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Abstract

Innovation fosters economic growth and the long-run dynamics of national economies. However, recent literature shows that innovation is also a source of increasing income inequalities. Public policies face thus an important trade-off between efficiency and equity effects of innovation. What are the possible policy strategies to address this trade-off? The paper presents a model in which innovations can be developed by both private firms and public companies. Technological change increases the profit share in the long-run, exacerbating income inequalities between firms' owners, employed workers, and the unemployed. I empirically calibrate the model for the US economy and carry out a simulation analysis to investigate the effects of different policies aimed at reducing the inequality effects of innovation. Specifically, the analysis compares two distinct policy strategies: one is based on a standard economic policy approach that increases taxes to finance welfare spending; the other is based on a new approach – the Entrepreneurial State – in which the profits of innovations developed by public R&D companies are used to finance welfare programs. The results point out the advantages and drawbacks of different strategies and show that the optimal policy strategy largely depends on the policy maker's preferences regarding the income distribution.

JEL codes: O30; O33; O40; O41; I38; D63

Key words: Innovation; income inequalities; labor share; public policies; Entrepreneurial State; public R&D.

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1 Introduction

Innovation research has traditionally studied the positive effects that technological change has on economic performance (productivity, economic growth, and international competitiveness). However, the process of Schumpeterian creative destruction inherently generates winners and losers, affecting the relative position of economic agents in the income distribution. Until recently, though, there has been scant research on the negative effects that innovation may have on income inequalities (Madsen et al., 2021).

This topic has now begun to attract increasing attention. Recent literature investigates automation technologies and how these affect labor demand and wage inequalities between workers that have different skills and perform different tasks (Acemoglu and Restrepo, 2018). Another strand of research shows that innovation fosters monopoly rents of incumbents, strengthening top-income inequalities (Aghion et al. 2019) and contributing to the decline in the labor share (Autor et al., 2020).

The fact that technological change has positive effects on the economic performance of national systems while also having negative consequences in terms of income inequalities presents an important trade-off for policy-makers. From a normative standpoint, how should we assess the trade-off between the efficiency and equity effects of innovation, and what should public policies do to address this? This important question is seldom considered in extant research. Some recent studies discuss possible policies that may tackle the negative effects of automation on wage inequalities (e.g. Berg et al., 2021), and others have begun to investigate whether and how public authorities should regulate AI (Acemoglu and Lensman, 2023). With a few exceptions, though, the normative dimension of the innovation-inequalities relation represents an important theme that calls for further research.

Motivated by this question, the present paper seeks to investigate how different public policies may address the inequality effects of innovation. This question is paramount and timely. The pace of innovation is increasingly rapid, and new technological advances that we observe today have the potential to lead to pervasive socio-economic transformations. While these technological advances unfold rapidly, it is therefore crucial to develop a conceptual framework that enables policy-makers to implement an appropriate and inclusive policy strategy to cope with these transformations.

To study this question, the paper presents a theoretical model in which innovation fosters monopoly rents of R&D firms, increasing the profit share earned by capitalists (firms' owners) and lowering the labor share of employed workers. Inspired by Aghion et al. (2019), the model focuses on income inequalities in terms of the labor share, i.e. it studies how innovation leads to changes in the functional distribution of income between capitalists, employed workers, and the unemployed.[1] However, to investigate the role of public policies, the model also draws insights from recent models of automation and policy that consider a variety of public spending and fiscal measures that can alleviate the inequality effects of technological change (Loebbing, 2019; Prettner and Strulik, 2020; Jaimovich et al., 2021; Berg et al., 2021; Thuemmel, 2022; Guerrero et al., 2022; Costinot and Werning, 2023). Compared to these recent works, the specific novelty of the present

[1] The decline in the labor share has been related to several possible explanatory factors, in addition to technological change, such as sectoral shifts and transformations, globalization, institutional changes in the labor market, changes in product market competition policies and regulation, financial deepening, and privatization of public companies (Grossman and Oberfield, 2022). The decline in the labor share is closely related to the rising income inequalities that many advanced economies have experienced in recent years (ILO et al., 2015).

model is the following. I posit that public R&D companies may invest in R&D and develop new blueprints (vertical innovations), competing with private R&D companies. When public R&D companies develop innovations, the resulting profits may be retained by the State and used to finance public welfare schemes aimed at reducing the inequality effects of innovation.

The model is empirically calibrated for the US. The US economy provides a relevant case due to its rapid pace of technological progress as well as its large and rapidly increasing income inequalities. The main purpose of the calibrated model is to carry out a simulation analysis to investigate the effects of different policies aimed at reducing the inequality effects of innovation and to assess which of them are better suited to address the trade-off between efficiency and equity.

Specifically, the analysis seeks to compare two different policy approaches. One is standard: the Government introduces welfare schemes targeting the unemployed, such as spending transfers and education policies, and it finances the additional public spending by means of higher taxes. The other is a new policy approach that the present paper puts forward. I call it the *Entrepreneurial State* approach because it resembles some of the main ideas that were recently introduced in the literature originated by Mazzucato's (2013) book. The main idea of the Entrepreneurial State approach is that public R&D is important because it is able to carry out long-run risky investments to develop new science and technologies in societally relevant directions (Mazzucato, 2013; Dosi et al., 2023). Based on this general idea, the present paper extends this approach and argues that the profits that public R&D companies obtain by developing and commercializing innovations may also represent an additional source of public revenues, which the Government can use to finance welfare and redistribution schemes that reduce the inequality effects of innovation. In short, the new policy approach proposed in the paper intends to create a direct link between a more active engagement of public companies in R&D markets, on the one hand, and the policies to reduce income inequalities, on the other.[2]

The simulation analysis considers a variety of policy packages that specify further these two policy approaches, i.e. comprising different combinations of welfare policies financed by different types of tax increases and other sources of public revenues. The results of this comparison are twofold. A first main result is that – when I define social welfare as a simple utilitarian function that sums up all agents' utility without imposing preferences for any specific social group – the Entrepreneurial State policy approach performs better than all other policy packages because it leads at the same time to an improvement in the relative position of unemployed workers, lower inequalities between employed workers and capitalists, as well as higher efficiency and GDP per capita growth. The better performance of the new policy approach compared to the other policy packages is due to the fact that, by using the innovation profits of public R&D companies to finance welfare schemes, it does not incur in distortionary effects related to tax increases, and it does therefore enable to achieve a better balance between redistribution and growth objectives.

