (10e)$$

$$PMHS = \frac{u_{MHS} \cdot b_{MHS} \cdot \eta_{MHS}}{1 - \eta_{MHS} \cdot u_{MHS}} \quad (10f)$$

In the wage-setting function in equation (10a), the term u_{FLS} represents the endogenous unemployment rate of low-skilled female labor, while the coefficient b_{FLS} is the unemployment benefit associated with low-skilled female unemployment. The coefficient η_{FLS} denotes the average wage elasticity of the demand for low-skilled female labor. The wage-setting function in equation (10b) defines the price of the low-skilled male labor as determined by the endogenous unemployment rate of low-skilled male labor, u_{MLS} , the unemployment benefit associated with low-skilled male unemployment, b_{MLS} , and the average wage elasticity of the demand for low-skilled male labor, η_{MLS} . Similarly, the wage-setting functions in equations (10c)-(10f) refer to the formation of prices for female and male labor with medium and high skill levels.

The market-clearing conditions for the primary factor markets establish that the demand for each primary factor is equal to the supply of each primary factor, the condition of equilibrium that is maintained through price fluctuations. As explained above, the labor market is imperfectly competitive. The equilibrium between the labor demand and the labor supply is ensured by the variation of the unemployment rate, as indicated in equation (11):

$$\sum_{is} (1 - u_{g,p}) L_{g,p}^{is} = \sum_j L_{j,g,p} \quad (11)$$

The superscript is designates the institutional sectors. The subscript g is represented by the set $\{M, F\}$, which denotes the gender subset comprising male and female subgroups. The subscript p , which is characterized by the set $\{LS, MS, HS\}$, indicates the skill types. The term $u_{g,p}$ is the unemployment rate differentiated by gender and by skill level. The variable $L_{g,p}^{is}$ represents the labor endowment by institutional sector, gender, and skill level, while $L_{j,g,p}$ is labor demand by gender and by skill type, expressed by each activity.

The equilibrium between capital demand and capital supply takes the following form:

$$\sum_{is} K^{is} = \sum_j K_j \quad (12)$$

In equation (12), the variable K^{is} is used to express the capital endowment by institutional sector, whereas K_j represents capital demand by industry. The variables in equations (11) and (12) are expressed in nominal terms.

The total production by commodity, denoted as $P_i Q_i$, which corresponds to domestic production and imports, is entirely absorbed by each of the components of final demand, including intermediate consumption $\sum_j b_{i,j}$, final consumption by households and NPISHs by commodity C_i^{hh} , government consumption by commodity G_i^{pub} , gross investment by commodity I_i , and exports by commodity E_i :

$$P_i Q_i = P_i \left(\sum_j b_{i,j} + C_i^{hh} + G_i^{pub} + I_i + E_i \right) \quad (13)$$

The income generated in production processes is distributed among the institutional sectors in the form of compensation of employees, mixed income, and gross operating surplus, depending on the respective institutional sector's ownership of the primary factors of production. Therefore, the formation of primary income by institutional sector can be expressed as follows:

$$Y^{is} = \sum_g \sum_p L_{g,p}^{is} + K^{is} \quad (14)$$

The variable Y^{is} is used to designate primary income by institutional sector.

The subsequent phase of the circular flow of income is the generation of disposable income, which is derived by aggregating primary incomes to the inflows and outflows that result from taxation and interinstitutional transfers. These accounting entities are functions of primary incomes. The determination of disposable income is subject to variation according to the institutional sectors under consideration, namely households and NPISHs (*hh*), financial and nonfinancial corporations (*corp*), the government (*pub*) and the Rest of the World (*row*):

$$Yd^{hh} = Y^{hh} + \sum_{is_in} Y^{is} tr_{is_in}^{hh} + Tr_{pub}^{hh} + Tr_{row}^{hh} - \sum_{t_inc} Y^{hh} ty_{t_inc}^{hh} - \sum_{is_out} Y^{hh} tr_{is_out}^{hh} \quad (15)$$

$$Yd^{corp} = Y^{corp} + \sum_{is_in} Y^{is} tr_{is_in}^{corp} + Tr_{pub}^{corp} + Tr_{row}^{corp} - \sum_{t_inc} Y^{corp} ty_{t_inc}^{corp} - \sum_{is_out} Y^{corp} tr_{is_out}^{corp} \quad (16)$$

$$Yd^{pub} = Y^{pub} + \gamma_{t_out}^{pub} \sum_i tq_{i,t_out} P_i Q_i + \gamma_{t_act}^{pub} \sum_j tq_{j,t_act} P_j Q_j + \sum_{t_inc} Y^{priv} ty_{t_inc}^{priv} + \sum_{is_in} Y^{priv} tr_{is_in}^{priv} + Tr_{row}^{pub} - Tr_{pub}^{row} \quad (17)$$

$$\begin{aligned}
Yd^{row} = & Y^{row} + \sum_i Pm_i M_i \\
& + \gamma_{t_out}^{row} \sum_i tq_{i,t_out} P_i Q_i \\
& + \gamma_{t_act}^{row} \sum_j tq_{j,t_act} P_j Q_j + \sum_{is_in} Y^{priv} tr_{is_in}^{priv} + Tr_{pub}^{row} - \sum_{t_inc} Y^{row} ty_{t_inc}^{row} \\
& - Tr_{row}^{is}
\end{aligned} \tag{18}$$

The variables Tr_{pub}^{is} and Tr_{row}^{is} represent the flows of transfers paid by the government and the Rest of the World, respectively. It is assumed in the model that these flows are exogenous. Domestic production by activity is designated as Q_j . The variable Y^{priv} denotes the sum of the primary incomes of the private institutional sectors (*priv*), which are households and NPISHs, financial and nonfinancial corporations. The coefficient $ty_{t_inc}^{is}$ is the implicit rate of taxes on income paid by institutional sector and collected by the government, whereas the quotas $tr_{is_in}^{is}$ and $tr_{is_out}^{is}$ represent, respectively, the implicit rates of transfers received and paid by the institutional sectors. The implicit tax rates on commodities and on activities are indicated as tq_{i,t_out} and tq_{j,t_act} , respectively. The shares $\gamma_{t_out}^{pub}$ and $\gamma_{t_act}^{pub}$ are the proportions of net taxes on commodities and taxes less subsidies on activities collected by the government. The shares $\gamma_{t_out}^{row}$ and $\gamma_{t_act}^{row}$ represent the shares of taxes on commodities and taxes on activities collected by the Rest of the World. The summation $\sum_i Pm_i M_i$ records the value of total imports.

The solution to the maximization process of the utility function of households allows for the determination of consumption levels that are compatible with disposable income, which is defined according to the following relation:

$$Yd^{hh} = C^{hh} + S^{hh} \tag{19}$$

The variables C^{hh} and S^{hh} represent the levels of consumption and savings of households, respectively.

As regards the public administration, the institutional sector does not pursue the objective of maximizing the utility function. Conversely, the government implements fiscal policies and measures that result in either a deficit ($S^{pub} < 0$) or a surplus ($S^{pub} > 0$). The government deficit or surplus is determined residually as follows:

$$S^{pub} = Yd^{pub} - G^{pub} \tag{20}$$

The government deficit or surplus is calculated as the difference between government revenues Yd^{pub} (see equation 16) and the level of public expenditure G^{pub} .

The disposable income of financial and nonfinancial corporations is equivalent to the level of savings, as these institutional sectors do not engage in final demand for consumption:

$$Yd^{corp} = S^{corp} \tag{21}$$

The disposable income of the Rest of the World is a macroeconomic closure condition in relation to exports and the net lending or borrowing position of Italy towards the Rest of the World:

$$S^{row} = \sum_i E_i - Yd^{row} \quad (22)$$

The summation $\sum_i E_i$ represents total exports, while the variable S^{row} is net lending or borrowing position. In particular, foreign demand, as identified by exports, is a function of the endogenous domestic prices of commodities, the exogenous foreign prices of commodities, the exogenous income of the Rest of the World, and the exogenous nominal exchange rate.

