# Scenarios of technological progress in Italy: what can we expect?

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**ABSTRACT**
The simple but deep sense of technological progress (TP) lies in the possibility of improving human life. The immediate question thereafter is clearly about the distribution of the gains from TP. With the diffusion of automation and artificial intelligence, fears about the implications of TP on employment and wages have gained renewed importance. While scholars are divided on the effects of this new wave of TP, they agree that every economy will be affected differently, and hence, it will require tailored policy measures. In this paper, we frame how TP could affect the Italian economy, as it is now. We simulate four different scenarios through a dynamic computable general equilibrium model with three types of labour and six types of households. We calibrate the model on the social accounting matrix, and we find that TP returns higher growth patterns albeit with disruptive effects on labour.

**KEYWORDS**
Automation and robotisation; skills and employment; labour demand; Dynamic CGE model; social accounting matrix

**JEL**
C68; D58; E16; E24; J24

## 1. Introduction

Humanity has always been aware that machines can eventually replace human work. Sometimes, this has been taken as an Eldorado, some others as a simple figuration, as in the case of Aristoteles. Quite often, this has been taken as a serious concern. The replacement of human work through machines can be identified as automation (e.g. Autor 2015; Acemoglu and Restrepo 2020). Automation is appealing as far as it can save human work that can be then reallocated to other tasks with obvious benefits. Yet, automation can also turn into a threat for work. Automation is serendipitous, and it is often unexpected and unforeseeable in terms of implications. In the initial phases of a new automation wave, there are always fears that it can bring to job displacements. Once adjustments have occurred, the conclusion is often that the initial concerns were mostly unwarranted (OECD, 2019). John Maynard Keynes, after having coined the term 'technological unemployment' (Keynes 1931), recognised that the labour income share had remained constant throughout the whole nineteenth century despite the great

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technological advancement of that period (Keynes 1939).[1] Almost one century later, many authors, as for example, Nedelkoska and Quintini (2018) observe that ‘despite the massive sectoral transformations within a single century, OECD countries have been adding, not losing jobs in net terms’.

The current wave of ‘intelligent automation’ (Dosi and Mohnen 2019) has started fearing economists, observers and politicians especially in the aftermath of the 2008 Great Depression (e.g. Jung et al. 2017). Whereas jobless growth was already a feature of some (e.g. US) economies during the 1990s and the early 2000s, the joblessness of the post-crisis recovery fuelled the *déjà-vu* that this wave of automation might be really ‘different this time’ (e.g. Akst 2013; Servoz 2019). Because of its reliance on ‘developments in artificial intelligence, adaptive automated learning and robotics’ (Koster and Brunori 2021: 1397), the current wave of automation has induced several scholars (e.g. Korinek and Stiglitz 2017; Autor and Salomons 2017) to believe in an unprecedented substitution of labour with capital rather than in the complementarity between the two. For this reason, economists and economic policy advisors (e.g. Usanov and Chivot 2013; Peralta-Alva and Roitman 2018; Servoz 2019) have been warning about the need of prompt policy answers to counteract the risks of a structural abundancy of any type of labour (from low to high-skilled through medium-skilled) with exploding income disparities and social inequalities.

In view of the heterogeneity among countries in regard to their ‘potential [. . .] to implement automation processes’ (Koster and Brunori 2021: 1398), policy measures have to take in due consideration ‘country-specific circumstances and preferences’ (Peralta-Alva and Roitman 2018: 2). Hence, there is need of appropriate modelling tools, capable of depicting the economy as it is now and as it might evolve following to the expected wave of automation. Prompting a model-based framework to guide policy action is then a priority, and this paper seeks to provide such a country-tailored framework for Italy. We disentangle the consequences of automation by using MODEL, which is a disaggregated dynamic Computable General Equilibrium (CGE) model based on a Social Accounting Matrix (SAM). For its own nature, MODEL allows depicting the specific features of each production process with regard to the adopted technology and the primary factors’ use, and it portrays the income allocation, distribution and use by Institutional Sector (Severini et al. 2019). Since automation is likely to affect labour in medium-skilled occupations first (Autor and Dorn 2013; Goos, Manning, and Salomons 2014) because routine cognitive and routine manual tasks are the ones which are more liable to be fully automated (Autor, Levy, and Murnane 2003), we disaggregate the ‘compensation of employees’ into three types of labour (low-skill, medium-skill and high-skill). With this differentiation, we can account for the uneven effects of automation throughout the labour market. To have a flavour of the consequences of automation on income distribution, the SAM also accounts for six types of households, which resemble the six income brackets in the Italian personal income tax (PIT) system.

We model automation as worker-replacing technological change (Korinek and Stiglitz 2017: 4) in order to differentiate it from traditional “capital deepening or factor-augmenting technologies” (Acemoglu and Restrepo 2020: 2190). Hence, we couple an

[1]Keynes (1939) did not prevent Bennion (1943) to revamp his wording later, however.

increase in the capital productivity[2] with an increase in the substitution elasticity between capital and labour in the production function. The factor-biased technological change serves to mimic the necessary advancement in the quality of physical capital, which permits the replacement of labour. Since time and intensity of the diffusion of the new automation technologies over the next decades are still uncertain (e.g. Dosi and Virgillito 2019; OECD, 2019), we adopt a scenario approach. We frame two main scenarios in order to build two boundaries, within which the economy might plausibly evolve in the coming years. In the first scenario (which we call *optimistic*), capital is assumed to become a substitute for low-skilled and medium-skilled labour, whereas in the second scenario (which we call *pessimistic*), capital turns out into an efficient substitute also for high-skilled labour.

Besides studying the optimistic and the pessimistic scenario, we investigate two further scenarios, which we respectively call *conservative* and *intermediate*. In the conservative scenario, we assume no automation but just a traditional form of factor-biased technological change (i.e. the same as the one assumed in the other two scenarios), in the sense that we assume that capital is a complement of all types of labour. This allows us quantifying the effects of the more traditional form of labour-augmenting TP. By contrast, in the intermediate scenario, capital is a substitute for low-skilled and medium-skilled labour (as in the optimistic scenario) at the beginning, and then it gradually turns into a substitute for high-skilled labour (as in the pessimistic scenario). The scope of the intermediate scenario is to complete the optimistic scenario, which does not account for any substitutability between capital and high-skilled labour, and to mitigate the pessimistic scenario, which assumes that capital is replacing high-skilled labour since the very beginning.

The empirical literature on the effects of automation on labour is quite extensive, but only few studies adopt an ex-ante perspective in order to frame how automation might affect labour in the coming years. Most of the papers provide econometric estimates of how automation in its various forms (e.g. ICT digitalisation, artificial intelligence, adaptive automated learning, robotics, etc.) has already affected labour in the past.[3] However, the pace of automation diffusion has been accelerating so strongly that estimates referring to the 1990s or the early 2000s are hardly informative for the future ten or fifteen years. Moreover, the ex-ante studies mostly provide 'little systematic evidence on the equilibrium impact of automation technologies' (Acemoglu and Restrepo 2020: 2189). We are only aware of three papers (Jung et al. 2017; Peralta-Alva and Roitman 2018; Costantini and Sforna 2020) which use the CGE approach, which allows taking 'into account how other sectors and occupations will respond to [the] changes' (Acemoglu and Restrepo 2020) from an ex-ante perspective. Apart from the paper by Peralta-Alva and Roitman (2018) that uses a DSGE to 'simulate the impact of technological change on labour' in the US economy and Jung et al. (2017) who focus on South Korea, the paper by Costantini and Sforna (2020) is the only one that provides an analysis for EU, without distinguishing however among single countries. To the best of our knowledge, the study contained in this paper is the first ex-ante equilibrium analysis,

[2]Indeed, what makes automation attractive is its cost-saving feature.

[3]Jestl (2022), for example, provides a brief but interesting overview of these papers, which he groups according to the aggregation level (sectoral, firm, regional) adopted in the analysis.

which quantifies the effects of automation on the labour market and on the economy for Italy. For its contribution, it complements the paper by Paba et al. (2020) who study the effects of robots, ICT and globalisation on the Italian local labour markets for the period 1991–2011.

In view of the urgency 'for policymakers to take the risk of high technological unemployment [. . .] quite seriously' (Usanov and Chivot 2013: 11), the analysis contained in this paper aims to provide the necessary framework for the design of any initiative in terms of policy intervention. The paper is organised as follows. Section 2 describes the disaggregated dynamic CGE model used to develop the analysis. Section 3 discusses the simulation scenarios, while Section 4 contains the simulations' results. Section 5 provides a brief discussion of some immediate policy implications, and Section 6 concludes.

## 2. The SAM-based dynamic CGE model for Italy

The methodology used to simulate the effects of TP in Italy is represented by a SAM-based CGE model for the Italian economy, inspired to the models developed by Socci et al. (2020, 2021). This approach combines the ability of a general model to measure the impact of an exogenous shock on the main macroeconomic variables, with the high degree of detail offered by SAM in terms of activities involved in the production processes, composition of the labour factor and income flows among Institutional Sectors (Pyatt and Round 1985; Reinert and Roland-Holst 1997; Ahmed et al. 2019). For this reason, the first step in deriving the model is represented by the predisposition of the full detailed SAM database, followed by the formalisation of the main relations among agents. This phase requires the declaration of functional forms, endogenous and exogenous parameters and the main assumption underneath the market equilibria, profit conditions and macro-economic closures.

### *2.1. Description of macroeconomic database*

The construction of scenarios to assess the impact of TP in Italy in a general framework requires the construction of a database able to track the circular flow of income, from the production processes to the final demand formation, passing through the income generation, distribution and utilisation (Pyatt and Round 1985). This detailed picture of the economic system is provided by the Social Accounting Matrix (SAM), which combines the detailed and disaggregated information on production processes, value added by components and Institutional Sectors' income accounts in a well-defined time frame (Mainar-Causapé, Ferrari, and McDonald 2018). The SAM represents the valuable database to calibrate analysis models aimed at exploring the impact of policy measures or exogenous shocks on the economic system (Ciaschini and Socci 2007).