[2]There is extensive literature on State-owned enterprises (SOEs), highlighting among other things their important contribution to financing welfare and social programs (e.g. Lin et al., 2001). Recent research shows also that SOEs are often actively engaged in R&D and advanced knowledge production (Meissner et al., 2019), and that they have been important for innovation and knowledge diffusion in developing and transition economies, such as China, Brazil and Russia (Girma et al., 2009). There are also important examples of the relevant role that SOEs have played in R&D markets in European economies, such as the French-Italian public companies STMicroelectronics and Thales Alenia Space (Benassi and Landoni, 2019).

However, a second and more general result extends the first one. When social welfare is instead defined by assigning different weights to capitalists, employed workers, and the unemployed (hence considering some of these groups more important than others for national social welfare), the benefits and costs of the different policy approaches vary with the policy maker's distributional preferences. In this more general case, the Entrepreneurial State policy approach becomes progressively less appealing and more costly for the society if the group of capitalists is regarded as more important than the group of employed workers according to the Government's preferences. In short, the overall conclusion is that there is no clear first-best policy to reduce the inequality effects of innovation, because what the best policy is largely depends on the policy maker's distributional preferences.

The paper makes two contributions to extant research. First, it contributes to ongoing research on innovation and inequalities by shifting the focus to the normative dimension and investigating how different public policies may reduce income inequalities effects of innovation and address the trade-off between efficiency and equity. In particular, the work points out the important role of public R&D companies and suggests that the profits of these may represent an important new additional channel to finance public welfare schemes. Second, the study contributes to the current debate on the Entrepreneurial State by considering an important societal challenge or 'mission' – the reduction of income inequalities – that has not yet been studied in this literature. This extension is important because, ideally, an Entrepreneurial State should not only seek to direct technological change in specific societally relevant directions, but it should also make sure that these directions will promote a more equal and more inclusive society.

The paper is organized as follows. Section 2 will present the model. Section 3 will provide information on the empirical calibration. Section 4 will present and discuss the results of the policy simulation analysis. Section 5 will illustrate how the effects of the various policies change when the policy-maker has different preferences regarding income distribution. Section 6 will conclude, summarize the main results and contributions, and briefly discuss possible future extensions of this line of research. An Online Appendix will provide additional material.

2 The model

2.1 Related models

Table A1 in the Online Appendix presents an overview of the theoretical works that are more closely related to the present model. The model is based upon and it combines features from two strands of modelling research. The first is represented by endogenous growth models in which innovation fosters top-income inequalities and affects the functional income distribution. Specifically, Aghion et al. (2019) present an endogenous growth model in which intermediate goods producers invest in R&D to develop vertical innovations that increase the productivity of final goods production. When new innovations are introduced, entrepreneurs increase their profits and income share, whereas workers increase their income in absolute terms but decrease their share *vis-à-vis* entrepreneurs. Our model follows Aghion et al. (2019)'s description of R&D and their focus on the effects of vertical innovations on the functional income distribution.

The second strand of research is a set of recent models on automation and policy (Loebbing, 2019; Prettner and Strulik, 2020; Jaimovich et al., 2021; Berg et al., 2021;

Thuemmel, 2022; Guerrero et al., 2022; Costinot and Werning, 2023). These models do not provide an explicit modeling of the R&D sector (except Prettner and Strulik, 2020) and instead focus on technical change represented by automation. Inspired by the seminal work of Acemoglu and Restrepo (2018), these models feature workers' heterogeneity (in terms of skills and/or tasks) and a CES production function in which robots progressively substitute low-skilled workers. The main focus in this approach is the study of the effects of automation on wage inequalities, particularly between high- *versus* low-skilled workers, and of how different public policies (welfare spending and tax reforms) can attenuate the impacts of innovation on such inequalities. The present paper follows this type of models in two respects: (1) it considers automation and workers' heterogeneity in addition to R&D and innovation as in Aghion et al. (2019); (2) it focuses on how public policies can deal with the inequality effects of innovation.

Compared to previous works, the present model will study the following idea. Public companies compete with private firms in the R&D market. When public R&D companies develop and commercialize new innovations, the resulting profits may be retained by the State and used to finance public welfare schemes aimed at reducing the inequality effects of innovation. The recent work of Dosi et al. (2023) does also model public R&D companies in the context of an Entrepreneurial State, but it focuses on their ability to develop new technological trajectories and the related growth effects. By contrast, the present model seeks to investigate the ways in which public R&D companies may contribute to address inequality effects of innovation.

2.2 Households

There are N_H households in the economy. Preferences of individual i at time t are:[3]

$$U_i = C_i - \frac{LS_i^{1+\frac{1}{\epsilon}}}{1+\frac{1}{\epsilon}} \tag{1}$$

Equation (1) is a standard quasi-linear utility function in which U_i denotes i's utility level, C_i is consumption, LS_i is labor supply, and parameter ϵ is a constant labor supply elasticity ($\epsilon > 0$; see Thuemmel, 2022; Jacobs and Thuemmel, 2022; Costinot and Werning, 2023). In this formulation, individual utility is positively related to consumption and negatively related to the amount of working time. Each individual works LS_i units of time and earns labor income based on the wage level W_i. Wages are heterogeneous (as explained later in the labor market section of the model). Gross labor earnings (GE_i) at time t are:

$$GE_i = W_i \cdot LS_i \tag{2}$$

The government imposes linear income labor taxes TI.[4] Hence net labor income (net earnings) of individual i is:

$$NE_i = W_i \cdot LS_i - TI \cdot GE_i \tag{3}$$

and the agent's budget constraint is:

[3] I omit the time index t in the presentation of the model for simplicity.