In the end, the macroeconomic closure on investment and savings posits that gross investment is assumed to be driven by gross savings. Therefore, it can be expressed as follows:

$$\sum_{is} S^{is} = \sum_i I_i \quad (23)$$

3.4 Imperfect competition in the SAM-based CGE model

The model introduced assumes that the markets are perfectly competitive. This hypothesis implies that the equilibrium price for each commodity is equal to the marginal cost of production, which represents the lowest price that sellers are able to offer. Consequently, the market does not allow firms to generate additional profits. However, the assumption of perfectly competitive market regimes is inconsistent with the prevailing characteristics of modern economic systems. In practice, firms do not always behave as price-takers; rather, it is reasonable to assume that they can all act as price-makers. Various factors, including state monopoly conditions, product non-homogeneity, and marketing strategies, can influence the price elasticity of demand and benefit firms in the formation of the price charged.

The most frequently occurring market structure settings in the economic literature are monopoly (Hoffmann, 2003), oligopoly (Orlov & Grethe, 2012), and monopolistic competition (Hertel & Swaminathan, 1996). Monopoly can be exerted through patenting (Loisel, 2009; Baccianti & Löschel, 2014) or state-owned enterprises (Ye et al., 2016), but this market imperfection often associates with oligopoly when monopolist firms interact to sell differentiated products (Norman, 1990). It is thus possible to express the relationship between price and marginal costs in the following manner:

$$P_i \mu_i = MC_i \quad (24)$$

$$\text{with } \mu_i = \left(1 - \frac{1}{|\epsilon_i|}\right) \quad (25)$$

$$P_i = \left(1 - \frac{1}{|\epsilon_i|}\right)^{-1} MC_i \quad (26)$$

The parameter ϵ_i represents the price elasticity of demand by commodity. The value $\frac{1}{|\epsilon_i|}$ can be interpreted as the mark-up. In a perfectly competitive market, where prices are equal to marginal or average costs, the mark-up is equal to zero. An increase in this value is indicative of an increase in the market power of the firm. The magnitude of the mark-up is influenced by a number of factors, including the market share, the conjectural

variation parameter, and the perceived price elasticity of demand (Ihadiyan & Bouzahzah, 2003). Its specification is derived from Lerner's profit margin formula, which is a measure of the degree of monopolistic power and is equal to the inverse of the perceived price elasticity of demand (Lerner, 1934). This parameter indicates the responsiveness of demand to price variations.

If firms adopt a strategic approach, the aforementioned measure incorporates expectations of competitors' reactions, which are considered in light of the firms' own strategic objectives. Accordingly, the price elasticity of demand is regarded as either 'expected' or 'perceived'. If the mark-up on marginal production costs is maintained at a constant level, a change in costs will result in a proportional change in price. This assertion is applicable in both perfect and imperfect competition market regimes.

However, mark-ups fluctuate in accordance with the price elasticity of demand assumed in the model. Consequently, a price increase linked, for instance, to augmented production costs is associated with a diminished price elasticity of demand (in absolute value), which results in an augmented profit margin. In the analysis conducted, the price elasticity of demand is assumed to vary exogenously. When firms succeed in acquiring market power, they appropriate a portion of the consumer surplus and generate an additional profit, which can be calculated as follows:

$$\pi_i = \left(1 - \frac{1}{|\epsilon_i|}\right) P_i Q_i \quad (27)$$

The extra-profit of the i^{th} commodity, denoted as, π_i is calculated by multiplying the mark-up of the i^{th} commodity, the price, and the quantity produced of the same commodity. The role of extra-profit within the economic system becomes crucial for policy impact assessment. It is assumed that the redistribution of extra-profits to institutional sectors in the form of capital remuneration is already included in the database and formalized in the main equations of the model. A new issue arises when the level of the mark-up is greater than zero, thereby generating positive profits in the simulation. In this instance, the additional profits are still distributed to the institutional sectors in accordance with the factor ownership shares. In formal terms, the resulting disposable income can be expressed as follows:

$$Y^{is} = \sum_g \sum_p L_{g,p}^{is} + K^{is} + \sum_i \pi_i^{is} \quad (28)$$

In order to understand the effects of introducing market imperfections in CGE modeling, the outcomes of policy scenarios under imperfect competition will be compared with those obtained through the use of a model with the standard closure, following the rules of perfect competition. The aim is to highlight whether incorporating imperfect competition to the modeling may lead to significant differences in the results obtained. In particular, price fluctuations are expected to be more pronounced in imperfect competition than in perfect competition, as cost shocks may exert a more powerful influence. This phenomenon will produce direct, indirect, and induced effects on the entire economic system, and the comparison between the two market regimes is of great importance for economic policy analysis.

3.5 Policy scenarios for market imperfections

The influence of market imperfections on the economic system is investigated by removing the assumption of perfect competition in each commodity market when a ‘basic’ scenario is under consideration. Specifically, the simulation exercises are organized as follows:

1. The construction of the ‘basic’ scenario entails an increase in household consumption by 1% of GDP within the economic system, which operates under the assumption of perfect market competitiveness.
2. The construction of the ‘degree of monopoly’ scenarios consists of the replication of the ‘basic’ scenario under the assumption that an exogenous shock to the price elasticity of demand gives rise to two distinct mark-ups on marginal costs. The values for the mark-up are charged one at a time to the price of each single commodity in order to observe separately the impact on the economic system in comparison to the performance under perfectly competitive conditions. The values for the mark-ups in the two ‘degree of monopoly’ cases are as follows:

$$\begin{array}{ll} \mu_i = 0.1 & \text{low degree of monopoly case} \\ \mu_i = 0.4 & \text{high degree of monopoly case} \end{array}$$

3. The comparison of the ‘monopoly degree’ with the ‘basic’ scenarios is conducted to compare the results of the ‘basic’ scenario simulations with and without perfect competition in the commodity markets. This comparison allows for the determination of the discrepancy between macroeconomic variables under different assumptions about the market structure.

3.5.1 ‘Basic’ scenario: simulation results

The ‘basic’ scenario entails the simulation of a standard shock to household consumption under the assumption of perfect competition. The shock is defined as standard, amounting to 1% of GDP. Furthermore, the shock is distributed across all goods and services in accordance with the household consumption structure reflected in the SAM (i.e., the share of household consumption by commodity in total household consumption). In a context of perfect competition in commodity markets, an increase in final demand by households is associated with a 1.72% increase in real GDP relative to the benchmark, as illustrated in Table 1.

Table 1. Increase in household consumption by 1% of GDP: impact on the main real macroeconomic variables (percentage change from the benchmark).

<i>Aggregate</i>	<i>% change</i>
Real GDP	1.72
Households and NPISHs consumption	3.20
Investment	2.22
Exports	-1.06
Imports	1.35

Source: CGE model estimates.

This estimated outcome is derived from the direct and indirect effects of the expansion of production and demand for intermediate consumption across all economic activities, as well as the induced effects of an increased spending capacity of households. The increase in household consumption can be quantified as a stimulus of final demand by the institutional sector, amounting to 3.20% in comparison to the benchmark equilibrium. This stimulus prompts an acceleration in production processes and encourages the growth of final demand for investment by 2.22%, as well as imports (+1.35%), in order to support the intensified production needs. Conversely, while imports increase, exports contract by -1.06%, due to the loss of competitiveness resulting from the upward effect on the price level.