The SAM used in this paper was developed and published in a previous study (Zotti et al. 2020), in which a different approach was used to analyse the structure of the Italian system and, more importantly, what is the structure of the policies from the demand side that could better affect the labour demand by typology.[4] It is obtained combining data from the National

[4]In Zotti et al. (2020), the SAM represented the database for the Macro Multiplier methodology, as developed in Ciaschini and Socci (2007).

Accounting Matrix (NAM) relative to 2014 (ISTAT 2019a), the Input–Output table at purchaser's price (ISTAT 2019b) for the same year and the Programme for the International Assessment of Adult Competencies (PIAAC) data (OECD, 2019). It encompasses a disaggregation of the production into 63 activities and 63 commodities[5], three value-added components (labour compensation of employees including employers' contributions, gross operating surplus, mixed income) per each activity and six main Institutional Sectors (Financial and Non-Financial Corporations, Households, Non-Profit Institutional Sectors – NPISh, Public Administrations and Rest of the World) as shown in Table S1.

The objective of the research made it necessary to furtherly specify the characteristics of the labour demanded by each production process according to the typology of the occupation and the characteristics of the workers involved, as in Zotti et al. (2020). Specifically, the flows related to 'compensation of employees' is broken down according to three occupation levels and eight types of workers. The occupation levels are low-skilled, medium-skilled and high-skilled, and the workers are classified from the combination of three attributes (formal education, digital competences and gender), each one with two specifications. The educational attainment is split between low-medium-educated (no formal education to high school diploma) and high-educated (university degree).[6] Digital competences are computed on the base of the capability/incapability of using a computer with internet access at the workplace, allowing the breakdown of workers into 'PC users' (capable of using a computer) and 'no PC users' (incapable of using a computer).[7] Per each of these categories, we also consider the gender attribute. Therefore, we obtain a final breakdown of the compensation of employees into 24 components according to the workers' categories (or 'workers' groups"). This means that, compared to Table S1, the row and the column no. 3 are broken down into 3a, 3b, . . . , 3x, for a total of 24 additional rows and columns.

The value added allocated to the primary factors is subsequently distributed to the Institutional Sectors on the base of the property shares of the primary factors. In order to highlight the effects of TP on income distribution, we provide a further breakdown of households into six income classes according to the five personal income tax (PIT) brackets actually in force, plus an additional class defined by upper limit of €2,840.81 (that is the threshold to be fiscally independent). This means that, compared to Table S1, the row and the column no. 9 are broken down into 9a, 9b, . . . , 9f, for a total of 6 additional rows and columns. This disaggregation allows understanding how the primary incomes deriving from the 24 typologies of compensation of employees and gross operating surplus and mixed income are distributed to each group of households as well as to other Institutional Sectors, as shown in Table S3.

Regarding the secondary income distribution, transfers between public administration and Institutional Sectors are obtained through the elaboration of data on the current transfers from the Information System on the Public Administration operations (SIOPE) database released by the Ministry of Economy and Finance and the Bank of Italy[8] and the

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[5]See Tables A1 and A2 in appendix A for the list of commodities and activities.

[6]This disaggregation is carried out using data from the OECD *Programme for the International Assessment of Adult Competencies* (PIAAC) since it is compatible and complementary to the ISTAT data on digital competences.

[7]This index is obtained as a weighted average of the use of email (5%), the use of internet to better understand questions related to work (7%), e-commerce and e-government (10%), the use of MS-Excel (13.5%), the use of MS-Word (17.5%), the use of complex programming (22%) and the use of video-conference and other real-time participation to discussion (25%). For this disaggregation, we have used the data from PIAAC database integrated by EU-SILC.

[8]See https://www.siope.it/Siope/.

Public Finance statistics from ISTAT.[9] Finally, the disposable income by each Institutional Sector is destined to final consumption or savings, which contributes to finance the capital formation (investment by commodity).

### 2.2. Description of the dynamic CGE model

The SAM, describing the income formation, distribution and use within the economic system, represents the proper database to calibrate the dynamic CGE model, in order to analyse different scenarios for TP in Italy. When developing a SAM-based CGE model, this latter shows a structure and functioning strictly dependent on the relations expressed in the database. Therefore, even though there might be other applications for the Italian Economy, there are no other CGE models developed on this same SAM, and this is enough to make the current CGE model very different and from the others. In particular, the detailed breakdown of compensation of employees and households' groups allows quantifying the different impact of the different TP scenarios on wages, occupation, income distribution, welfare as well as on the main macroeconomic variables in disaggregate terms. This disaggregation involves a more articulated structure of the production process, a more detailed functioning of the labour market and a more articulated imputation of labour incomes to Institutional Sectors (Households and Rest of World).

Specifically, the model is a dynamic CGE model with a multi-input, multi-output and multisectoral structure that solves the optimisation problem following the Ramsey approach of optimal economic growth under certainty (Lau, Pahlke, and Rutherford 2002). Model equations entail conditions for firms' profit maximisation, conditions for intertemporal utility maximisation (Socci et al., 2021) and market-clearing conditions together with intertemporal constraints. The dynamic of the model is driven by the capital accumulation condition, by which capital stock in each period is obtained by adding the investment to the capital stock at the previous time (reduced by the depreciation). The model is characterised by a finite time horizon; therefore to allow the convergence of the model to a stable equilibrium in the last period, we assume that in the last period the growth rate of the investment equalises the growth rate of aggregate production (Lau, Pahlke, and Rutherford 2002).[10]

Most of the parameters of the model, indicating the technical coefficients of the production function, the shares of income by components associated with each production process, the quota of income by component, the shares of income distributed among Institutional Sectors, all tax shares, transfers shares, propensities to consumption and saving by Institutional Sector, and quotas of final demand components per each commodity are calculated on the SAM database. Few remaining parameters, which are needed to reproduce the economic reality in a more articulate manner, are necessarily obtained from estimates in the literature, or from well-recognised macroeconomic assumptions (e.g. the absence of substitutability among intermediate goods), or from standard considerations about the features of selected markets (e.g. the labour market segmentation).[11] The robustness analysis on the parameters calibrated on the SAM is not required, since they replicate the functioning

[9] See https://www.istat.it/it/archivio/204387.
[10] The complete formulation of the model is presented in the Appendix B.
[11] See Appendix B for a list of parameters employed in the model.

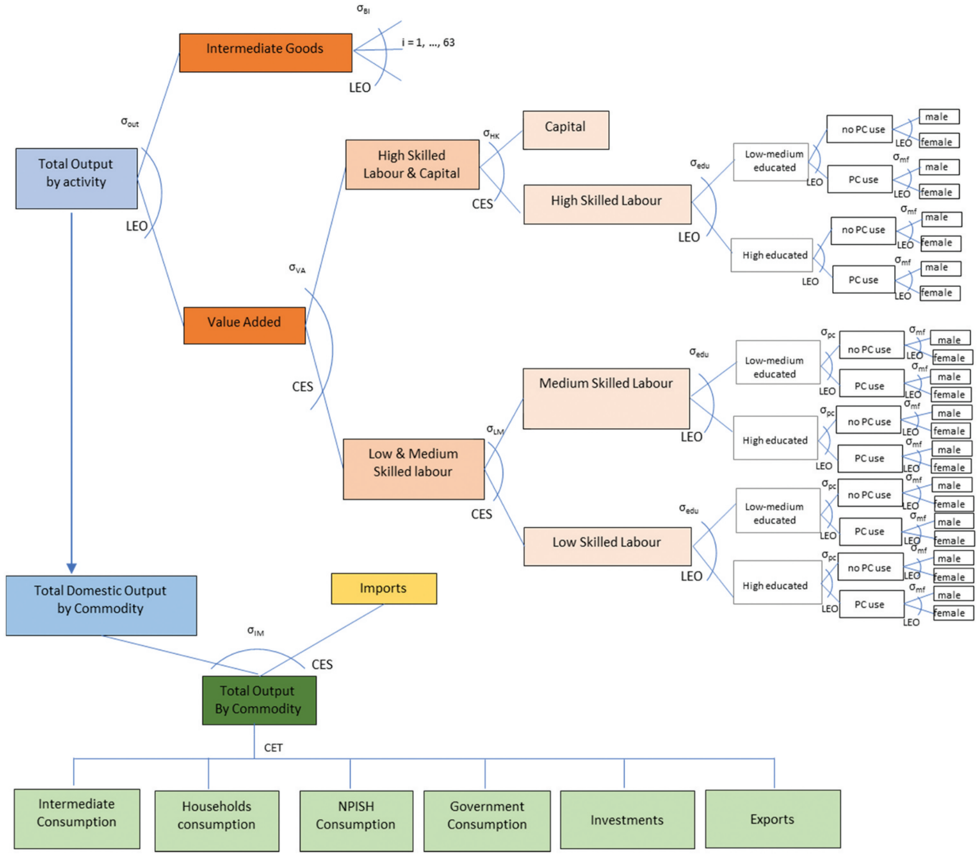


**Figure 1.** The relations among agents and markets in MODEL model. Source: Our elaboration.

of the economic system that is already ascertained by the National Institute of Statistics (ISTAT) which published the main data. As regard to the parameters referring to the elasticity of substitution between factors in the production function, many are set equal to zero and few, which are not zero, follows a well-corroborated theoretical setting (Severini et al. 2020; Socci et al. 2020, 2021).[12]

As mentioned above, the production processes are modelled following the structure of the SAM. It means considering 63 production activities that generate their output (63 commodities) through 63 different nested production functions structured as shown in Figure 1 The total output by activities in each period (top left of the Figure 1 derives from the combination of intermediate consumption and value added. The intermediate consumption is obtained from the aggregation of intermediate goods assuming a Leontief function. Value added is obtained combining two aggregates, 'Capital and High-skilled labour' and 'Low- and Medium-skilled labour'.