[4] As explained later in section 4, in some of the policy experiments I have also considered non-linear income taxes that make the fiscal system more progressive by imposing a higher tax rate on workers that have higher wage.

$$C_i = GE_i \cdot (1 - TI) \tag{4}$$

At any time t, individuals maximize the utility function (1) by choosing optimal labor supply, taking wage rates and labor income taxes as given, under the budget constraint noted in (4). The first order conditions lead to the following optimal level of labor supply:

$$LS_i = [W_i(1 - TI)]^{\epsilon} \tag{5}$$

Hence, an individual's labor supply in any period is a positive function of its wage level and a negative function of the tax rate on labor income TI.

2.3 Final Goods Sector

The supply-side of the economy is composed of two sectors: final goods producers and R&D firms. In the final goods (FG) sector, there are N_{FG} firms. FG firms are homogeneous, and the sector is characterized by perfect competition. FG firms employ labor and capital machineries to produce goods and services for final consumption. Following Acemoglu and Restrepo (2018), I model each FG firm's production using a CES (constant elasticity of substitution) task-based production function:

$$Y_{FG} = ALK\left[LTS(N;I) \cdot (AL \cdot L)^{\frac{\sigma-1}{\sigma}} + KTS(N;I) \cdot (AK \cdot K)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{6}$$

In the task-based production function (6), L is labor employed in production, K is capital machineries that are rented and employed in production,[5] σ is the elasticity of substitution between K and L, AL is labor productivity, AK is capital productivity, and ALK is total factor productivity. As elaborated by Acemoglu and Restrepo (2018), the main idea of the task-based production is that at any time t, a share of production tasks can be carried out by labor ($LTS(N, I)$: the *labor task content of production*), and the remaining share of tasks will be automated and carried out by machines ($KTS(N, I)$: the *capital task content of production*). Both LTS and KTS are defined between 0 and 1. The labor and capital task contents of production change over time. At any given time t, these shares depend on two variables: N, which is the number of tasks that can be carried out by labor, and I, which is the *automation threshold*. I is the threshold level of skills that a worker must have in order to be able to carry out production tasks. If a worker's skill level S_i is below this threshold, the worker will not be employed by firms. The automation threshold is endogenous, and it depends on the costs of labor (W) and capital (R) respectively.[6] Regarding the variable N, this may also change over time as a consequence of technological change because innovations will create new tasks that can be performed by skilled workers. In short, increases in I widen the number of tasks that can be done by machines (automation); and increases in N represent the creation of new complex tasks that can be done by skilled labor (e.g. creation of new skilled jobs that

[5]For simplicity, I assume that capital K is exogenously available, and that it can be rented at a fixed rental price R. Hence, innovations (production of new blueprints) will affect the quality or productivity of existing capital, but they will not be embodied in new vintages of capital.

[6]Specifically, Acemoglu and Restrepo (2018: 1496) show that the automation threshold is such that the effective cost of labor must equal the cost of capital. This means that the automation threshold increases with W (more expensive labor fosters automation), decreases with AL (more productive labor makes automation less convenient), and decreases with R (more expensive capital makes automation less convenient).

did not exist before). From now on, I will drop for simplicity the notation $(N; I)$ and simply denote the labor and capital task contents as LTS and KTS.

In this model, workers have heterogeneous skill levels. Workers' skill levels S_i are randomly drawn from a uniform probability distribution at time t_0. At any time t, workers are divided into two groups: skilled workers that are able to carry out production tasks ($I < S_i < N$) and unskilled workers whose skill level is not sufficient to carry out production tasks ($0 < S_i < I$) and that will therefore be displaced by machines. At any time, there are N_S skilled workers that are employed in production and N_{UN} unskilled workers that are unemployed.

Although skill levels are randomly drawn at the beginning of the model, these can change over time for two reasons. First, for skilled workers, the skill level increases over time when N increases, i.e. when automation creates new tasks:

$$S_{i,t+1} = S_{i,t} + \alpha_N \cdot \sum B_{RD,t} \tag{7}$$

The growth of the skill level S_i is a linear function of the amount of new blueprints B_{RD} produced by the R&D sector in a period (that will be defined further in the next sub-section). The parameter α_N denotes the elasticity of skills with respect to the R&D stock. Equation (7) represents the idea that technological change will lead to the creation of new tasks, and these will in turn lead to skill upgrading of workers employed in production (i.e. due to learning by doing mechanisms related to new job tasks). Second, for unskilled workers that are unemployed, the Government has a welfare policy that provides re-training activities (this will be further explained in the Government's sub-section below). When this policy is active, unemployed workers that benefit from re-training activities will be randomly assigned a new skill level, and if the latter is above the automation threshold, they will find a new job.

In summary, in line with Acemoglu and Restrepo (2018)'s framework, the task-based production function noted in (6) outlines five distinct types of technological change: (i) *substitution effect*: increases in I decrease the share of tasks done by L *vis-à-vis* K; (ii) *creation of new tasks*: increases in N increase the tasks to be done by L; (iii) *labor-augmenting*: increases in A_L that foster productivity for all tasks done by L; (iv) *capital-augmenting*: increases in A_K that foster productivity for all tasks done by K; (v) *total factor productivity growth*, which increases productivity for both L and K.