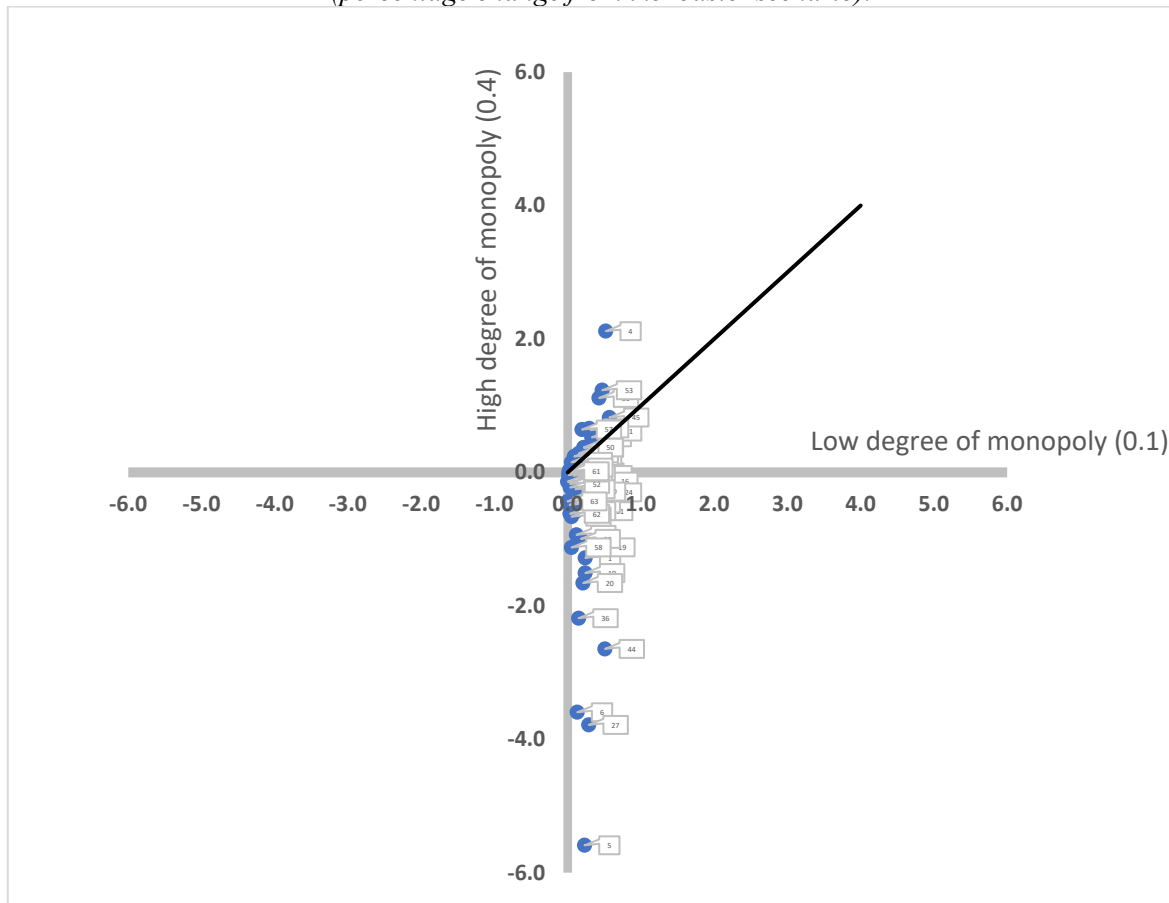
3.5.2 ‘Degree of monopoly’ scenario: simulation results and comparison

Two distinct simulation exercises are constructed in the ‘degree of monopoly’ scenario with the objective of ascertaining the impact of varying degrees of market monopoly on GDP expansion relative to the ‘basic’ scenario of the increase in household consumption under perfect competition. The low degree of monopoly case assumes a mark-up equal to 0.1. The high degree of monopoly case considers a mark-up equal to 0.4.

Figure 3 shows the impact of the two different degrees of monopoly in each individual commodity market on real GDP relative to the ‘basic’ scenario. The horizontal axis records the percentage change in real GDP relative to the ‘basic’ scenario in the presence of a low degree of monopoly ($\mu_i = 0.1$). The vertical axis, in contrast, records the percentage changes in real GDP in comparison to the ‘basic’ scenario with a high degree of monopoly ($\mu_i = 0.4$). The combinations of percentage changes in real GDP in the two monopoly cases are concentrated between the first and the fourth quadrants. This indicates that none of the commodity markets result in negative macroeconomic changes when they abandon the hypothesis of perfect competition, whether the degree of monopoly is low or high. It is important to note that each commodity market has a distinctive macroeconomic reaction to the two degrees of monopoly.

The positioning of the combination of the two real GDP changes relative to the ‘basic’ scenario in the first quadrant suggests that both the degrees of monopoly introduced in a specific commodity market exert a positive influence on real GDP at the aggregate level. In other words, a higher degree of monopoly in a specific commodity market is associated with a higher real GDP change at the aggregate level in comparison to the perfect competition scenario. Conversely, the positioning of the combination of the two real GDP changes in the fourth quadrant indicates that a lower degree of monopoly in a particular commodity market is associated with a higher real GDP change at the aggregate level with respect to the perfect competition scenario.

Figure 3. Real GDP change under the two degrees of monopoly in each commodity market (percentage change from the 'basic' scenario).



Source: elaboration on CGE estimates.

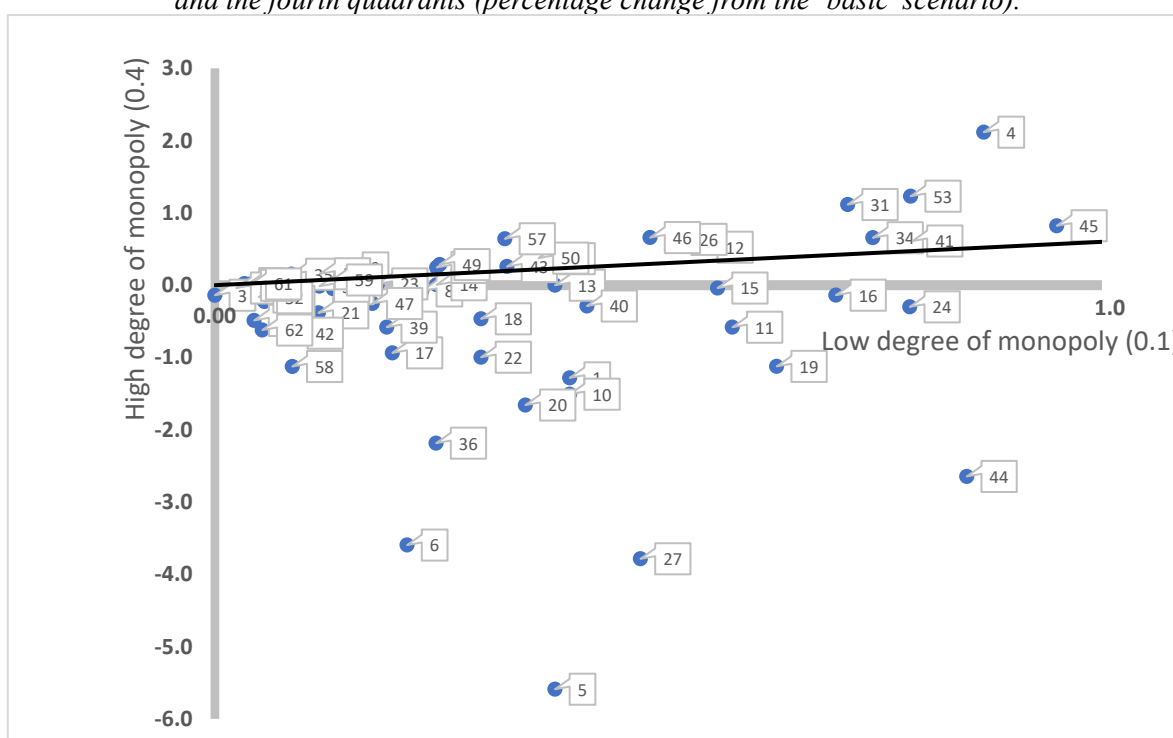
It can be observed in Figure 3 that while the changes in real GDP range from approximately -6% to 2% in the case of a high degree of monopoly, these changes are consistently positive in the case of a low degree of monopoly power, with a range of 0 to 1%. The vertical axis (mark-up = 0.4) depicts two distinct commodity markets, situated on opposite sides: the Mining and quarrying commodity market (denoted as n. 4), and the Food products, beverages, and tobacco products commodity market (indicated as n. 5). Figure 3 indicates that the departure from perfect competition in certain commodity markets would be advantageous for the overall economic system, as it would result in a more pronounced positive change in real GDP compared to the 'basic' scenario. This would indicate that, to some extent, the existence of a certain degree of monopoly in specific commodity markets is an effective means of bolstering GDP expansion and income distribution.