The aggregate 'Capital and High-skilled labour' is obtained combining 'Capital' and 'High-skilled labour' and assuming that capital can be interchangeable with high-skilled labour with a positive elasticity of substitution ($\sigma_{HK} = 0.528$) in all activities (Van Der

[12]For this motivation, we considered these parameters robust and did not include a section dedicated to the sensitivity analysis.

Werf 2008). 'High-skilled labour' is also an aggregate, is obtained by combining the different characteristics of the workers involved in such occupation that encompass respectively the education, digital competences and gender (the elasticity of substitution in all these nests is assumed to be null $\sigma_L = 0$).[13]

The aggregate 'Low- and Medium-skilled labour' considers the combination of 'Low-skilled labour' and 'Medium-skilled labour' that are assumed to be interchangeable in all production process, thus with a positive value of the elasticity of substitution ($\sigma_{LM} = 1.67$) following the estimations of Krusell et al. (2000). Then, similarly to the previous labour nests, the 'Low-skilled labour' and the 'Medium-skilled labour' aggregates are obtained combining the different characteristics of the workers assuming a Leontief function ($\sigma_{edu}$, $\sigma_{PC}$, $\sigma_{mf}$ are all equal to 0).

The total output produced by each activity can be split into the production of commodities that are typically associated with the activity itself (principal production) and other products, commonly defined as secondary or subsidiary productions (UN 2009). Therefore, the 'Total Domestic Output by Commodity' is obtained through the aggregation of the principal and the secondary productions from each activity. The domestic output by commodity is subsequently combined with the imported goods to determine the 'Total Output by Commodity' or total supply. 'Imports' depend on relative domestic/foreign prices, foreign inflation rate and nominal exchange rate (these two variables are assumed exogenous) and are not perfectly substitutable with the domestic products according to the Armington assumption (Armington 1969).[14]

The demand by commodity in each period is allocated according to a Constant Elasticity of Transformation (CET) function among (i) intermediate consumption by activity, depending on the volume of output by activity; (ii) Households' consumption expenditure, depending on the relative price of commodities and the consumption level in each period (this latter derive from the intertemporal maximisation of the consumers' utility); (iii) NPISH' consumption expenditure, that is treated exactly as the household's consumption; (iv) Public Administration consumption expenditure that is fixed in real terms; (v) investment which are assumed to be saving-driven; and (vi) exports to the Rest of the World which are endogenous.

The consumption of Households and NPISH in each period is determined through the maximisation of the intertemporal utility under the constraint of the disposable income earned over the time lapse considered and under adaptive expectations (Lau, Pahlke, and Rutherford 2002). The disposable income derives from the sum of primary factors incomes (labour and capital), transfers from other Institutional Sectors, net of transfers

[13]Since there is no relevant literature nor available which can corroborate any assumption about the substitutability between these types of workers, it is necessary to resort to the case of either perfect substitutability or perfect complementarity. Both these assumptions allow avoiding the typical problems related to the introduction of exogenous parameters (i.e. sensitivity analysis and robustness checks, see Grassini 2009). For this reason, we assumed the complementarity in these nests, as the worst possible scenario that encompasses an immobility of the labour market for the above-mentioned typologies of workers, and focus on the substitutability among low-medium-skilled occupations, that show more contributions in the literature. This might raise question about the opportunity to have such a deep distinction in workers characteristics. The rational, behind such a deep disaggregation is related to the potential information that can be collected from the simulation results in disaggregate terms.

[14]Following the Armington assumption, consumers are able to perceive the differences between imported and domestic goods even if they belong to the same category. Therefore, we assume that domestic and imported goods are imperfect substitutable and the elasticity of substitution is positive as in Zotti et al. (2020).

paid to other Institutional Sectors (these include income taxes and other unilateral transfers). All transfers are endogenously determined as the product between the transfer rate (calibrated from the SAM) and the income base (endogenous), with the exception of transfers from Public Administrations and the Rest of the World that are considered fixed in real terms.

The Government consumption expenditure in each period is assumed to be constant in real terms. This assumption is motivated by the strict constraints imposed to the Italian Government as a consequence of the high level of public deficit. At the same time, the Government disposable income is variable during the time lapse as it depends on the taxes' revenues, primary incomes and net transfers from other Institutional Sectors. The difference between the Government disposable income and the value of consumption expenditure that arising in each period, is saved as a potential income source to be alternatively destined to reduce the public deficit or expand the public expenditure (Socci et al. 2021).

The level of investment depends on the total amount of savings collected in each period within the economic system by all Institutional Sectors (saving-driven hypothesis). The global value of investments is added to the capital stock of the previous period net of depreciation, serving the formation of the next period capital stock. The initial value of the capital stock, as well as all the other parameters referred to the shares, quotas, tax rates, etc., is calibrated from the SAM in order to allow the model replicating the flows of the SAM as they are in the first period. In the subsequent periods, the model reproduces the steady-state growth path determined assuming exogenous depreciation rate, interest rate and total output growth rate, that are all compatible with the level of investment and the initial flow of capital registered in the SAM (Lau, Pahlke, and Rutherford 2002).

The demand of goods from the Rest of World (exports) depends on the domestic price of goods (endogenous), foreign price of goods (exogenous), the foreign income (exogenous) and the nominal exchange rates (exogenous). Thus, assuming that the gross saving of the Rest of World is constant in nominal terms over the time, the balance with the foreign accounts is granted through a fluctuation of the real exchange rate.[15]

The balance between total demand and total supply in the market of commodities is ensured by prices' fluctuation reflecting the perfect competitiveness of markets.

As regard to the price of primary factors, we assume the perfect competitiveness in the market of capital. It means that the price (or rental) of capital derives from the balance between the demand (endogenous) and the supply (exogenous in the first period) and follows the rule by which the marginal productivity of capital corresponds to the marginal cost.

As for labour, the 24 categories of workers have 24 levels of salaries that are assumed to be unique for all the production processes. These are determined through the wage curve that is decreasing in the unemployment rate (increasing in employment and decreasing in the labour supply). This assumption constitutes a deviation from the profit maximisation rule and considers the low competitiveness of labour markets explainable by many reasons (i.e. the collective bargaining and the efficiency wages). Specifically, we assume that wages arise from the negotiation between firms, whose objective is the profit

[15]We consider the small open economy assumption.

maximisation, and Labour Union, as a "right-to-manage" process, according to the typical Nash bargaining Maximin. The parties bargain only over employed wages and Firms decide over their labour demand at the bargained wage (Böhringer, Boeters, and Feil 2005). Labour supply is exogenous and it grows at an exogenous growth rate.[16]

## 3. The simulation scenarios

Modelling the ongoing wave of TP requires a composite shock in order to take account of the two main exogenous changes at work. These are the increase in the capital productivity on the one side and a change in the degree of substitutability between labour and capital on the other. The productivity increase clearly belongs to this wave of progress as well as to many others in the past. The change in the labour-capital substitutability by contrast features the novelty of this wave of TP, which consists in the introduction of automation technologies that are labour replacing. The modelization of the productivity increase is standard, and it replicates the trend in productivity over the last ten years in Italy (ISTAT 2020).[17] As for the change in the labour-capital substitutability, uncertainty about its size and its timing is higher. For this reason, we hypothesise a number of different scenarios with the idea that they can only provide a broad depiction of the changes to come.

We design four scenarios (see Table 1). The first of them entails the sole increase in the capital productivity, and for this reason, it is labelled conservative (C). The other three scenarios describe the current wave of labour-replacing TP. The conservative scenario serves two purposes. Besides being a confirmation for the overall consistency of the model, it provides a picture of the economy as it would change in the case of a standard wave of TP. In this sense, it serves as a further point of reference (beyond the benchmark) for a more thorough assessment of the effects of the current wave of TP, which is simulated in the other scenarios.

We respectively label the three scenarios with labour-replacing TP optimistic (O), pessimistic (P) and intermediate (I). In the optimistic scenario, the initial complementarity between the Capital–High-skilled-labour nest and the Low-skilled–Medium-skilled

**Table 1.** Simulation scenarios for the substitutability of different skilled labour and capital.

| Scenarios | | $\sigma_{HK}$ | $\sigma_{LM}$ | $\sigma_{VA}$ |
|---|---|---|---|---|
| C | Conservative | 0.5218 | 1.6670 | 0.5218 |
| O | Optimistic | 0.5218 | 1.6670 | 1.5000 |
| P | Pessimistic | 1.6670 | 1.6670 | 1.5000 |
| M | Intermediate | 0.5218–>1.6670 | 1.6670 | 1.5000 |

[16]The model replicates in the first period the flows of the SAM and in the subsequent periods it reproduces the steady state growth path determined assuming exogenous depreciation rate, interest rate and total output growth rate that are compatible with the level of investment and the initial stock of capital derived from the SAM (Lau, Pahlke, and Rutherford 2002).

[17]Over the 2011–2020 period, the average yearly growth rate of productivity has been 0.9%.

-labour nest turns into substitutability by the first simulation period. By construction, this change is assumed to be unexpected and once-and-for-all. It indicates that the already installed capital stock can efficiently replace low- and medium-skilled labour, and this substitution becomes more and more intense as the capital productivity exogenously increases. The pessimistic scenario embeds the optimistic scenario, and it further assumes that capital and high-skilled labour (which are complement in the capital–high-skilled-labour nest) become substitutes. The idea behind this scenario is that TP goes quite beyond the mere robotisation or automation of repetitive tasks, and it takes more advanced shapes as in the case of artificial intelligence. As in the optimistic scenario, the change in the elasticity of substitution occurs once and for all in the first simulation period.