As noted above, the substitution effect (i) is endogenously determined by relative factor prices. As for the other four types of technological change, the model posits that they are a function of the stock of new blueprints $B_{RD,t}$ that are produced by R&D firms at time t (and that will be defined further in the next sub-section):

$$\frac{\partial N}{\partial A} = \alpha_N \cdot \sum B_{RD,t} \tag{8}$$

$$\frac{\partial AL}{\partial A} = \alpha_{AL} \cdot \sum B_{RD,t} \tag{9}$$

$$\frac{\partial AK}{\partial A} = \alpha_{AK} \cdot \sum B_{RD,t} \tag{10}$$

$$\frac{\partial ALK}{\partial A} = \alpha_{ALK} \cdot \sum B_{RD,t} \tag{11}$$

The four parameters $\alpha_N, \alpha_{AL}, \alpha_{AK}, \alpha_{ALK}$ measure the effects of changes in the stock of new blueprints on each of the four components (or directions) of technological change.

Hence, changes over time in the four technology parameters of the task-based production function are defined as follows:

$$N_t = N_{t-1} + \alpha_N \cdot \sum B_{RD,t} \tag{8'}$$

$$AL_t = AL_{t-1} + \alpha_{AL} \cdot \sum B_{RD,t} \tag{9'}$$

$$AK_t = AK_{t-1} + \alpha_{AK} \cdot \sum B_{RD,t} \tag{10'}$$

$$ALK_t = ALK_{t-1} + \alpha_{ALK} \cdot \sum B_{RD,t} \tag{11'}$$

In short, the new blueprints produced in the R&D sector that are used as input by FG firms affect the task-based production function in the final goods sector by changing one or more of the components of the vector A: $[N, A_L, A_K, A_{LK}]$. The advantage of this approach is that it combines insights from the endogenous growth model with vertical innovations of Aghion et al. (2019) and the task-based modeling approach introduced by Acemoglu and Restrepo (2018) and used in different forms in the recent automation and policy modeling literature (Loebbing, 2019; Prettner and Strulik, 2020; Jaimovich et al., 2021; Berg et al., 2021; Thuemmel, 2022; Guerrero et al., 2022; Costinot and Werning, 2023). The formulation adopted here is quite flexible, and it makes it possible to analyze the effects of R&D on different directions of technological change.[7]

I now consider the problem of final good producers and derive optimal conditions for this type of firm. For each FG firm, net profits Π_{FG} are given by revenues minus production costs. The latter consist of labor costs to hire workers, rental costs for capital machineries, costs to purchase innovations from the R&D sector, and linear taxes on profits. Hence, net profits are:

$$\Pi_{FG} = (1 - TP)\left(Y_{FG} \cdot P_{FG} - L_{FG} \cdot W_{FG} - K_{FG} \cdot R - B_{FG} \cdot P_B\right) \tag{12}$$

where Y_{FG} is the demand for goods faced by each FG firm; P_{FG} is the price of final goods, which I set to 1 for simplicity (a *numeraire*); L_{FG} is labor; W_{FG} is wage level in the FG sector; K_{FG} is capital; R is rental price of capital; B_{FG} is the number of blueprints that the FG firm purchases from the R&D sector; P_B is the cost of a blueprint produced by R&D firms; and TP is the profit tax rate defined as a fixed proportion of profits (linear profit tax as in Jaimovich et al., 2021). To maximize profits Π_{FG}, the final goods firm chooses inputs L_{FG}, K_{FG} and B_{FG} subject to the production technology (6), taking wage level, rental cost, prices of blueprint, profit tax rate, and demand for goods Y_{FG} as given. Regarding the latter, since the market is competitive, total demand for each FG firm is an nth fraction of the total demand of consumers:

$$Y_{FG} = \frac{\sum C_i}{N_{FG}} \tag{13}$$

Since sector FG is perfectly competitive, firm's profit must be zero in equilibrium. The first-order conditions for FG firms are:

[7] To simplify this multidimensional representation of technological change, I have initially set up a baseline model in which these four parameters are 0, meaning that the creation of new blueprints does not have any direct effect on the automation process and on the productivity parameters. Subsequently, simulation analyses have considered changes in each of these four components of A, while keeping the others fixed. Hence, in different simulations, I have analyzed the effects of different types of technological change by varying the four parameters $\alpha_N, \alpha_{AL}, \alpha_{AK}, \alpha_{ALK}$.

$$\frac{\partial \Pi_{FG}}{\partial L_{FG}} = 0 \quad \Rightarrow \quad \frac{\partial Y_{FG}}{\partial L_{FG}} = W_{FG} \tag{14}$$

$$\frac{\partial \Pi_{FG}}{\partial K_{FG}} = 0 \quad \Rightarrow \quad \frac{\partial Y_{FG}}{\partial K_{FG}} = R \tag{15}$$

$$\frac{\partial \Pi_{FG}}{\partial B_{FG}} = 0 \quad \Rightarrow \quad \frac{\partial Y_{FG}}{\partial B_{FG}} = P_B \tag{16}$$

To obtain analytical solutions, I analyze the model for the simplified case: $\frac{\sigma-1}{\sigma} = 1$.[8] The first-order conditions for labor and capital lead to the following expressions:

$$\frac{\partial \Pi_{FG}}{\partial L_{FG}} = 0 \quad \Rightarrow \quad W_{FG} = ALK \cdot AL \cdot LTS \tag{17}$$

$$\frac{\partial \Pi_{FG}}{\partial K_{FG}} = 0 \quad \Rightarrow \quad R = ALK \cdot AK \cdot KTS \tag{18}$$

Since firm's profit must be zero, the demand for blueprints may be written as:

$$B_{FG} = \frac{1}{P_B} \cdot (Y_{FG} - L_{FG} \cdot W_{FG} - K \cdot R) \tag{19}$$

Using first-order condition (14), labor demand is:

$$L_{FG} = \frac{1}{W_{FG}} \cdot (ALK \cdot LTS)\,(ALK \cdot Y_{FG} - KTS \cdot AK \cdot K) \tag{20}$$

and demand for capital is given by:

$$K_{FG} = \frac{1}{R} \cdot (ALK \cdot KTS)\,(ALK \cdot Y_{FG} - LTS \cdot AL \cdot L) \tag{21}$$