From an examination of this initial graph, it can be recognized that an increase in the mark-up, which is indicative of a greater degree of monopoly and, consequently, a higher price for commodities, results in a corresponding weakening of the performance of real GDP in comparison to the scenario of perfect competition. The distribution of extra-profits to the institutional sectors in the form of additional capital remuneration affects the determination of primary incomes (see equation 28), disposable incomes, and thus the allocation of income between consumption and savings. The disposable income generated by this process of extra-profit distribution appears to offset the rising final prices of commodities only up to a certain mark-up level. At this level of price

increase and above, the stimulus to final demand that is originated by the distribution of extra-profit is no longer as influential as the increase in prices. The two effects in operation, the price effect and the income effect, have varied impacts on the system's reactions to ascending mark-up pricings.

Figure 4 provides an enlargement of the first and fourth quadrants of the graph in Figure 3, with the objective of facilitating a clearer and more detailed analysis of the sectoral response to the explicit price-setting behavior in each commodity market. It is possible to closely visualize the commodity markets in which the two degrees of monopoly ensure a substantial improvement in aggregate performance in terms of real GDP variation when compared to the perfect competition assumption.

Figure 4. Real GDP change under the two degrees of monopoly in each commodity market – focus on the first and the fourth quadrants (percentage change from the 'basic' scenario).



Source: elaboration on CGE model estimates.

As displayed in Figure 4, the markets that contribute to a markedly positive economic performance when they deviate from the assumption of perfect competition are Mining and quarrying (indicated by n. 4), Security and investigation activities, services to buildings and landscape activities, office administrative, office support and other business support activities (denoted as n. 53), Land transport and transport via pipelines (indicated by n. 31), Legal and accounting activities, activities of head offices, management consultancy activities (labeled as n. 45), and Architectural and engineering activities, technical testing and analysis (classified by n. 46). The real GDP changes observed in these five commodity markets are positively correlated with the increasing degree of monopoly.

Table 2 shows the detail of the full set of results. In particular, the table shows the 63 commodity markets with the associated changes in real GDP under the two degree of monopoly cases distinguished into

two columns, the low degree of monopoly and the high degree of monopoly. The table allows noticing that when the mark-up applied to individual commodities is relatively low, real GDP under market imperfection is always higher than real GDP under perfect competition, except for Fishing and aquaculture and Activities of households as employers that do not record any variation in GDP in the low degree of monopoly case. These outcomes relate to the role of extra-profits in the distributive mechanism. Once extra-profits are allocated to the institutional sectors in the form of capital remuneration according to the property of capital, the disposable income of institutional sectors increases. This additional source of income stimulates consumption and, in turn, reactivates the circular flow of income. Therefore, the greater price level that follows the introduction of the mark-up is offset by the income effect in the low degree of monopoly case.

While the low degree of monopoly case demonstrates a relatively univocal sectoral response, as expressed by the favorable impact on real GDP in comparison to the perfectly competitive setup across all commodity markets, the case of the high degree of monopoly shows differentiated sectoral impacts that extend beyond the interactions of the price and the income effects. In certain markets, such as those pertaining to food, tobacco, textiles, and construction, the presence of a high degree of monopoly is associated with a discernible reduction in real GDP relative to the scenario of perfect competition. In the case of other markets, some of which have already been identified in the analysis presented in Figure 4, the introduction of a high mark-up has been observed to stimulate considerably better economic performance than in the case of perfect competition. These markets can be traced to three macro sectors: network services, transport services, and professional services.

The network service industry is typically characterized by natural monopolies, as the distribution of their services relies on a physical infrastructure that requires a substantial initial investment. This subsequently becomes a substantial fixed cost in the day-to-day management of the service, which in turn affects the overall profitability of the sector and represents an entry barrier for firms seeking to enter the market. These include energy production and distribution and telecommunications. Transport services include a range of modes, namely land, water, air transportation, and ancillary services. Professional services encompass financial services, legal and accounting activities, engineering and architectural activities.

Table 2. Impact of the market imperfection on real GDP by commodity market (percentage change compared to the 'basic' scenario).

Commodities	Low degree of monopoly	High degree of monopoly
Agriculture, hunting and related service activities	0.24 ↑	-1.28 ↓
Forestry and logging	0.02 ↑	0.02 ↑
Fishing and aquaculture	0.00 →	-0.14 ↓
Mining and quarrying	0.52 ↑	2.12 ↑
Food products, beverages and tobacco products	0.23 ↑	-5.59 ↓
Textile products, wearing apparel and leather products	0.13 ↑	-3.60 ↓
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0.08 ↑	-0.05 ↓
Paper products	0.14 ↑	-0.08 ↓
Printing and reproduction of recorded media	0.09 ↑	0.24 ↑
Coke and refined petroleum products	0.24 ↑	-1.51 ↓
Chemical products	0.35 ↑	-0.58 ↓
Basic pharmaceutical products and pharmaceutical preparations	0.33 ↑	0.53 ↑
Manufacture of rubber and plastic products	0.23 ↑	0.00 →
Manufacture of other non-metallic mineral products	0.15 ↑	0.01 →
Manufacture of basic metals	0.34 ↑	-0.04 ↓
Manufacture of fabricated metal products, except machinery and equipment	0.42 ↑	-0.14 ↓
Manufacture of computer, electronic and optical products	0.12 ↑	-0.94 ↓
Manufacture of electrical equipment	0.18 ↑	-0.47 ↓
Manufacture of machinery and equipment n.e.c.	0.38 ↑	-1.12 ↓
Manufacture of motor vehicles, trailers and semi-trailers	0.21 ↑	-1.66 ↓
Manufacture of other transport equipment	0.07 ↑	-0.38 ↓
Manufacture of furniture, other manufacturing	0.18 ↑	-1.00 ↓
Repair and installation services of machinery and equipment	0.11 ↑	0.02 ↑
Electricity, gas, steam and air conditioning supply	0.47 ↑	-0.30 ↓
Water supply, sewerage, waste management and remediation activities	0.03 ↑	0.00 →
Sewerage, waste collection, treatment and disposal activities, materials recovery, remediation activities and other waste management services	0.31 ↑	0.63 ↑
Construction	0.29 ↑	-3.79 ↓
Wholesale and retail trade services, repair of vehicles and motorcycles	0.03 ↑	-0.49 ↓
Wholesale trade, except of motor vehicles and motorcycles	0.22 ↑	0.37 ↑
Land transport and transport via pipelines	0.43 ↑	1.12 ↑
Water transport	0.01 ↑	-0.04 ↓
Air transport	0.03 ↑	-0.16 ↓
Warehousing and support activities for transportation	0.45 ↑	0.66 ↑
Postal and courier activities	0.05 ↑	0.15 ↑
Accommodation and food service activities	0.15 ↑	-2.19 ↓
Publishing activities	0.03 ↑	-0.23 ↓
Motion picture, video and television programme production, sound recording and music publishing activities, programming and broadcasting	0.07 ↑	-0.01 ↓
Telecommunications	0.12 ↑	-0.58 ↓
Computer programming, consultancy and related activities, information service activities	0.25 ↑	-0.29 ↓
Financial service activities, except insurance and pension funding	0.47 ↑	0.61 ↑
Insurance, reinsurance and pension funding, except compulsory social security	0.05 ↑	-0.66 ↓
Activities auxiliary to financial services and insurance activities	0.20 ↑	0.26 ↑
Real estate activities	0.51 ↑	-2.65 ↓
Legal and accounting activities, activities of head offices, management consultancy activities	0.57 ↑	0.82 ↑
Architectural and engineering activities, technical testing and analysis	0.29 ↑	0.66 ↑
Scientific research and development	0.11 ↑	-0.25 ↓
Advertising and market research	0.15 ↑	0.25 ↑
Other professional, scientific and technical activities, veterinary activities	0.15 ↑	0.29 ↑
Rental and leasing activities	0.22 ↑	0.37 ↑
Employment activities	0.07 ↑	0.16 ↑
Travel agency, tour operator reservation service and related activities	0.03 ↑	-0.17 ↓
Security and investigation activities, services to buildings and landscape activities, office administrative, office support and other business support activities	0.47 ↑	1.23 ↑
Social work activities	0.20 ↑	0.64 ↑
Creative, arts and entertainment activities, libraries, archives, museums and other cultural activities, gambling and betting activities	0.05 ↑	-1.13 ↓
Arts, entertainment and recreation	0.08 ↑	0.07 ↑
Activities of membership organisations	0.02 ↑	0.00 →
Repair of computers and personal and household goods	0.02 ↑	0.02 ↑
Other personal service activities	0.03 ↑	-0.62 ↓
Activities of households as employers, undifferentiated goods- and services-producing activities of households for own use	0.00 →	-0.43 ↓