While it seems conceivable that the upcoming (or even the ongoing) wave of robotisation and automation will leave low-skilled and (possibly) medium-skilled labour partially unexploited, it is less immediate to think about the more revolutionary effect of artificial intelligence, which would have the consequence of turning even high-skilled labour into a relatively abundant factor. For this reason, the assumption that complementarity between capital and high-skilled labour switches into substitutability in the first simulation period may lead to an overestimation of the consequences of this wave of TP within the first simulation periods. For this reason, in the intermediate scenario, we assume that the elasticity of substitution between capital and high-skilled labour changes progressively throughout the entire simulation period.

## 4. Results

This section reports the main results of the four simulation scenarios (conservative, optimistic, pessimistic and intermediate). For each scenario, it illustrates the changes in the main macroeconomic variables in comparison to the benchmark. In order to provide a more complete picture of the effects of the advancement of TP, it reports the income changes for the six households' groups.

### *4.1. The conservative scenario*

This scenario portrays TP in a standard way, as an increase in the capital productivity throughout the ten-year simulation period. The degree of substitutability between capital and labour remains unchanged at the benchmark levels. As it is to expect, the effects on the economy are quite standard. The results in Table 2 show that real GDP and all other macroeconomic variables are higher than in the benchmark. Since capital becomes more productive, investment becomes more attractive and grows more than any other macroeconomic variable. Since the model accounts for involuntary unemployment, it is capable of showing the effects of any shock on employment. As indicated in Table 2, employment grows with economic activity and this is consistent with the assumption that capital and labour are complements in this scenario.

The generalised increase in the employment level has the effect of a slight income increase for all six income groups, as visible in Table 3.

**Table 2.** Conservative scenario vs benchmark: effects on main macroeconomic variables (% changes).

| | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | $t_8$ | $t_9$ |
|---|---|---|---|---|---|---|---|---|---|
| Real GDP | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Real consumption | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 |
| Real investment | 0.5 | 0.9 | 1.3 | 1.6 | 1.9 | 2.1 | 2.2 | 2.3 | 2.3 |
| Real government expenditure | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Real exports | 0.2 | 0.5 | 0.6 | 0.8 | 0.9 | 0.9 | 1.0 | 1.0 | 0.9 |
| Real imports | 0.2 | 0.4 | 0.6 | 0.7 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 |
| Low-skilled employment | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| Medium-skilled employment | 0.0 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| High-skilled employment | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 |
| Total employment | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

**Table 3.** Conservative scenario vs benchmark: effects on disposable income by income groups (% changes).

| Household group | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | $t_8$ | $t_9$ | $t_1$ |
|---|---|---|---|---|---|---|---|---|---|---|
| HH1 | 0.36 | 0.33 | 0.31 | 0.30 | 0.28 | 0.28 | 0.27 | 0.27 | 0.28 | 0.29 |
| HH2 | 0.88 | 0.78 | 0.69 | 0.62 | 0.57 | 0.52 | 0.48 | 0.45 | 0.43 | 0.40 |
| HH3 | 0.68 | 0.59 | 0.52 | 0.46 | 0.41 | 0.38 | 0.34 | 0.31 | 0.29 | 0.26 |
| HH4 | 0.50 | 0.45 | 0.40 | 0.37 | 0.33 | 0.31 | 0.29 | 0.27 | 0.25 | 0.24 |
| HH5 | 0.26 | 0.24 | 0.23 | 0.21 | 0.20 | 0.20 | 0.19 | 0.19 | 0.20 | 0.20 |
| HH6 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 |

### *4.2. The optimistic scenario*

In this scenario, we assume that low- and medium-skilled labour together become easier to replace through capital and high-skilled labour (which are assumed complements). In other words, this kind of TP consists in assuming that capital is capable of performing repetitive tasks, which previously pertained to human labour only. Since the involved tasks are elementary by assumption, the most affected labour segments are the low- and medium-skilled ones. This scenario 'appears to be the most plausible in the short term (in which) workers will benefit from the automation of a substantial number of routine tasks performed by humans until now' (Servoz 2019, p. 14). As shown in Table 4, the impact of this wave of technological progress on the economy is generally greater than in the conservative scenario. However, the possibility of substituting labour By contrast, the effect on the labour market is severely negative. Aggregate employment shrinks by 14.5% overall the simulation period. However, a deeper look at the disaggregate results allows observing the asymmetric effect on the three typologies of occupations. While the high-skilled employment gains from the increase of the capital productivity, the low- and medium-skilled employment suffer a sharp decrease.

In terms of households' income (see Table 5 below), the effects of the decrease in employment is visible in three groups of households (HH2, HH3 and HH4). There are two groups of households (HH1 on the low-income side and HH5 and HH6 on the high-

**Table 4.** Optimistic scenario vs benchmark: effects on main macroeconomic variables (% changes).

| | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | $t_8$ | $t_9$ |
|---|---|---|---|---|---|---|---|---|---|
| Real GDP | 0.2 | 0.5 | 0.7 | 0.9 | 1.2 | 1.4 | 1.7 | 1.9 | 2.2 |
| Real consumption | 0.1 | 0.1 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.6 |
| Real investment | 1.4 | 2.8 | 4.0 | 5.1 | 6.1 | 7.0 | 7.7 | 8.3 | 8.7 |
| Realgovernment expenditure | 0.1 | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 |
| Real exports | 0.3 | 0.7 | 1.1 | 1.6 | 2.1 | 2.7 | 3.3 | 3.9 | 4.6 |
| Real imports | 0.6 | 1.2 | 1.7 | 2.2 | 2.7 | 3.1 | 3.4 | 3.7 | 4.0 |
| Low-skilled employment | −3.6 | −7.0 | −10.2 | −13.1 | −15.8 | −18.3 | −20.7 | −22.9 | −25.0 |
| Medium-skilled employment | −3.5 | −6.6 | −9.6 | −12.3 | −14.9 | −17.2 | −19.5 | −21.6 | −23.6 |
| High-skilled employment | 1.1 | 2.2 | 3.1 | 3.9 | 4.6 | 5.2 | 5.7 | 6.1 | 6.4 |
| Total employment | −2.0 | −3.9 | −5.7 | −7.4 | −8.9 | −10.4 | −11.8 | −13.2 | −14.5 |

**Table 5.** Optimistic scenario vs benchmark: effects on disposable income by income groups (% changes).

| Household group | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | $t_8$ | $t_9$ | $t_1$ |
|---|---|---|---|---|---|---|---|---|---|---|
| HH1 | 1.54 | 1.65 | 1.79 | 1.95 | 2.13 | 2.33 | 2.56 | 2.81 | 3.08 | 3.38 |
| HH2 | 3.74 | 2.31 | 0.94 | −0.37 | −1.64 | −2.88 | −4.08 | −5.25 | −6.39 | −7.51 |
| HH3 | 2.87 | 0.93 | −0.89 | −2.63 | −4.28 | −5.86 | −7.37 | −8.81 | −10.20 | −11.53 |
| HH4 | 2.13 | 1.74 | 1.35 | 0.97 | 0.59 | 0.22 | −0.16 | −0.55 | −0.95 | −1.35 |
| HH5 | 1.12 | 1.20 | 1.30 | 1.41 | 1.54 | 1.69 | 1.84 | 2.02 | 2.21 | 2.42 |
| HH6 | 0.02 | 0.04 | 0.06 | 0.08 | 0.10 | 0.13 | 0.16 | 0.20 | 0.24 | 0.29 |

income side), which are better off following to the advancement of TP. For the low-income group, the reason for the increase in disposable income mainly lies in the income redistribution mechanisms, which are already in place in the economy. A general rise in the GDP brings about higher transfers to the low-income group, which in any case enjoys a supportive taxation scheme. High-income households are not yet directly affected, as employment in the high-skilled occupations rises.

### *4.3. The pessimistic scenario*

This scenario seeks to resemble a more disruptive form of TP, as in the case of the diffusion of artificial intelligence (AI). If AI is to be taken literally, it might be capable to substitute tasks that are even more complex. Differently from the optimistic scenario, this scenario assumes that capital also replaces high-skilled labour, and not only low- and medium-skilled. The results of this type of TP are given in Table 6. The effect on real GDP is positive and higher than in the case with lower labour-capital substitutability (see optimistic scenario) whereas the effect on employment is generally more severe, with a sharp decrease of high-skilled labour.