The optimal demand for labor of the FG firm is therefore:

$$L^*_{FG} = \frac{1}{W_{FG}\,(1 - KTS \cdot LTS)} \left[ALK^2 \cdot LTS \cdot Y_{FG}(AL - KTS)\right] \tag{22}$$

The optimal demand for labor is a negative function of wage level W_{FG} and a positive function of demand Y_{FG}, the labor task share LTS (dependent in turn on the automation threshold) and the productivity parameters AL and ALK. Final goods firms hire all workers they need from the available pool of skilled workers (whereas, as noted above, unskilled workers cannot be employed in production). I derive the optimal demand for capital by plugging L^*_{FG} into the demand for capital equation:

$$\begin{aligned} K^*_{FG} = \frac{1}{R\,(1 - KTS \cdot LTS)} &\left(ALK^2 \cdot KTS \cdot Y_{FG}\right) \cdot \\ \cdot \left[1 - (KTS \cdot LTS) + LTS\,(KTS \cdot A_K - A_L \cdot A_K)\right]& \end{aligned} \tag{23}$$

Finally, I derive the optimal demand for blueprints by plugging L^*_{FG} and K^*_{FG} into the demand for blueprints equation and using first-order conditions (14) and (15):

[8] This simplified case is in line with Acemoglu and Restrepo (2018), see their footnote 10, corollary 1, and appendix A and B.

$$B_{FG}^{*}=\frac{1}{P_B}\left[Y_{FG}-L_{FG}^{*}\left(ALK\cdot AL\cdot LTS\right)-K_{FG}^{*}\left(ALK\cdot A_K\cdot KTS\right)\right] \tag{24}$$

Equation (24) may also be written as a function of the technology parameters:

$$\begin{aligned} B_{FG}^{*}=\frac{1}{P_B}\cdot\{Y_{FG}-W_{FG}\left[\frac{Y\cdot ALK\cdot(AL-KTS)}{AL\cdot(1-KTS\cdot LTS)}\right]-\\ -R\left[\frac{Y\cdot ALK\cdot(1-KTS\cdot LTS)+LTS\cdot(AK\cdot KTS-AL\cdot AK)}{AK\cdot(1-KTS\cdot LTS)}\right]\} \end{aligned} \tag{25}$$

Hence, the optimal demand for blueprint is an inverse function of the blueprints' price P_B, a positive function of the demand for final goods faced by the FG firm, a negative function of the optimal levels of labor and capital, and a negative function of the productivity parameters ALK, AL, AK.

2.4 R&D Sector

The R&D sector is composed of N_{TRD} firms. R&D firms seek to develop new blueprints (disembodied technological progress) which are used as inputs in the production of final goods in the FG sector. The R&D sector is characterized by monopolistic competition, and the blueprints' price is determined as a mark-up on production costs.

Differently from previous endogenous growth models, this model has two types of R&D firms: private companies (RD) and public organizations (RD_{PUB}). Both private and public R&D companies produce new blueprints, and they compete in the R&D market to sell these blueprints to FG firms. For simplicity, I assume that public R&D companies do not produce basic or scientific knowledge, but they simply focus on the development of applied knowledge and innovation. The creation of new blueprints carried out by an R&D firm (private or public) in any period t is given by the following idea production function:

$$B_{RD,t}=\delta_t L_{RD,t} \tag{26}$$

This is a standard linear production function of blueprints (Aghion et al., 2019). $B_{RD,t}$ is the quantity of new blueprints that are produced at time t, i.e. the amount of new technological knowledge produced by each R&D firm. This is given by the product of $L_{RD,t}$, the amount of skilled labor employed in R&D (scientists), and the productivity of the R&D sector (δ_t).[9] Private and public R&D companies have the same production function of blueprints.[10] However, I allow the productivity of R&D to differ for private and public organizations. Specifically, public R&D productivity is defined as follows:

$$\delta_{PUB,t}=\frac{\delta_t}{\lambda} \tag{27}$$

[9]This standard formulation assumes for simplicity that the R&D sector does not use physical capital.

[10]Private and public R&D firms hire skilled workers (scientists, managers) from the same labor market, and paying the same wage level. Hence, skilled workers have equal incentives to work in the private or public sector. Therefore, the fact that the extra profits of public R&D firms will be used by the Government to finance welfare programs (as noted further below) does not affect skilled workers' incentives to work for public R&D companies.

The parameter λ is a discount factor that represents the possibility that public firms may be less efficient than private companies. The parameter takes values equal to or greater than 1: the higher its value, the less productive public R&D companies are *vis-à-vis* private R&D firms. In the baseline model, I will set $\lambda = 1$. In the simulation analysis, I will then vary this parameter and study its effects on the model's outcomes. [11] [12]

Among the total amount of blueprints that are produced in the R&D sector in any period t, a fraction τ is produced by private R&D firms, and the corresponding fraction $(1 - \tau)$ is produced by public R&D companies. The parameter τ represents the extent to which public R&D firms are involved in applied knowledge production. Hence, this policy parameter is meant to measure the involvement of the State in the R&D market, and therefore it is a proxy of the extent of the Entrepreneurial State in R&D markets. If $\tau = 1$, only private firms do R&D, which is the benchmark case in the baseline model. Lower values of τ represent a situation in which the Government owns some public R&D companies, meaning that it can steer their innovation activities, and so retain and make use of their innovation profits. The simulation analysis will study the effects of changes of this parameter in its range. Specifically, the policy simulation analysis will set up some policy packages in which there is a small number of public firms competing with private companies in the R&D sector, and the profits of these public R&D companies are used to finance welfare and redistribution programs, as explained further below.[13]

The total stock of technological knowledge at any time t is the sum of the stock in the previous period and the new blueprints that are developed in the R&D sector in the

[11] There is a large empirical literature providing evidence that State-owned enterprises are in general less productive than private firms (see recent review and comprehensive evidence in Merlevede & Muylle, 2025). However, there is no systematic evidence that specifically refers to productivity in the R&D sector. Therefore, the model does not assume differential productivity from the outset, but rather studies it in the simulation analysis.