Source: elaboration on CGE model estimates.

Since the beginning of the 2000s, Italy has taken a series of measures aimed at deregulating the aforementioned sectors. The institutional path to deregulation has been undertaken with the objective of fostering competition and, therefore, innovation, while simultaneously reducing prices and broadening the range of services and products available to consumers (International Monetary Fund, 2012; Ciapanna et al., 2020). The Italian NRRP has more recently set forth the objective of accelerating and pervasively deploying telecommunications networks in areas that currently lack coverage.¹⁸ The administrative burdens associated with the installation of these networks will be reduced, and the demand for ultra-wideband connections will be stimulated. Furthermore, the Plan has established regulations pertaining to the expeditious implementation of development plans for the distribution of electricity. The evolving institutional framework in the Electricity, gas, steam and air conditioning supply is reflected in the contraction of real GDP in the case of high degree of monopoly relative to the perfect competition scenario (-0.3%).

The Italian NRRP also aims to stimulate competition in transport services, which are typically configured as natural monopolies, especially with regard to expenditure on transport equipment and storage facilities. Indeed, Table 2 demonstrates that land transport and related services enhance macroeconomic performance when associated with a high degree of monopoly (these are Land transport and transport via pipelines, and Warehousing and support activities for transportation). In this respect, the NRRP requires local administrations to justify the in-house management of the transportation provision.

Another service that the NRRP oversees is waste management. Table 2 illustrates that the market for Sewerage, waste collection, treatment and disposal activities, materials recovery, remediation and other waste management activities exhibits a further improvement in its positive impact on real GDP as it transitions from a low to a high degree of monopoly, from a variation of +0.31% to +0.63%. This phenomenon is predominantly attributable to the cost of waste disposal facilities, which represents a significant entry barrier. Consequently, the national plan is focused on addressing the capacity gaps in this infrastructure.

As evidenced in Table 2, the expansion of real GDP is also identifiable in the context of a substantial monopoly with respect to the perfect competition assumption within the domain of administrative and professional services. As indicated by the OECD Product Market Regulation (PMR) indicators for 2023-2024, the entry barriers in professional and administrative services remain significant in Italy.¹⁹ The degree of regulation is rated on a scale from 1 to 43, with a rating of 40 indicating a high level of regulation. Among the professional services, architects, accountants, real estate agents, and civil engineers are subject to stringent regulation, while notaries and lawyers are less heavily regulated. From this perspective, the Italian NRRP has discerned the necessity to diminish the obstacles to entry and to create new avenues for the professional activities of the future, which are increasingly shaped by digital technologies. In order to achieve this objective, the NRRP has designated the Mission entitled Education and Research, with the goal of reforming the training period during the university path and facilitating access to professional activities.

¹⁸ <https://www.governo.it/sites/governo.it/files/PNRR.pdf>

¹⁹ <https://www.oecd.org/en/topics/product-market-regulation.html>

3.6 Sensitivity analysis

A sensitivity analysis is conducted on the results obtained from the static SAM-based CGE model for Italy under the ‘basic’ scenario to verify their stability with respect to the exogenous parameters. It is crucial to ascertain that the results of the constructed model are not susceptible to significant alteration by changes in the exogenous elasticities of substitution.

The sensitivity analysis is thus employed as an assessment method for evaluating the consistency of the model. Once the model has been constructed and the results for policy scenarios have been presented, the objective is to verify that the response of the system is not anomalous when the value of the exogenous parameters is increased or decreased by $\pm 10\%$ and $\pm 20\%$. In other words, the results are consistent with the macroeconomic theory in terms of both the magnitude and direction of the impacts.

In the event that the impact of a given policy is found to be significantly diminished or amplified, it may be necessary to establish a threshold for consistency. Similarly, in the event that the impacts of a specific policy exhibit a reversal of signs, the economic implications may become unreliable. This approach allows us to confirm the robustness of the impacts of the selected policies on the macroeconomic aggregates. The elasticity of substitution between the low/medium-skilled labor aggregate and the high-skilled labor and capital aggregate, indicated as σ_v , is identified as the crucial exogenous parameter in the production function. In the benchmark, the value of the elasticity of substitution σ_v is 0.67.

The results of the sensitivity analysis are presented in Table 3. It can be observed that the outcomes of the standard shock, which comprises an increase in household consumption by 1% of GDP relative to the benchmark, exhibit only minimal sensitivity to variations in the elasticity of substitution σ_v .

Table 3. Impact of the change in the elasticity of substitution σ_v on real macroeconomic aggregates (percentage change from the benchmark).

<i>Aggregate</i>	<i>-20%</i>	<i>-10%</i>	<i>Benchmark</i>	<i>+10%</i>	<i>+20%</i>
Real GDP	1.7218	1.7219	1.7218	1.7216	1.7212
Households and NPISHs consumption	3.2032	3.2027	3.2020	3.2009	3.1997
Investment	2.2123	2.2156	2.2194	2.2236	2.2282
Exports	-1.0578	-1.0590	-1.0606	-1.0628	-1.0654
Imports	1.3519	1.3516	1.3509	1.3500	1.3489

Source: CGE model estimates.

3.7 Conclusions

Since the 1980s, modelers and analysts have proposed a more realistic approach to price formation within CGE models. This involves introducing a fixed mark-up to describe the formation of prices in a monopoly situation and increasing returns to scale due to the presence of fixed costs. This experiment is based on the observation that a significant number of markets in the economy do not operate under conditions of perfect competition.

The inclusion of monopoly power in CGE models gives rise to a number of issues, primarily concerning the reconciliation of microeconomic and macroeconomic theories and foundations. In particular, there is a need to reconcile the partial equilibrium and general equilibrium frameworks. These issues arising

from this reconciliation effort pertain specifically to the transition from a single-commodity to a multi-commodity CGE model; price formation and the estimation of price elasticity of demand; and the redistribution of income among institutional sectors in the form of extra-profits generated by monopoly power.