As for the effects at households' level (see Table 7 below), the results in this scenario are qualitatively similar to those in the previous, optimistic scenario. However, the effects on income in the two high-income households' groups (HH5 and HH6) need a different explanation in this scenario in comparison to the previous, optimistic one. Here, employment strongly falls also in the high-skilled occupations and yet their income level rises

**Table 6.** Pessimistic scenario vs benchmark: effects on main macroeconomic variables.

| | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | $t_8$ | $t_9$ |
|---|---|---|---|---|---|---|---|---|---|
| Real GDP | 0.3 | 0.5 | 0.8 | 1.1 | 1.3 | 1.6 | 2.0 | 2.3 | 2.6 |
| Real consumption | 0.1 | 0.2 | 0.3 | 0.4 | 0.4 | 0.5 | 0.6 | 0.7 | 0.7 |
| Real investment | 1.3 | 2.5 | 3.6 | 4.6 | 5.6 | 6.4 | 7.2 | 7.8 | 8.3 |
| Real government expenditure | 0.1 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.6 | 0.7 |
| Real exports | 0.5 | 1.0 | 1.6 | 2.2 | 2.9 | 3.7 | 4.5 | 5.4 | 6.4 |
| Real Imports | 0.7 | 1.3 | 1.8 | 2.4 | 2.9 | 3.3 | 3.8 | 4.1 | 4.4 |
| Low-skilled employment | −3.8 | −7.2 | −10.4 | −13.4 | −16.2 | −18.8 | −21.2 | −23.6 | −25.8 |
| Medium-skilled employment | −3.5 | −6.8 | −9.9 | −12.8 | −15.5 | −18.0 | −20.4 | −22.8 | −25.0 |
| High-skilled employment | −4.3 | −8.3 | −11.9 | −15.3 | −18.5 | −21.4 | −24.2 | −26.9 | −29.4 |
| Total employment | −3.9 | −7.5 | −10.8 | −13.9 | −16.8 | −19.5 | −22.1 | −24.5 | −26.8 |

**Table 7.** Pessimistic scenario vs benchmark: effects on disposable income by income groups.

| Household group | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | $t_8$ | $t_9$ | $t_1$ |
|---|---|---|---|---|---|---|---|---|---|---|
| HH1 | 3.42 | 3.85 | 4.32 | 4.85 | 5.43 | 6.06 | 6.76 | 7.51 | 8.34 | 9.23 |
| HH2 | 8.33 | 6.78 | 5.34 | 3.99 | 2.70 | 1.45 | 0.25 | −0.92 | −2.08 | −3.21 |
| HH3 | 6.39 | 3.83 | 1.45 | −0.78 | −2.89 | −4.88 | −6.79 | −8.63 | −10.39 | −12.09 |
| HH4 | 4.75 | 3.94 | 3.17 | 2.42 | 1.67 | 0.93 | 0.17 | −0.60 | −1.39 | −2.20 |
| HH5 | 2.49 | 2.73 | 3.00 | 3.31 | 3.64 | 4.01 | 4.41 | 4.85 | 5.33 | 5.85 |
| HH6 | 0.05 | 0.36 | 0.70 | 1.06 | 1.45 | 1.88 | 2.35 | 2.88 | 3.47 | 4.14 |

quite considerably. In this case, the negative effect due to the higher unemployment is counterbalanced by the higher capital income rates, which these groups of actors gain from their assets.

### *4.4. The intermediate scenario*

The intermediate scenario assumes a slower advent of that type of TP, which implies a higher substitutability between capital and high-skilled labour. Indeed, the pessimistic scenario is expected (see Servoz 2019) to materialise in the medium-term. For this reason, the intermediate scenario assumes that capital becomes a substitute for high-skilled labour only gradually. The results are contained in Table 8.

In this intermediate scenario, the effect on employment (see Table 9) is slightly milder than in the pessimistic scenario, but more severe than in the optimistic scenario. This is consistent with the design of the simulation, which foresees a more gradual increase in the overall substitutability between labour and capital in comparison to the pessimistic scenario. At the same time, however, the substitutability becomes higher than in the optimistic scenario.

The effects on income levels in this scenario resemble those in the pessimistic scenario, with the only difference that they are slightly less severe. This is consistent with the design of this scenario, which by construction lies between the optimistic and the pessimistic frameworks.

**Table 8.** Intermediate scenario vs benchmark: effects on main macroeconomic variables.

| | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | $t_8$ | $t_9$ |
|---|---|---|---|---|---|---|---|---|---|
| Real GDP | 0.5 | 1.0 | 1.4 | 1.8 | 2.2 | 2.6 | 3.0 | 3.4 | 3.7 |
| Real consumption | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.8 |
| Real investment | 4.9 | 9.2 | 13.1 | 16.3 | 19.0 | 21.1 | 22.7 | 23.9 | 24.6 |
| Real government expenditure | 0.1 | 0.2 | 0.3 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
| Real exports | 0.6 | 1.2 | 1.9 | 2.5 | 3.3 | 4.1 | 5.0 | 5.9 | 7.0 |
| Real imports | 2.3 | 4.3 | 6.1 | 7.7 | 9.0 | 10.0 | 10.8 | 11.4 | 11.9 |
| Low-skilled employment | −2.9 | −5.7 | −8.4 | −11.0 | −13.6 | −16.1 | −18.6 | −21.0 | −23.3 |
| Medium-skilled employment | −2.8 | −5.5 | −8.0 | −10.6 | −13.0 | −15.5 | −17.9 | −20.3 | −22.7 |
| High-skilled employment | 1.2 | 0.8 | −1.0 | −4.0 | −8.1 | −12.9 | −18.4 | −24.2 | −30.3 |
| Total employment | −1.5 | −3.5 | −5.9 | −8.7 | −11.7 | −15.0 | −18.4 | −21.9 | −25.5 |

**Table 9.** Intermediate scenario vs benchmark: effects on disposable income by income groups.

| Household group | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ | $t_6$ | $t_7$ | $t_8$ | $t_9$ | $t_1$ |
|---|---|---|---|---|---|---|---|---|---|---|
| HH1 | 2.48 | 2.80 | 3.22 | 3.74 | 4.37 | 5.11 | 5.95 | 6.90 | 7.96 | 9.13 |
| HH2 | 6.04 | 5.21 | 4.42 | 3.63 | 2.82 | 1.97 | 1.06 | 0.08 | −0.96 | −2.08 |
| HH3 | 4.63 | 3.27 | 1.87 | 0.40 | −1.18 | −2.86 | −4.66 | −6.55 | −8.52 | −10.55 |
| HH4 | 3.44 | 3.40 | 3.26 | 3.00 | 2.60 | 2.05 | 1.34 | 0.46 | −0.57 | −1.75 |
| HH5 | 1.81 | 2.04 | 2.33 | 2.68 | 3.07 | 3.52 | 4.01 | 4.56 | 5.15 | 5.79 |
| HH6 | 0.03 | 0.03 | 0.10 | 0.27 | 0.55 | 0.95 | 1.48 | 2.17 | 3.01 | 4.02 |

In qualitative terms, these results align well with most of the theoretical literature on the effects of automation on labour (e.g. Acemoglu and Guerrieri 2008; Sachs and Kotlikoff 2012; Berg, Buffie, and Zanna 2017; Susskind 2017). Automation boosts GDP growth, but it has disruptive effects on labour. The higher the degree of substitutability between capital and labour, the worse the impact on occupation. The negative employment effect is counterbalanced by an increase in the capital rents that mitigate the fall in the disposable income of firms and households, with the consequence of boosting consumption and investment.

The comparison reveals trickier once the other term of comparison is the extensive empirical literature. A general result of this extensive literature is that the impacts of automation are far from straightforward, and this emerges clear both from ex-post econometric estimates and from ex-ante projections (e.g. OECD, 2019; Koster and Brunori 2021). Several authors (e.g. Acemoglu and Restrepo 2020, Jestl, 2022) report about studies, which find a positive relationship between automation (or innovation in general, see e.g. Dosi and Mohnen 2019) and employment, as well as about studies, in which the effects are either the opposite or mixed. Ex-ante projections, in turn are very heterogeneous in terms of results. Frey and Osborne (2017), for example, predict that up to 47% of US jobs are at risk due to automation in the next 10–20 years while other studies (e.g. Arntz, Gregory, and Zierahn 2016; 2017; Nedelkoska and Quintini 2018) that follow very closely the approach by Frey and Osborne (2017) find however, that only 9–14% of all jobs in the OECD countries might go lost in the next decades.

One possible source of heterogeneity among existing results is due to the differences in the aggregation level adopted in the various studies. Some papers look at the firm-level effects (e.g. Aghion, Antonin, Bunel, & Jaravel, 2020; Bessen, 2019; Acemoglu and Restrepo 2020; Koch, Manuylov, & Smolka, 20211) while others take the production sector as the reference scale (e.g. Gentili et al. 2020; Ghodsi, Reiter, Stehrer, & Stöllinger, 2020; Graetz & Michaels, 2018). In any case, these contributions can usually capture the direct but not the indirect effects (Vivarelli, 2012) with the consequence that 'results are likely to be either over- or underestimated (Pianta, 2005)' (Jung, S. et al., 2017: 426). Quite differently, our study is *per construction* capable of capturing the equilibrium effects of automation.

For this reason, it is sensible to compare the results of our study only with the ones of other CGE models rather than with the entire ex-ante literature.[18] Altogether, we are aware of three CGE models, which directly deal with the effects of automation on labour. These are Jung et al. (2017), Peralta-Alva and Roitman (2018) and Costantini and Sforna (2020). The first focuses on South Korea, the second is about the US, while the third uses GTAP and looks at the automation impacts on the EU as a whole. Interesting and informative as they can be, the results of these studies are hardly comparable with our results. One main reason is that every country reacts to the diffusion of automation in a unique way (e.g. Koster and Brunori 2021), which depends on an array of country-specific peculiarities. In the case of Italy, for example, there is agreement that the economy has been relatively slow in the adoption of innovation (see, e.g. Piva and Vivarelli 2005; Falzoni and Tajoli 2008; Pilat et al., 2002). Automation, as a specific form of innovation could have also spread with a certain delay throughout the Italian economy (Paba et al., 2020). This is one of the reasons why the results of our ex-ante quantification of the automation impacts can be far different from the ones obtained by Paba et al. (2020) for the period 1991–2011.[19]

## 5. Policy implications

The main aim of this paper is to provide a detailed modelling framework for the simulation of scenarios of automation diffusion in the Italian economy. The relevance of the paper lies in the fact that it takes a different approach in comparison to most of the literature, which mostly relies on econometric estimates of the effects of automation or on ex-ante projections of these effects in a framework, which, however, lacks an equilibrium perspective. The design and the simulation of scenarios of policy intervention are the natural continuation of this study, but this is a task, which lies beyond the scope of the present paper. Under these premises, the scope of this section is to show how the results obtained through model simulations match with the indications of policy intervention given in the literature (e.g. Korink and Stiglitz; Koster and Brunori 2021).