[12] Huang et al. (2023) present an endogenous growth model in which public R&D firms increase the productivity of private R&D companies through a spillover effect (so-called *personnel-interaction* mechanism). My model, for simplicity, does not consider explicitly direct interactions and spillover effects between public and private R&D activities. However, this effect is implicitly part of the model, because, as explained further below, public R&D contributes to the dynamics of the knowledge stock, which in turn fosters the productivity of private R&D over time (see equation 29 below).

[13] The reason why the share of public R&D firms in the market is modelled by means of a policy parameter and studied through simulation analysis (instead of making it an endogenous outcome of the model) is the following. When the Government wants to own a new public R&D firm, it can do so by acquiring shares of an existing private R&D company, and/or using a public holding company. This decision is rational for the social planner if the marginal benefits of setting up and managing a new public firms are higher than the marginal costs. As shown in the online appendix A3, the marginal benefit of increasing the number of public R&D companies is that the labor share increases and the functional distribution of income improves. On the other hand, the marginal cost is that GDP per capita decreases (if public companies are less productive than private R&D firms). Since there is a trade-off between the positive effects on the labor share and the negative effects on GDP per capita, in this model there is no single optimal level of τ: different values of this parameter lead to different outcomes in terms of efficiency (GDP per capita) and equity (income distribution and the labor share). Hence, the social planner's decision of whether to set up a new public company is analytically complex, because it requires a value judgment of this trade-off based on the set of social preferences adopted by the Government. To highlight this trade-off, and avoid this analytical complexity, I have chosen to model the share of public R&D firms using this policy parameter, and then study the space of outcomes and policy options by means of simulation analysis. Furthermore, it may also be considered that the Government's decision to enter the R&D market by acquiring one or more private R&D companies is a largely political decision, that is motivated by political economy dimensions that go beyond mere cost-benefit assessments (e.g. political feasibility; economic policy tradition and ideology) and that are not considered in this model.

period:

$$AT_t = AT_{t-1} + \sum B_{RD,t} \tag{28}$$

An important variable that governs the dynamics of the R&D sector over time is δ_t, which is the productivity of R&D in the idea production function (26). Productivity of R&D varies over time according to the following motion equation:

$$\delta_t = \mu \cdot AT_{t-1}^{\rho} \tag{29}$$

Equation (29) models productivity dynamics as the product of three components. The first is μ, which is the mean probability that an innovation is found (representing technological opportunities in a given historical age). This event is stochastic and it follows a normal distribution with mean μ and unit variance. The second component on the RHS of (29) is A_{t-1}, which is the total stock of knowledge A in the previous period. The third component is ρ, a parameter defined between 0 and 1 that denotes intertemporal knowledge spillovers, representing the idea that the productivity of R&D increases steadily over time as a function of the stock of knowledge in the previous period (Prettner and Strulik, 2020).[14]

The maximization problem of R&D firms is as follows. The price of a new blueprint P_B is defined as a mark-up rule over the marginal costs of the R&D firm:

$$P_B = \frac{W(1+\beta)}{\delta_t} \tag{30}$$

where $\frac{W}{\delta_t}$ are marginal costs and β is a constant mark-up parameter ($0 < \beta < 1$). The revenues of the R&D firm are:

$$R_{RD} = P_B \cdot \delta_t \cdot L_{RD} \tag{31}$$

where L_{RD} is the amount of labor employed in the production of blueprints. The costs of R&D labor sustained by the R&D firm are:

$$C_{RD} = W_{RD} \cdot L_{RD} \tag{32}$$

Similarly to the FG sector, R&D firms must also pay a profit tax, whose rate TP is the same as in the final goods sector. Further, in some of the policy experiments presented in section 3 of the paper, I have considered the possibility that the Government may also introduce a tax on R&D, which is defined as a flat tax rate TRD on R&D costs. If the R&D tax is positive, its rationale is to induce R&D firms to decrease investments in innovation. This could be done either to reduce inequalities created by innovations (e.g. in specific industrial sectors) or to slow down the creation and diffusion of some innovations that present possible societal or ethical risks (e.g. some types of artificial intelligence innovations). Considering both profit tax and R&D tax, the net profits of the R&D firm are:

$$\Pi_{RD} = (1 - TP) \cdot (P_B \cdot \delta_t \cdot L_{RD} - W_{RD} \cdot L_{RD} \cdot TRD) \tag{33}$$

[14] This spillover parameter does also implicitly incorporate the idea of imitation. When an innovator develops new knowledge, this will increase the R&D productivity in the next period, and hence all other firms' possibility to innovate (imitate) in the next periods. Hence, this is in line with Aghion et al. (2019)'s idea that imitation by new innovators will erode the lead of incumbents, reducing inequality between the two types of firms.