The results presented represent an initial effort to ascertain whether an increase in the degree of monopoly in specific markets can result in a notable alteration in the capacity of a CGE model to serve as an instrument for policy impact analysis. The simulation exercises demonstrate that there is a notable sectoral differentiation that is not univocal when considering a high degree of monopoly with respect to the assumption of perfect competition. This pronounced sectoral differentiation is influenced by a multitude of factors. These include the institutional framework in place, the extent to which previous international and national regulations have been integrated into the market under consideration, and the fact that each sector is defined by distinct technologies and market characteristics.

The distribution of profits to institutional sectors as supplementary capital remuneration exerts an influence on the determination of disposable income, which in turn affects the use of income. This distribution of profits appears to mitigate the impact of rising final prices of goods to a certain extent, up to a point where the boost to final demand becomes less significant in comparison to the rising prices. The interplay between the price effect and the income effect results in different responses from the system to the increasing mark-up pricing.

In addition to the interplay of price and income effects, the results demonstrate that the evolving competition-oriented regulation has exerted its effects in specific markets, particularly those typically configured as natural monopolies, such as electricity, gas, and steam supply. Conversely, in some other natural monopolies, such as professional and administrative services, the legislation has not yet had its intended effect. The National Recovery and Resilience Plan has recently initiated efforts to deregulate or, at the very least, stimulate competition.

Further theoretical and empirical research is required to gain a deeper understanding of the characteristics of each market in order to refine the analysis and integrate microeconomic and macroeconomic perspectives on this topic. For example, the price elasticity of demand is perceived by each firm in the market. The endogenous determination of changes in price elasticity of demand can be used to derive changes in mark-up and to examine the feedback effects of economic policies on mark-up, income distribution, redistribution, and use.

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Appendix A

A.1. The classification of commodities in the SAM for Italy.

<i>Code</i>	<i>Definition</i>	<i>Code</i>	<i>Definition</i>
g1	Products of agriculture, hunting and related services	g34	Warehousing and support services for transportation
g2	Products of forestry, logging and related services	g35	Postal and courier services
g3	Fish and other fishing products; aquaculture products; support services to fishing	g36	Accommodation and food services
g4	Mining and quarrying	g37	Publishing services
g5	Food products, beverages and tobacco products	g38	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services
g6	Textiles, wearing apparel and leather products	g39	Telecommunications services
g7	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	g40	Computer programming, consultancy and related services; information services
g8	Paper and paper products	g41	Financial services, except insurance and pension funding
g9	Printing and recording services	g42	Insurance, reinsurance and pension funding services, except compulsory social security
g10	Coke and refined petroleum products	g43	Services auxiliary to financial services and insurance services
g11	Chemicals and chemical products	g44	Real estate services including imputed rents of owner-occupied dwellings
g12	Basic pharmaceutical products and pharmaceutical preparations	g45	Legal and accounting services; services of head offices; management consulting services
g13	Rubber and plastics products	g46	Architectural and engineering services; technical testing and analysis services
g14	Other non-metallic mineral products	g47	Scientific research and development services
g15	Basic metals	g48	Advertising and market research services
g16	Fabricated metal products, except machinery and equipment	g49	Other professional, scientific and technical services; veterinary services
g17	Computer, electronic and optical products	g50	Rental and leasing services
g18	Electrical equipment	g51	Employment services
g19	Machinery and equipment n.e.c.	g52	Travel agency, tour operator and other reservation services and related services
g20	Motor vehicles, trailers and semi-trailers	g53	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services
g21	Other transport equipment	g54	Public administration and defence services; compulsory social security services
g22	Furniture; other manufactured goods	g55	Education services
g23	Repair and installation services of machinery and equipment	g56	Human health services
g24	Electricity, gas, steam and air-conditioning	g57	Social work services
g25	Natural water; water treatment and supply services	g58	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services
g26	Sewerage; waste collection, treatment and disposal industries; materials recovery; remediation industries and other waste management services	g59	Sporting services and amusement and recreation services
g27	Constructions and construction works	g60	Services furnished by membership organisations
g28	Wholesale and retail trade and repair services of motor vehicles and motorcycles	g61	Repair services of computers and personal and household goods
g29	Wholesale trade services, except of motor vehicles and motorcycles	g62	Other personal services
g30	Retail trade services, except of motor vehicles and motorcycles	g63	Services of households as employers; undifferentiated goods and services produced by households for own use
g31	Land transport services and transport services via pipelines		
g32	Water transport services		
g33	Air transport services		

A.2. The classification of activities in the SAM for Italy.

<i>Code</i>	<i>Definition</i>	<i>Code</i>	<i>Definition</i>
a1	Crop and animal production, hunting and related service industries	a34	Warehousing and support industries for transportation
a2	Forestry and logging	a35	Postal and courier industries
a3	Fishing and aquaculture	a36	Accommodation and food service industries
a4	Mining and quarrying	a37	Publishing industries
a5	Manufacture of food products; beverages and tobacco products	a38	Motion picture, video, television programme production; programming and broadcasting industries
a6	Manufacture of textiles, wearing apparel, leather and related products	a39	Telecommunications
a7	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	a40	Computer programming, consultancy, and information service industries
a8	Manufacture of paper and paper products	a41	Financial service industries, except insurance and pension funding
a9	Printing and reproduction of recorded media	a42	Insurance, reinsurance and pension funding, except compulsory social security
a10	Manufacture of coke and refined petroleum products	a43	Industries auxiliary to financial services and insurance industries
a11	Manufacture of chemicals and chemical products	a44	Real estate industries including imputed rents of owner-occupied dwellings
a12	Manufacture of basic pharmaceutical products and pharmaceutical preparations	a45	Legal and accounting industries; industries of head offices; management consultancy industries
a13	Manufacture of rubber and plastic products	a46	Architectural and engineering industries; technical testing and analysis
a14	Manufacture of other non-metallic mineral products	a47	Scientific research and development
a15	Manufacture of basic metals	a48	Advertising and market research
a16	Manufacture of fabricated metal products, except machinery and equipment	a49	Other professional, scientific and technical industries; veterinary industries
a17	Manufacture of computer, electronic and optical products	a50	Rental and leasing industries
a18	Manufacture of electrical equipment	a51	Employment industries
a19	Manufacture of machinery and equipment n.e.c.	a52	Travel agency, tour operator reservation service and related industries
a20	Manufacture of motor vehicles, trailers and semi-trailers	a53	Security and investigation, service and landscape, office administrative and support industries
a21	Manufacture of other transport equipment	a54	Public administration and defence; compulsory social security
a22	Manufacture of furniture; other manufacturing	a55	Education
a23	Repair and installation of machinery and equipment	a56	Human health industries
a24	Electricity, gas, steam and air conditioning supply	a57	Residential care industries and social work industries without accommodation
a25	Water collection, treatment and supply	a58	Creative, arts and entertainment industries; libraries, archives, museums and other cultural industries; gambling and betting industries
a26	Sewerage, waste management, remediation industries	a59	Sports industries and amusement and recreation industries
a27	Construction	a60	Industries of membership organisations
a28	Wholesale and retail trade and repair of motor vehicles and motorcycles	a61	Repair of computers and personal and household goods
a29	Wholesale trade, except of motor vehicles and motorcycles	a62	Other personal service industries
a30	Retail trade, except of motor vehicles and motorcycles	a63	Industries of households as employers; undifferentiated goods- and services-producing industries of households for own use
a31	Land transport and transport via pipelines		
a32	Water transport		
a33	Air transport		

Appendix B

Sets

i	Commodities
j	Activities
g	Gender
p	Skill level
is	Institutional sectors
$priv$	Private institutional sectors
hh	Households and NPISHs
$corp$	Financial and nonfinancial corporations
pub	Government
row	Rest of the World