Two main policy indications are worth considering for their consistency with the results in Section 4. One is based on the idea that workers can better cope with the diffusion of automation if they undergo effective upskilling programmes. The other is concerned with the need for counterbalancing the redistribution effects that automation may generate. In the optimistic scenario, employment in the high-skilled occupations

[18]Among others, this literature includes the studies of Frey and Osborne (2013, 2017), Brynjolfsson and McAfee (2014), Ford (2015), World Development Report (2016), McKinsey Global Institute (2017), Arntz, Gregory, and Zierahn (2016; 2017), Nedelkoska and Quintini (2018).

[19]Even one very recent study (i.e. Jestl, 2022 that dates June 2022) focuses on the period 2001–2016.

rises, whereas it shrinks in the low- and medium-skilled ones. If this were the real scenario, a possible policy message could be that it is necessary to provide ambitious training programmes in order to upskill those workers, which the advancement of TP makes (temporarily) redundant in the economy. Indeed, workers with a medium-low level of formal education are also capable of providing their labour services in the high-skilled segment of the labour market, which means that upskilling programmes can ideally become effective quite quickly. Since employment in low–medium-skilled occupations decreases by almost one forth, it is of primary importance to ease the absorption of these workers in high-skill occupations. In the wide literature about the need of upskilling programmes to keep workers in the labour market, Peralta-Alva and Roitman (2018) explicitly advocate higher public spending on education for workers in the low-skilled occupations, and they suggest to finance these outlays through higher personal income taxes for workers in high-skill occupations and an increase in the VAT rate. OECD (2004) reports about some experiments with training programmes. For example, in the US State of Caroline during '90 the hosiery manufacturing addressed the challenge of technological change and the relocation process by developing LS workers' cognitive- and problem-solving skills. At this aim, manufacturers instituted the Hosiery Technological Center (HTC) transferring technological knowledge to new labour force and to experienced machine-technicians and operators.

If we accept the idea that training policies can be effective (see however, e.g. Meagre and Evans, 1998 and Robinson, 1995), there is the possibility of a general upgrading process as it has happened in Germany and Switzerland (see, e.g. Manning, 2004 and in Autor, Levy, and Murnane 2003). This type of evolution would confirm the OECD (2019) study, which provides a general view of employment patterns due to digitalisation and other ICT innovations in the context of globalisation and demographic changes.

The second policy indication derives from the results regarding the pessimistic scenario, but it can also prove sensible in the optimistic scenario. In the former case, employment sharply decreases throughout the whole labour market. Physical capital, which in this case can be seen as artificial intelligence, becomes capable of replacing even high-skilled labour. Since the effects on GDP are roughly positive, it is important to ascertain how income is distributed among the Institutional Sectors and across the various households' income groups. Results regarding the income effects on the six income groups show that the benefits of TP are unevenly distributed in the society. The results of the simulation highlight that the advancement in TP generates winners and losers at the same time. The risk is that losers oppose the changes arising from the advancement of TP (Korinek and Stiglitz, 2017). Since the effects of TP are overall positive (at aggregate level), it is important to design appropriate redistribution policies with the aim of letting all actors partaking the benefits from TP.

Along the two policy indications above, which typically belong to the area of employment and taxation policy, there may be further fields of intervention to consider. One is suggested by the observation that 'the risk of an overall drop in employment is [perhaps] limited at the aggregate level, [but] certain industries and regions may see net declines in the number of jobs available' (OECD, 2019). This means that regional policies and policies for facilitating labour mobility (OECD, 2019) may have an important role in dealing with the impacts of automation. Regional policies in particular, might look at regional comparative advantages in order to foster those sectors which are most likely to support local economies. A second promising area of intervention can be the green economy. The relevant literature in this field (e.g. Consoli et al., 2016) claims that green jobs tend to be better-skilled, which means that a greener economy could be more resilient to the negative effects of automation and at the same time, upskilling programmes should target the green sphere of the economy. The policies, which have been just sketched pose a number of questions that can be tackled only in a separate paper. One point regards the size of the redistribution interventions whereas another one is about the costs of these policies and a third one is about their welfare effects. If upskilling policies clearly need public financing, redistributive policies can in any case imply implementation costs, which may finally cause a welfare reduction. In terms of welfare, it is important to investigate whether the positive effect of automation on GDP reverberates on higher tax revenues and whether these higher revenues can translate into higher public spending (with a positive effect on welfare). A thorough analysis would ideally require comparing the welfare level before the advent of TP with the one at the end of the simulation period and with the one in which the selected policies are implemented. To assess the effect of policies, it is important to design specific simulations, which are the potential development of this study.

## 6. Conclusions and further research agenda

The current wave of automation poses a number of challenges to the labour factor, which are not new in their nature, but they are in their alleged magnitude. The major point of concern is perhaps the risk of booming unemployment and soaring inequalities. This paper studies how automation could affect the Italian economy and the Italian labour market in particular. It employs a dynamic multisectoral CGE with six income groups of households and labour market segmentation in order to account for the uneven effects of automation across workers' and income groups. In consideration of the uncertainties regarding the timing and the effects of automation, the study distinguishes four possible scenarios. Every scenario assumes a progressive increase in the capital productivity and a specific evolution in the degree of substitutability between labour and capital, in order to mimic the diffusion of automation.

Our results align well with the literature (e.g. Servoz 2019; Berg, Buffie, and Zanna 2017; Peralta-Alva and Roitman 2018). Automation boosts GDP growth, but it has disruptive effects on labour. The higher the degree of substitutability between capital and labour, the worse the impact on occupation. The negative employment effect is counterbalanced by an increase in the capital rents that mitigate the fall in the disposable income of firms and households, with the consequence of boosting consumption and investment.

Our analysis is based on a very tight setting (i.e. the CGE) in which any assumption has its own scope and it potentially represents a limitation for the whole research. In the case of our study, for example, the segmentation of the labour market into is a valuable peculiarity of the model. However, the size of each workers' group is exogenous, i.e. it is constant. This means excluding the possibility that workers undertake upskilling programmes and move from one (e.g. low-skilled) group to another (e.g. medium-skilled or high-skilled) group. If the labour demand for one given group shrinks, wage and employment levels in that group fall. From a certain perspective, this assumption may be seen as a lack of flexibility in the model and hence a possible weakness. However, it allows quantifying the pure effects of automation, i.e. those effects, which the policy maker has to count with when designing the policy response. Moreover, there is acknowledgement about a certain reluctancy of unskilled labour forces towards upskilling (Koster and Brunori 2021). In this sense, the exogenous labour market segmentation might be a way of capturing a particular aspect of the real world.

For the debate on the effects of automation on a single economy as Italy, these results are important because they provide a first broad framework for policy intervention. The results highlight the risk that income inequalities boom between a small elite endowed with worker-replacing capital and a large mass of dismissed workers. It is important to provide support to the disadvantaged categories of actors among the Institutional Sectors of the economy. Indeed, it is well known that the inactivity due to unemployment depreciates human capital. One important area of policy intervention might be the upskilling of workers with the aim of increasing sectoral and hence aggregate productivity.

The quantification of the effects of the current automation wave on the economy and on the labour markets appears the appropriate foundation to assess any policy aiming at counteracting the unwanted side-effects of the current wave of TP. Confronted with this type of analysis however, it is fair to recall that automation is also expected to have 'significant risks of decreasing job quality' (OECD, 2019: 44). While the CGE methodology is capable to capture the quantitative effects of the automation, it cannot account for the ones connected with the qualitative aspects of labour. This is clearly an intrinsic limitation of our study and it directly follows from the quantitative nature of the CGE methodology. In this sense, our contribution needs to be complemented by other methodologies in order to gain a more complete picture of the issue at hand.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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# Appendices

## Appendix A: Classification of commodities and activities in the SAM

**Table A1.** Classification of commodities in SAM.

| No. | Commodity | No. | Commodity |
|---|---|---|---|
| 1 | Products of agriculture, hunting and related services | 33 | Air transport services |
| 2 | Products of forestry, logging and related services | 34 | Warehousing and support services for transportation |
| 3 | Fish and other fishing products; aquaculture products; support services to fishing | 35 | Postal and courier services |
| 4 | Mining and quarrying | 36 | Accommodation and food services |
| 5 | Food products, beverages and tobacco products | 37 | Publishing services |
| 6 | Textiles, wearing apparel and leather products | 38 | Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services |
| 7 | Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials | 39 | Telecommunications services |
| 8 | Paper and paper products | 40 | Computer programming, consultancy and related services; information services |
| 9 | Printing and recording services | 41 | Financial services, except insurance and pension funding |
| 10 | Coke and refined petroleum products | 42 | Insurance, reinsurance and pension funding services, except compulsory social security |
| 11 | Chemicals and chemical products | 43 | Services auxiliary to financial services and insurance services |
| 12 | Basic pharmaceutical products and pharmaceutical preparations | 44 | Real estate services including imputed rents of owner-occupied dwellings |
| 13 | Rubber and plastics products | 45 | Legal and accounting services; services of head offices; management consulting services |
| 14 | Other non-metallic mineral products | 46 | Architectural and engineering services; technical testing and analysis services |
| 15 | Basic metals | 47 | Scientific research and development services |
| 16 | Fabricated metal products, except machinery and equipment | 48 | Advertising and market research services |
| 17 | Computer, electronic and optical products | 49 | Other professional, scientific and technical services; veterinary services |
| 18 | Electrical equipment | 50 | Rental and leasing services |
| 19 | Machinery and equipment n.e.c. | 51 | Employment services |
| 20 | Motor vehicles, trailers and semi-trailers | 52 | Travel agency, tour operator and other reservation services and related services |
| 21 | Other transport equipment | 53 | Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services |
| 22 | Furniture; other manufactured goods | 54 | Public administration and defence services; compulsory social security services |
| 23 | Repair and installation services of machinery and equipment | 55 | Education services |
| 24 | Electricity, gas, steam and air-conditioning | 56 | Human health services |
| 25 | Natural water; water treatment and supply services | 57 | Social work services |