R&D firms maximize profits by choosing the optimal level of skilled workers L_{RD} that they seek to hire subject to the production function of blueprints (26) and taking as given the wage level of workers, the tax rate on profit, the tax on R&D (if it applies), and the demand for blueprints. Regarding the latter point, the total demand of blueprints in the economy at any time t is the sum of the blueprints demanded by FG firms (see (24) and (25)) and the blueprints demanded by the Government via public procurement (PRD; this will be specified further in the Government sub-section below). On aggregate, the total demand of blueprints must equal the total supply by R&D firms:

$$\sum_{FG=1}^{N_{FG}} B^*_{FG} + PRD = \sum_{TRD=1}^{N_{TRD}} B^*_{TRD} \tag{34}$$

As noted above, a fraction τ of this total demand is satisfied by private R&D firms, and the corresponding fraction $(1-\tau)$ is produced by public R&D firms. Assuming that each R&D firm faces the same demand for blueprints as all other firms in the sector, the demand for blueprints faced by each R&D firm is given by:

$$B^*_{RD} = \frac{\tau(\sum B^*_{FG} + PRD)}{N_{RD}} \quad \text{for private R\&D firms}$$

$$B^*_{PUB} = \frac{(1-\tau)(\sum B^*_{FG} + PRD)}{N_{PUB}} \quad \text{for public R\&D firms} \tag{35}$$

where N_{RD} is the number of private R&D firms and N_{PUB} is the number of public R&D firms (hence: $N_{RD} + N_{PUB} = N_{TRD}$). The first-order condition that maximizes the R&D firm's profits is:

$$\frac{\partial \Pi_{RD}}{\partial L_{RD}} = 0 \Rightarrow W_{RD} \cdot TRD = P_B \cdot \delta_t \tag{36}$$

that may also be written as:

$$W_{RD} \cdot TRD = P_B \cdot A^{\rho}_{t-1} \tag{37}$$

This optimality condition is similar to that in Prettner and Strulik (2020: 254). Its interpretation is that when labor costs increase (and/or if the R&D tax is positive), the R&D firm must charge a higher price of blueprint (i.e. increase the mark-up) unless such cost increase is compensated by inter-temporal knowledge spillovers and productivity growth. The optimal labor demand of the R&D firm is:

$$L^*_{RD} = \frac{B_{RD}}{\delta} = \frac{B_{RD} \cdot (1+\beta)}{\delta \cdot TRD} = \frac{P_B \cdot B_{RD}}{W_{RD} \cdot TRD} \tag{38}$$

where B_{RD} equals B^*_{RD} for private R&D firms and B^*_{PUB} for public R&D firms. Hence, the optimal demand for labor of R&D firms is a positive function of the quantity of blueprints B_{RD} that the firm seeks to produce, a positive function of the blueprint's price P_B, a negative function of the wage level W_{RD}, and a negative function of the innovation tax TRD (which, if imposed, increases R&D labor costs). Regarding public R&D companies, if these have lower productivity than private R&D firms ($\lambda > 1$; see equation (27) above), they must hire more skilled workers than private companies in order to produce a given amount of blueprints.[15]

2.5 Labor Market

As noted in section 2.3, at any time t there are N_{UN} workers that are unemployed because their skill level is below the automation threshold I, and N_S skilled workers that are employed in production either in the FG or in the R&D sector. The wage level of the N_S skilled workers is determined in the labor market through a twofold mechanism. First, a collective wage bargaining determines the average wage level. Second, each worker determines her own wage level by bargaining with the employer. Regarding the first mechanism, collective wage bargaining is based on aggregate labor supply and demand. Labor supply is the sum of individual labor supply (see equation (5) above):

$$LS = \sum_{i=1}^{N_H} LS_i = \sum_{i=1}^{N_H} [W_i(1 - TI)]^{\epsilon} \tag{39}$$

Labor demand is the sum of firms' demand for skilled workers, considering both FG and R&D firms (private and public):

$$LD = \sum_{FG=1}^{N_{FG}} L^*_{FG} + \sum_{TRD=1}^{N_{TRD}} L^*_{TRD} \tag{40}$$

The average wage of skilled workers employed in the FG and R&D sectors must be the same (otherwise all workers would seek employment in the sector that has higher wage). The average wage is determined by the equilibrium condition:

$$\sum_{i=1}^{N_H} [W_i(1 - TI)]^{\epsilon} = \sum_{FG=1}^{N_{FG}} L^*_{FG} + \sum_{TRD=1}^{N_{TRD}} L^*_{TRD} \tag{41}$$

The RHS of (41) can be rewritten as:

$$\sum_{FG=1}^{N_{FG}} \left\{ \frac{1}{W(1 - KTS \cdot LTS)} \cdot \left[ALK^2 \cdot LTS \cdot Y_{FG} \cdot (AL - KTS) \right] \right\} + \sum_{TRD=1}^{N_{TRD}} \frac{P_B \cdot B_{RD}}{W_{RD} \cdot TRD} \tag{42}$$

Since the average wage level of employed workers must respect the condition: $W_E = \frac{\sum W}{\sum_{LS_i}}$, the equilibrium level of wage at time t is:[16]

[15] If $\lambda > 1$, public R&D companies will have higher marginal costs than private R&D firms. However, public companies will not be able to sell new blueprints at a higher price than the one set by private firms (P_B), and they will therefore have lower marginal profits than private companies. In spite of their lower profitability, the Government still seeks to have public firms in the R&D market as these serve *public purpose*, i.e. because the Government wants to retain some of their profits in order to finance welfare programs (as discussed further below).

[16] To derive the analytical condition (43), I have set for simplicity $\epsilon = 1$ (see discussion in section 3 on the empirical calibration of the model). I have carried out simulation analyses to study how variations of this parameter in its range of definition affect the model's outcomes. For values of ϵ lower than 1, *ceteris paribus*, the model leads to a lower equilibrium labor share. However, the transitional dynamics and analytical properties of the model are not affected by variations in the parameter.

$$W^* = \frac{N_{FG} \cdot L_{FG} + N_{TRD} \cdot L_{RD}}{\sum L_{S_i}(1 - T_I)} \quad (43)$$