Parameters

d_i^Q	Share of domestic commodities in total production
δ_i^Q	Share of domestic commodities in total production in the cost function
ρ_Q	Exponent of the CES production function linked to σ_Q
σ_Q	Elasticity of substitution between domestic and imported commodities
pmw_i	Price of imported commodities
$infw$	Foreign inflation rate
exr	Nominal exchange rate
d_j^D	Share of intermediate inputs in domestic output by activity
δ_j^D	Share of intermediate inputs in domestic output by activity in the cost function
ρ_D	Exponent of the CES production function linked to σ_D
σ_D	Elasticity of substitution between intermediate inputs and value added
$d_{i,j}^{BI}$	Share of intermediate inputs in total demand for intermediate inputs by activity
$\delta_{i,j}^{BI}$	Share of intermediate inputs in total demand for intermediate inputs by activity in the cost function
σ_{BI}	Elasticity of substitution between intermediate inputs
δ_j^v	Share of the low/medium-skilled labor aggregate in total value added in the cost function
σ_v	Elasticity of substitution between the low/medium-skilled labor aggregate and the high-skilled labor and capital aggregate
δ_j^{LMS}	Share of the low-skilled labor aggregate in total low/medium-skilled labor aggregate in the cost function
σ_{LMS}	Elasticity of substitution between the low-skilled labor aggregate and the medium-skilled labor aggregate
δ_j^{HSK}	Share of the high-skilled labor aggregate in total high-skilled labor and capital aggregate in the cost function
σ_{HSK}	Elasticity of substitution between the high-skilled labor aggregate and capital
δ_j^{LS}	Share of female labor in total low-skilled labor in the cost function
σ_{LS}	Elasticity of substitution between female and male labor in the low-skilled labor aggregate
δ_j^{MS}	Share of female labor in total medium-skilled labor in the cost function
σ_{MS}	Elasticity of substitution between female and male labor in the medium-skilled labor aggregate
δ_j^{HS}	Share of female labor in total high-skilled labor in the cost function
σ_{HS}	Elasticity of substitution between female and male labor in the high-skilled labor aggregate
b_{FLS}	Low-skilled female unemployment benefit
b_{MLS}	Low-skilled male unemployment benefit
b_{FMS}	Medium-skilled female unemployment benefit

b_{MMS}	Medium-skilled male unemployment benefit
b_{FHS}	High-skilled female unemployment benefit
b_{MHS}	High-skilled male unemployment benefit
η_{FLS}	Average wage elasticity of the demand for low-skilled female labor
η_{MLS}	Average wage elasticity of the demand for low-skilled male labor
η_{FMS}	Average wage elasticity of the demand for medium-skilled female labor
η_{MMS}	Average wage elasticity of the demand for medium-skilled male labor
η_{FHS}	Average wage elasticity of the demand for high-skilled female labor
η_{MHS}	Average wage elasticity of the demand for high-skilled male labor
π_i	Extra-profit by commodity
π_i^{is}	Extra-profit by commodity and by institutional sector
$tr_{is_out}^{is}$	Implicit rates of transfers paid to other institutional sectors
$tr_{is_in}^{is}$	Implicit rates of transfers received from other institutional sector
$ty_{t_inc}^{is}$	Implicit tax rate on income paid by institutional sector
tq_{i,t_out}	Implicit tax rates on commodities
tq_{j,t_act}	Implicit tax rates on activities
$\gamma_{t_out}^{pub}$	Share of net taxes on commodities collected by the public administration
$\gamma_{t_act}^{pub}$	Share of taxes less subsidies on activities collected by the public administration
$\gamma_{t_out}^{row}$	Share of net taxes on commodities collected by the Rest of the World
$\gamma_{t_act}^{row}$	Share of taxes less subsidies on activities collected by the Rest of the World
Tr_{pub}^{is}	Transfers paid by the public administration to the other institutional sectors
Tr_{row}^{is}	Transfers paid by the Rest of the World to the other institutional sectors
χ_{is}^U	Share of consumption in disposable income by institutional sector
σ_U	Elasticity of substitution between consumption and savings
$\delta_{is,i}^C$	Share of consumption of the i^{th} commodity in the consumption bundle by institutional sector
σ_C	Elasticity of substitution between commodities in the consumption bundle
δ_i^I	Share of the demand for investment by commodity in total gross investment
σ_I	Elasticity of substitution between commodities in the investment bundle
δ_i^E	Share of the demand for export by commodity in total exports
σ_E	Elasticity of substitution between commodities in the Rest of the World export bundle

Variables

Q_i	Total output by commodity
P_i	Price of commodities
$Q_{dom,i}$	Quantity of domestic commodities
M_i	Quantity of imports
$P_{dom,i}$	Price of domestic commodities
Pm_i	Price of imports
Q_j	Domestic output by activity
$P_{dom,j}$	Price of domestic output by activity
Pbj_j	Price of intermediate commodity by activity
$bi_{i,j}$	Demand for each intermediate input by activity
BI_j	Demand for intermediate inputs by activity
VA_j	Demand for value added by activity
Pva_j	Price of value added by activity
$PLMS_j$	Price of the low/medium-skilled labor aggregate by activity

$PHSK_j$	Price of the high-skilled labor and capital aggregate by activity
PLS_j	Price of the low-skilled labor aggregate by activity
PMS_j	Price of the medium-skilled labor aggregate by activity
PHS_j	Price of the high-skilled labor aggregate by activity
PK	Price of capital
$PFLS$	Price of female labor in the low-skilled labor aggregate
$PMLS$	Price of male labor in the low-skilled labor aggregate
$PFMS$	Price of female labor in the medium-skilled labor aggregate
$PMMS$	Price of male labor in the medium-skilled labor aggregate
$PFHS$	Price of female labor in the high-skilled labor aggregate
$PMHS$	Price of male labor in the high-skilled labor aggregate
u_{FLS}	Low-skilled female unemployment rate
u_{MLS}	Low-skilled male unemployment rate
u_{FMS}	Medium-skilled female unemployment rate
u_{MMS}	Medium-skilled male unemployment rate
u_{FHS}	High-skilled female unemployment rate
u_{MHS}	High-skilled male unemployment rate
L_j	Labor demand by activity
$L_{j,g,p}$	Labor demand by activity, by gender, and by skill
K_j	Capital demand by activity
t_{out}_i	Net taxes on commodities
t_{act}_j	Taxes less subsidies on activities
Y^{is}	Primary income by institutional sector
L^{is}	Labor endowment by institutional sector
$L_{g,p}^{is}$	Labor endowment by institutional sector, by gender, and by skill
K^{is}	Capital endowment by institutional sector
Yd^{is}	Disposable income by institutional sector
U^{is}	Utility by institutional sector
C^{is}	Consumption by institutional sector
S^{is}	Saving by institutional sector
Pu_{is}	Price index of utility by institutional sector
Pc_{is}	Price index of consumption by institutional sector
C_i^{is}	Quantity consumed by commodity and by institutional sector
PI	Price index of investment
I_i	Demand for investment by commodity
E_i	Export demand by commodity