(*Continued*)

**Table A1.** (Continued).

| No. | Commodity | No. | Commodity |
|---|---|---|---|
| 26 | Sewerage; waste collection, treatment and disposal industries; materials recovery; remediation industries and other waste management services | 58 | Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services |
| 27 | Constructions and construction works | 59 | Sporting services and amusement and recreation services |
| 28 | Wholesale and retail trade and repair services of motor vehicles and motorcycles | 60 | Services furnished by membership organisations |
| 29 | Wholesale trade services, except of motor vehicles and motorcycles | 61 | Repair services of computers and personal and household goods |
| 30 | Retail trade services, except of motor vehicles and motorcycles | 62 | Other personal services |
| 31 | Land transport services and transport services via pipelines | 63 | Services of households as employers; undifferentiated goods and services produced by households for own use |
| 32 | Water transport services | | |

**Table A2.** Classification of activities in SAM.

| No. | Activity | No. | Activity |
|---|---|---|---|
| 1 | Crop and animal production, hunting and related service industries | 33 | Air transport |
| 2 | Forestry and logging | 34 | Warehousing and support industries for transportation |
| 3 | Fishing and aquaculture | 35 | Postal and courier industries |
| 4 | Mining and quarrying | 36 | Accommodation and food service industries |
| 5 | Manufacture of food products; beverages and tobacco products | 37 | Publishing industries |
| 6 | Manufacture of textiles, wearing apparel, leather and related products | 38 | Motion picture, video, television programme production; programming and broadcasting industries |
| 7 | Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials | 39 | Telecommunications |
| 8 | Manufacture of paper and paper products | 40 | Computer programming, consultancy, and information service industries |
| 9 | Printing and reproduction of recorded media | 41 | Financial service industries, except insurance and pension funding |
| 10 | Manufacture of coke and refined petroleum products | 42 | Insurance, reinsurance and pension funding, except compulsory social security |
| 11 | Manufacture of chemicals and chemical products | 43 | Industries auxiliary to financial services and insurance industries |
| 12 | Manufacture of basic pharmaceutical products and pharmaceutical preparations | 44 | Real estate industries including imputed rents of owner-occupied dwellings |
| 13 | Manufacture of rubber and plastic products | 45 | Legal and accounting industries; industries of head offices; management consultancy industries |
| 14 | Manufacture of other non-metallic mineral products | 46 | Architectural and engineering industries; technical testing and analysis |
| 15 | Manufacture of basic metals | 47 | Scientific research and development |
| 16 | Manufacture of fabricated metal products, except machinery and equipment | 48 | Advertising and market research |
| 17 | Manufacture of computer, electronic and optical products | 49 | Other professional, scientific and technical industries; veterinary industries |
| 18 | Manufacture of electrical equipment | 50 | Rental and leasing industries |
| 19 | Manufacture of machinery and equipment n.e.c. | 51 | Employment industries |
| 20 | Manufacture of motor vehicles, trailers and semi-trailers | 52 | Travel agency, tour operator reservation service and related industries |
| 21 | Manufacture of other transport equipment | 53 | Security and investigation, service and landscape, office administrative and support industries |
| 22 | Manufacture of furniture; other manufacturing | 54 | Public administration and defence; compulsory social security |
| 23 | Repair and installation of machinery and equipment | 55 | Education |
| 24 | Electricity, gas, steam and air conditioning supply | 56 | Human health industries |
| 25 | Water collection, treatment and supply | 57 | Residential care industries and social work industries without accommodation |
| 26 | Sewerage, waste management, remediation industries | 58 | Creative, arts and entertainment industries; libraries, archives, museums and other cultural industries; gambling and betting industries |
| 27 | Construction | 59 | Sports industries and amusement and recreation industries |
| 28 | Wholesale and retail trade and repair of motor vehicles and motorcycles | 60 | Industries of membership organisations |

(*Continued*)

**Table A2.** (Continued).

| No. | Activity | No. | Activity |
| --- | --- | --- | --- |
| 29 | Wholesale trade, except of motor vehicles and motorcycles | 61 | Repair of computers and personal and household goods |
| 30 | Retail trade, except of motor vehicles and motorcycles | 62 | Other personal service industries |
| 31 | Land transport and transport via pipelines | 63 | Industries of households as employers; undifferentiated goods- and services-producing industries of households for own use |
| 32 | Water transport | | |

## Appendix B: The specification of the MODEL model

| Set | |
|---|---|
| t | Time period |
| T | Terminal period |
| a, aa | Activity |
| i, j | Commodity |
| h, hh | Private Institutional Sectors (Households, NPISH, Financial and Non-Financial firms) |
| g | Public Administration |
| row | Rest of World |
| l,ll | Labour type |

| Exogenous parameters | |
|---|---|
| $\sigma_{out} = 0$ | Elasticity of substitution between intermediate goods and value added |
| $\sigma_{BI} = 0$ | Elasticity of substitution among intermediate goods |
| $\sigma_{VA} = 0.582$ | Elasticity of substitution between Low–Medium-skilled labour and High-skilled labour and capital (Van Der Werf 2008) |
| $\sigma_{HK} = 0.582$ | Elasticity of substitution between High-skilled labour and Capital |
| $\sigma_{LM} = 1.667$ | Elasticity of substitution between low-skilled and medium-skilled labour |
| $\sigma_{edu} = 0$ | Elasticity of substitution between Low–Medium and High-educated labour |
| $\sigma_{pc} = 0$ | Elasticity of substitution between PC-use and no-PC-use |
| $\sigma_{mf} = 0$ | Elasticity of substitution between male and female labour |
| $\sigma_{q} = 0$ | Elasticity of substitution between principal and secondary productions |
| $\sigma_{IM1,2} = 0.5$<br>$\sigma_{IM3,4,10} = 0.2$<br>$\sigma_{IM5-9,11-26} = 0.3$<br>$\sigma_{IM27} = 0.4$<br>$\sigma_{IM28-53} = 0.6$<br>$\sigma_{IM54-63} = 0.3$ | Elasticity of substitution between domestic and imported commodities. It is commodity specific. |

(*Continued*)

(Continued).

| | |
|---|---|
| $\sigma_I = 1$ | Elasticity of substitution among investment commodities |
| $d_a^D$ | Share parameter in the output production function |
| $\gamma = 1$ | Capital productivity |
| $EXR^t = 1$ | Nominal exchange rate |
| $pwm_i^t$ | Price of foreign goods |
| $pm_i^t$ | Price of imported goods |
| $L^{st}_h$ | Labour endowment by Institutional Sector |
| $L^{st}_{row}$ | Labour supply from Rest of World |
| $K^{st}_h$ | Capital endowment by Institutional Sector |
| $K^{st}_g$ | Capital endowment of Government |
| $K^{st}_{row}$ | Capital supply from Rest of World |
| $KS_0$ | Initial capital stock |
| $Tr_g$ | Transfers from Government |
| $Tr_{row}$ | Transfers from Rest of World |
| $G_g^t = \sum_i g_{i,g}^t$ | Government consumption bundle |
| $S_g^0$ | Government saving/deficit |
| $Y_{row}^t$ | Disposable income of Rest of World |
| $S_{row}^t$ | Savings of Rest of World |
| Endogenous Variables | |
| $X_a^t$ | Total output by activity |
| $BI_a^t$ | Intermediate goods aggregate |
| $Pbi_a^t$ | Price of intermediate goods aggregate |
| $bi_{i,a}^t$ | Intermediate good demand by activity |
| $VA_a^t$ | Value added |
| $Pva_a^t$ | Price of value added |
| $PHK_a^t$ | Price of High-skilled labour and Capital aggregate |
| $PML_a^t$ | Price of low- and medium-skilled labour |

(*Continued*)

(Continued).

| | |
|---|---|
| $plm^t$ | Price of medium-skilled labour |
| $pll^t$ | Price of low-skilled labour |
| $pl_{l,t}$ | Salary by labour type |
| $P_i^t$ | Price of goods |
| ${L^d}^t_{l,a}$ | Labour demand by typology and activity |
| ${K^d}^t_a$ | Capital demand by activity |
| $KS_t$ | Capital stock |
| $rk_t$ | Rent of capital |
| $pk_t$ | Price of capital |
| $Pq_i^t$ | Domestic price of goods |
| $IM_i^t$ | Imports by goods |
| $Pa_a^t$ | Price of total output by activity |
| $YF_h^t$ | Income from primary factors by Institutional Sectors |
| $Y_h^t$ | Disposable Income by Institutional Sector |
| $Y_h$ | Global disposable Income by Institutional Sector |
| $YF_g^t$ | Government Income from primary factors |
| $Y_h^t$ | Government disposable income |
| $Y_g$ | Government Global disposable income |
| $C_h^t$ | Aggregate consumption by Institutional Sector |
| $S_h^t$ | Savings by Institutional Sectors |
| $S_g^t$ | Government savings |
| $S_{row}^t$ | Savings of Rest of World |
| $U_h$ | Intertemporal Utility by Institutional Sector |
| $Pu_h$ | Price of utility by Institutional Sector |
| $Pc_h^t$ | Index price of the consumption bundle by Institutional Sector |
| $p_I^t$ | Index price of Investment |
| $def_g^t$ | Change in Government deficit |

(*Continued*)

(Continued).