Equations

Production block

$$Q_i = \left[d_i^Q Q_{dom,i}^{\rho_Q} + (1 - d_i^Q) M_i^{\rho_Q} \right]^{\frac{1}{\rho_Q}}$$

$$(1 - tq_{i,t_{out}}) P_i = \left[\delta_i^Q P_{dom,i}^{(1-\sigma_Q)} + (1 - \delta_i^{dom}) P m_i^{(1-\sigma_Q)} \right]^{\frac{1}{1-\sigma_Q}}$$

$$Q_{dom,i} = (d_i^Q)^{\sigma_Q} Q_i \left(\frac{P_i}{P_{dom,i}} \right)^{\sigma_Q}$$

$$M_i = (1 - d_i^Q)^{\sigma_Q} Q_i \left(\frac{P_i}{Pm_i} \right)^{\sigma_Q}$$

$$Pm_i = \frac{pmw_i(1 + infw)}{exr}$$

$$Q_j = \left[d_j^D BI_j^{\rho_D} + (1 - d_j^D) VA_j^{\rho_D} \right]^{\frac{1}{\rho_D}}$$

$$(1 - tq_{j,t,act}) P_{dom,j} = \left[\delta_j^D Pbi_j^{(1-\sigma_D)} + (1 - \delta_j^D) Pva_j^{(1-\sigma_D)} \right]^{\frac{1}{1-\sigma_D}}$$

$$BI_j = (d_j^D)^{\sigma_D} Q_j \left(\frac{P_{dom,j}}{Pbi_j} \right)^{\sigma_D}$$

$$Pbi_j = \sum_i \left(\delta_{i,j}^{BI} P_i^{(1-\sigma_{BI})} \right)^{\frac{1}{1-\sigma_{BI}}}$$

$$bi_{i,j} = (d_{i,j}^{BI})^{\sigma_{BI}} Q_j \left(\frac{Pbi_j}{P_i} \right)^{\sigma_{BI}}$$

$$VA_j = (1 - d_j^D)^{\sigma_D} Q_j \left(\frac{P_{dom,j}}{Pva_j} \right)^{\sigma_D}$$

$$Pva_j = \left[\delta_j^v \cdot PLMS_j^{(1-\sigma_v)} + (1 - \delta_j^v) \cdot PHSK_j^{(1-\sigma_v)} \right]^{\frac{1}{1-\sigma_v}}$$

$$PLMS_j = \left[\delta_j^{LMS} \cdot PLS_j^{(1-\sigma_{LMS})} + (1 - \delta_j^{LMS}) \cdot PMS_j^{(1-\sigma_{LMS})} \right]^{\frac{1}{1-\sigma_{LMS}}}$$

$$PHSK_j = \left[\delta_j^{HSK} \cdot PHS_j^{(1-\sigma_{HSK})} + (1 - \delta_j^{HSK}) \cdot PK^{(1-\sigma_{HSK})} \right]^{\frac{1}{1-\sigma_{HSK}}}$$

$$PLS_j = \left[\delta_j^{LS} \cdot PFLS^{(1-\sigma_{LS})} + (1 - \delta_j^{LS}) \cdot PMLS^{(1-\sigma_{LS})} \right]^{\frac{1}{1-\sigma_{LS}}}$$

$$PMS_j = \left[\delta_j^{MS} \cdot PFMS^{(1-\sigma_{MS})} + (1 - \delta_j^{MS}) \cdot PMMS^{(1-\sigma_{MS})} \right]^{\frac{1}{1-\sigma_{MS}}}$$

$$PHS_j = \left[\delta_j^{HS} \cdot PFHS^{(1-\sigma_{HS})} + (1 - \delta_j^{HS}) \cdot PMHS^{(1-\sigma_{HS})} \right]^{\frac{1}{1-\sigma_{HS}}}$$

$$PFLS = \frac{u_{FLS} \cdot b_{FLS} \cdot \eta_{FLS}}{1 - \eta_{FLS} \cdot u_{FLS}}$$

$$PMLS = \frac{u_{MLS} \cdot b_{MLS} \cdot \eta_{MLS}}{1 - \eta_{MLS} \cdot u_{MLS}}$$

$$PFMS = \frac{u_{FMS} \cdot b_{FMS} \cdot \eta_{FMS}}{1 - \eta_{FMS} \cdot u_{FMS}}$$

$$PMMS = \frac{u_{MMS} \cdot b_{MMS} \cdot \eta_{MMS}}{1 - \eta_{MMS} \cdot u_{MMS}}$$

$$PFHS = \frac{u_{FHS} \cdot b_{FHS} \cdot \eta_{FHS}}{1 - \eta_{FHS} \cdot u_{FHS}}$$

$$PMHS = \frac{u_{MHS} \cdot b_{MHS} \cdot \eta_{MHS}}{1 - \eta_{MHS} \cdot u_{MHS}}$$

Primary incomes and disposable incomes

$$Y^{is} = \sum_g \sum_p L_{g,p}^{is} + K^{is}$$

$$Y^{is} = \sum_g \sum_p L_{g,p}^{is} + K^{is} + \sum_i \pi_i^{is}$$

$$Yd^{hh} = Y^{hh} + \sum_{is_in} Y^{is} tr_{is_in}^{hh} + Tr_{pub}^{hh} + Tr_{row}^{hh} - \sum_{t_inc} Y^{hh} ty_{t_inc}^{hh} - \sum_{is_out} Y^{hh} tr_{is_out}^{hh}$$

$$Yd^{corp} = Y^{corp} + \sum_{is_in} Y^{is} tr_{is_in}^{corp} + Tr_{pub}^{corp} + Tr_{row}^{corp} - \sum_{t_inc} Y^{corp} ty_{t_inc}^{corp} - \sum_{is_out} Y^{corp} tr_{is_out}^{corp}$$

$$Yd^{pub} = Y^{pub} + \gamma_{t_out}^{pub} \sum_i tq_{i,t_out} P_i Q_i + \gamma_{t_act}^{pub} \sum_j tq_{j,t_act} P_j Q_j + \sum_{t_inc} Y^{priv} ty_{t_inc}^{priv} + \sum_{is_in} Y^{priv} tr_{is_in}^{priv} + Tr_{row}^{pub} - Tr_{pub}^{row}$$

$$Yd^{row} = Y^{row} + \sum_i Pm_i M_i + \gamma_{t_out}^{row} \sum_i tq_{i,t_out} P_i Q_i + \gamma_{t_act}^{row} \sum_j tq_{j,t_act} P_j Q_j + \sum_{is_in} Y^{priv} tr_{is_in}^{priv} + Tr_{pub}^{row} - \sum_{t_inc} Y^{row} ty_{t_inc}^{row} - Tr_{row}^{is}$$

Consumption block

$$U^{is} = \left(C^{is} \frac{\sigma_U - 1}{\sigma_U} + S^{is} \frac{\sigma_U - 1}{\sigma_U} \right)^{\frac{\sigma_U}{\sigma_U - 1}}$$

$$Pu_{is} = \left[\chi_{is}^U P C_{is}^{(1-\sigma_U)} + (1 - \chi_{is}^U) P I^{(1-\sigma_U)} \right]^{\frac{1}{1-\sigma_U}}$$

$$C^{is} = \chi_{is}^U U^{is} \left(\frac{P u_{is}}{P c_{is}} \right)^{\sigma_U}$$

$$S^{is} = (1 - \chi_{is}^U) U^{is} \left(\frac{P u_{is}}{P I} \right)^{\sigma_U}$$

$$P c_{is} = \left(\sum_i \delta_{is,i}^C P_i^{1-\sigma_C} \right)^{\frac{1}{1-\sigma_C}}$$

$$C_i^{is} = \delta_{is,i}^C U^{is} \left(\frac{P c_{is}}{P_i} \right)^{\sigma_C}$$

$$P I = \left(\sum_i \delta_i^I P_i^{1-\sigma_I} \right)^{\frac{1}{1-\sigma_I}}$$

$$I_i = \delta_i^I I \left(\frac{P I}{P_i} \right)^{\sigma_I}$$

$$E_i = \delta_i^E Y d^{row} \left(\frac{p m w_i \cdot (1 + inflw)}{P_i} \right)^{\sigma_E}$$

Market clearing conditions

$$\sum_{is} (1 - u_{g,p}) L_{g,p}^{is} = \sum_j L_{j,g,p}$$

$$\sum_{is} K^{is} = \sum_j K_j$$

$$P_i Q_i = P_i \left(\sum_j b_{i,j} + C_i^{hh} + G_i^{pub} + I_i + E_i \right)$$

$$\sum_{is} S^{is} = \sum_i I_i$$