| | |
|---|---|
| $I_i^t$ | Demand of goods for Investment |
| Equations | |
| $X_a^t = \left(d_a^D BI_a^{t\,\rho_D} + \left(1 - d_a^D\right) VA_a^{t\,\rho_D}\right)^{\frac{1}{\rho_D}}$ | 1a |
| $Pa_a^t = \left(\delta_a^D Pbi_a^{t\,(1-\sigma_{out})} + \left(1 - \delta_a^D\right) Pva_a^{t\,(1-\sigma_{out})}\right)^{\frac{1}{(1-\sigma_{out})}}$ | 1b |
| $BI_a^t = \delta_a^D \cdot X_a^t \cdot \left(\frac{Pa_a^t}{Pbi_a^t}\right)^{\sigma_{bi}}$ | 2 |
| $VA_a^t = \left(1 - \delta_a^D\right) \cdot X_a^t \cdot \left(\frac{Pa_a^t}{Pva_a^t}\right)^{\sigma_{out}}$ | 3 |
| $Pbi_a^t = \left(\sum_i \delta_{i,a}^{BI} P_i^{t\,(1-\sigma_{BI})}\right)^{\frac{1}{(1-\sigma_{BI})}}$ | 4 |
| $bi_{i,a}^t = \delta_{i,a}^{BI} \cdot X_a^t \cdot \left(\frac{Pbi_a^t}{P_i^t}\right)^{\sigma_{BI}}$ | 5 |
| $Pva_a^t = \left(\delta_a^{HK} PHK^{t\,(1-\sigma_{va})} + \left(1 - \delta_a^{HK}\right) PML^{t\,(1-\sigma_{va})}\right)^{\frac{1}{(1-\sigma va)}}$ | 6 |
| $PHK^t = \left(\gamma \cdot \delta_a^K rk_t^{\,(1-\sigma_{HK})} + \left(1 - \delta_a^K\right) pHL_t^{\,(1-\sigma_{HK})}\right)^{\frac{1}{(1-\sigma_{HK})}}$ | 7 |
| $PML^t = \left(\delta_a^M plm^{t\,(1-\sigma_{ML})} + \left(1 - \delta_a^M\right) pll^{t\,(1-\sigma_{ML})}\right)^{\frac{1}{(1-\sigma_{ML})}}$ | 8 |
| $ML_a^d t = (1 - \delta_a^{HK}) \cdot VA_a^t \cdot \left(\frac{Pva_a^t}{PML_t}\right)^{\sigma_{va}}$ | 9 |
| $HK_a^d t = \delta_a^{HK} \cdot VA_a^t \cdot \left(\frac{Pva_a^t}{PHK_t}\right)^{\sigma_{va}}$ | 10 |
| $K_a^d t = \delta_a^K \cdot HK_a^t \cdot \left(\frac{PHK_t}{rk_t}\right)^{\sigma_{HK}}$ | 11 |
| $HL_a^d t = (1 - \delta_a^K) \cdot HK_a^t \cdot \left(\frac{PHK_t}{pHL_t}\right)^{\sigma_{HK}}$ | 12 |
| $LM_a^d t = \delta_a^M \cdot ML_a^t \cdot \left(\frac{PML_t}{plm_t}\right)^{\sigma_{ML}}$ | 13 |
| $LL_a^d t = \left(1 - \delta_a^M\right) \cdot ML_a^t \cdot \left(\frac{PML_t}{pll_t}\right)^{\sigma_{ML}}$ | 14 |
| $pl_{l,t} = \left(-\varepsilon_{npl,l} \cdot u_{l,t} \cdot b - \frac{a}{1+t}\right) \cdot \frac{1}{1+\varepsilon_{npl,l} \cdot u_{l,t}}$ | 15 |
| $\varepsilon_{npl,l} = \sum_{s=1}^{n} -\sigma_s \Phi_s \cdot \prod_{v=1}^{s-1} (1 - \Phi_v)$ | 16 |
| $X_a^t = \left(\sum_i \delta_{a,i}^q q_{i,a}^t\right)^{\frac{1}{(1-\sigma_q)}}$ | 17 |
| $P_i^t \left(1 - \sum_{out} tq_i^{out}\right) = \left(\delta_i^O Pq_i^{t\,(1-\sigma_M)} + \left(1 - \delta_i^O\right) Pm_i^{t\,(1-\sigma_M)}\right)^{\frac{1}{(1-\sigma_M)}}$ | 18 |
| $Pm_i^t = pwm_i^t (1 + \pi^t)/EXR^t$ | 19 |
| $Pq_i^t = \left(\sum_a \delta_{i,a}^q Pa_a^{t\,(1-\sigma_q)}\right)^{\frac{1}{(1-\sigma_q)}}$ | 20 |
| $IM_i^t = \left(1 - \delta_i^O\right) \cdot Q_i^t \cdot \left(\frac{P_i^t}{Pm_i^t}\right)^{\sigma_M}$ | 21 |
| $YF_h^t = \left[L^{s\,t}_{h,l} pl_{l,t} + K^{s\,t}_{h} rk_t\right]$ | 22 |
| $Y_h^t = YF_h^t \left(1 - \sum_{inc} ty_h^{inc} - \sum_{tras} tr_h^{tras}\right) + \sum_{hh} \sum_{tras} tr_{hh}^{tras} YF_{hh}^t + \sum_g Tr_g^t + Tr_{row}^t$ | 23 |
| $Y_h = \sum_{t=1}^{T} Y_h^t \cdot \left(\frac{1}{1+r}\right)^t + KS_h^{tfirst} \cdot pk^{tfirst} - KS_h^T \cdot pk^T \cdot \left(\frac{1}{1+r}\right)^T$ | 24 |
| $pk^t = (1 - \tau) \cdot pk^{t+1} + rk_t$ | 25 |
| $I^{tfirst} = \frac{(\tau+g) \cdot \sum_h K^{s\,tfirst}_h \cdot rk_{tfirst}}{(\tau+r)}$ | 26 |

(*Continued*)

(Continued).

| | |
|---|---|
| $\tau = \frac{g \cdot \sum_h K{s}_h^{tfirst} \cdot rk_{tfirst} - r \cdot I^{tfirst}}{I^{tfirst} - \sum_h K{s}_h^{tfirst} \cdot rk_{tfirst}}$ | 27 |
| $YF_h^t = K{s}^t_h \cdot rk_t$ | 28 |
| $YF_g^t = K{s}^t_g \cdot rk_t + \sum_h \sum_{inc} ty_h^{inc} YF_h^t$ | 29 |
| $Y_g^t = YF_g^t - \sum_g Tr_g - Tr_{row}$ | 30 |
| $Y_g = \sum_{t=1}^{T} Y_g^t \cdot \left(\frac{1}{1+r}\right)^t + KS_g^{tfirst} \cdot pk^{tfirst} - KS_g^T \cdot pk^T \cdot \left(\frac{1}{1+r}\right)^T$ | 31 |
| $maxU_h = \sum_{t=0}^{T} \left(\frac{1}{1+\rho}\right)^t C_h^t$ <br> s.t. <br> $\sum_h C_h^t = \sum_i Q_i^t - \sum_i \sum_a bi_{i,a}^t - \sum_g G_g - \sum_i I_i^t - \sum_i e_i^t$ <br> $KS_{t+1} = KS_t(1-\tau) + I_t \ \sum_{t=0}^{T} \left(\frac{1}{1+\rho}\right)^t C_h^t \cdot Pc_h^t = Y_h$ | 32 |
| $Pu_h = \prod_t \left(\frac{Pc_h^t}{1+r}\right)^{alpha(t)}$ | 33 |
| $alpha(t) = \frac{\left(\frac{1+g}{1+r}\right)^{t-1}}{\sum_t \left(\frac{1+g}{1+r}\right)^{t-1}}$ | 34 |
| $C_h^t = \frac{U_h}{1+r} \cdot \left(\frac{Pu_h}{Pc_h^t \cdot (1+r)}\right)^{alpha(t)}$ | 35 |
| $Pc_i^t = \left(\sum_i \delta_{i,h}^C \cdot P_i^{t\,(1-\sigma_C)}\right)^{\frac{1}{(1-\sigma_C)}}$ | 36 |
| $c_{i,h}{}^t = \delta_{i,h}^C \cdot U_h \cdot \left(\frac{Pc_i^t}{P_i^t}\right)^{\sigma_C}$ | 37 |
| $U_g = \sum_{t=0}^{T} G_g^t + def_g^t$ | 38 |
| $p_I{}^t = \left(\sum_i \delta_i^I \cdot P_i^{t\,(1-\sigma_I)}\right)^{\frac{1}{(1-\sigma_I)}}$ | 39 |
| $I_i^t = \delta_i^I \cdot I^t \cdot \left(\frac{p_I{}^t}{P_i^t}\right)^{\sigma_I}$ | 40 |
| $e_i^t = \delta_i^E \cdot Y_{row}^{tfirst} \cdot (1+g_{row})^t \cdot \left(\frac{pwm_i^t(1+\pi^t)/EXR^t}{P_i^t}\right)^{\sigma_e}$ | 41 |
| $Q_i^t = \sum_a bi_{i,a}^t + \sum_h c_{i,h}^t + \sum_g g_{i,g}^t + I_i^t + e_i^t$ | 42 |
| $\sum_i I_i^t = \sum_h S_h^t + \sum_g S_g^t + S_{row}^t$ | 43 |
| $\sum_i IM_i^t + \sum_h tr_h^{tras} \cdot YF_h^t + \sum_g Tr_g^{row} + L_{row,l}^s pl_{l,t} + K{s}^t_{row} rk_t = \sum_i e_i^t + \sum_h YF_h^t \cdot tr_h^{row} + \sum_g Tr_{row} + S_{row}^t$ | 44 |
| $\sum_a L{d}^t_{a,l} = \sum_h \left(1-u_{l,t}\right) L{s}^t_{h,l} + L{s}^t_{row,l}$ | 45 |
| $\sum_a K{d}^t_a = \sum_h K{s}^t_h + \sum_g K{s}^t_g + K{s}^t_{row}$ | 46 |
| $\frac{\sum_i I_i^T}{\sum_i I_i^{T-1}} = \frac{\sum_i Q_i^T}{\sum_i Q_i^{T-1}}$ | 47 |