According to (43), the average wage of employed workers increases from a period to the next when labor demand increases more than labor supply. Specifically, the average wage level in the economy is a positive function of labor demand in both final goods and R&D sectors, a negative function of labor supply, and a positive function of the income tax rate TI (given that higher income taxes decrease labor supply and thus increase wages). After the average wage level in the economy is determined, individual workers' wage is set by:

$$W_i = W^* \left[1 + \eta(S_i - S_A)\right] \quad (44)$$

where S_i is worker i's skill level, and S_A is the average skill level in the economy. Equation (44) notes that workers with higher (lower) skill levels than average will get a wage that is correspondingly higher (lower) than the average wage. Parameter η represents the strength of this bargaining effect, i.e. how important the skill level is to increase or decrease a worker's wage. This parameter, defined in the range $0 < \eta < 1$, represents country-specific institutional conditions in the labor market that define the extent to which workers' skills matter for wage formation. According to (44), more skilled workers will always have higher wages than less skilled workers, even when the average wage level W^* increases or decreases over time.[17]

2.6 Government and Social Welfare

The Government can make use of different public welfare policies to take care of unemployed workers and to reduce income inequalities between firms' owners and employed workers. Specifically, the model considers the following two standard welfare schemes:

1. TSPE: Spending Education: This policy provides re-training activities for the unemployed. The size of the education transfer to each worker is a lump sum (SPE). When this policy is in place, unemployed workers, after attending publicly funded training courses at time t, can randomly draw a new skill level. Unemployed workers will then be able to find a new job at time $t+1$ with a given probability j. Hence, when this policy is in place, the unemployment rate in the economy will gradually decrease over time.

2. TSPT: Spending Transfers: This policy scheme provides basic subsistence transfers to the unemployed. The spending transfers SPT is a lump sum provided to each unemployed individual. Its amount is such that it cannot be higher than the net earnings of the employed worker that has the lowest wage. In this way, by constraining spending transfers to be low, unemployed workers will have incentives to continue to actively seek employment in the next period. Hence:

$$SPT = \theta \cdot NE_{MIN} \quad (45)$$

where NE_{MIN} is the minimum (lowest) net earnings of employed workers, and the parameter θ (defined between 0 and 1) represents the generosity of the public welfare

[17] This means that the ranking of wage among workers will be the same before and after a change in the aggregate (mean) wage level; however, the absolute difference between workers' wage will increase when the mean wage level increases. Hence, this formulation implies that wage increases will enlarge wage inequalities among workers, in line with models in the automation and policy literature.

system. The total amount of spending transfers carried out by the Government in each period t is therefore:

$$TSPT = SPT \cdot N_{UN} \tag{46}$$

In addition to these public welfare schemes, the Government has also two other types of public spending:

3. TSPRD: Public R&D Procurement: Public R&D procurement is a policy that the Government may use to foster R&D and innovations related to new technological trajectories that are considered of particular societal relevance (say, for instance, green innovations that contribute to environmental sustainability).[18] I posit that public R&D procurement is financed by the profits of public R&D firms. The underlying idea is that the introduction of public R&D firms in the economy will not only be important to reduce inequality effects of innovation, but it will also be useful to finance new innovations in socially desirable directions. $TSPRD$ is defined as:

$$TSPRD = SPP \cdot \sum \Pi_{PUB} \tag{47}$$

where $\sum \Pi_{PUB}$ denotes the total profits of public R&D firms, and SPP is a policy parameter that represents the fraction of public R&D firms' profits that are used to finance additional demand for blueprints.

4. TSPRES: Residual Public Spending: This represents all other public spending that the Government carries out in each period to finance basic education, health, infrastructures, and security and defence.

To finance the four public spending components noted above, the Government may use two approaches. A standard approach is to leverage ordinary fiscal measures, i.e. those noted in previous sections of the model: (i) income tax TI; (ii) profit tax TP; (iii) tax on R&D. The baseline version of the simulation model assumes that income and profit taxes only finance residual public spending (TSPRES); these baseline fiscal revenues must then be increased if the Government seeks to introduce and finance welfare policies.

A second approach to finance public welfare spending is *to make use of profits of public R&D firms*. This second approach is distinct but complementary to the standard approach. The basic idea is that the innovation profits that public R&D firms get when they develop and sell blueprints generate additional public resources, which the Government may, in principle, use for different purposes. Specifically, the model posits that public R&D revenues can be used in two ways: (a) they may be re-invested in the R&D sector via public procurement (TSPRD); and/or (b) they may be used to finance additional welfare spending (TSPE and TSPT). The rationale for using the profits of public R&D companies to finance welfare policies is to create *a direct link between the income inequalities that are generated as a consequence of firms' innovations, on the one hand, and the policies that seek to address these inequality effects, on the other.*[19]

[18] Public R&D procurement is considered an important policy instrument in the recent literature on the Entrepreneurial State. The rationale for this, according to Mazzucato (2013), is that "*the State should earn back a direct return on its risky investments. Such returns can be used to fund the next round of innovations, but also help cover the inevitable losses that arise when investing in high-risk areas*" (Mazzucato, 2013: 201).

[19] In many countries, parts of the profits of SOEs are in fact retained by the Government and used to finance social welfare programs (e.g. in China, see Lin et al., 2001). The specific point that is made here is that the Government may make use of the profits obtained by public R&D companies that commercialize innovations, in order to create an explicit link between the development of innovations and redistribution

Considering together the various components of public spending and public revenues noted above, the model imposes a fiscal constraint such that in any period the sum of public spending must be financed by the sum of public revenues:

$$TSPE + TSPT + TSPRD + TSPRES = T_{TI} + T_{TP} + T_{TRD} + \sum \Pi_{PUB} \tag{48}$$

Finally, the model also considers a different type of policy that the Government can implement in order to tackle the inequality effects of innovation: technology regulation (REG). Regulating technology means that policymakers, facing uncertainty about the possible negative effects that a new technology may have in the future, forbid its sale by R&D companies for a certain period of time, thus hampering the commercialization and diffusion of that type of innovation (consider, for instance, the current debate about the regulation of artificial intelligence technologies; Acemoglu and Lensman, 2023). If technology regulation is in place, profits of R&D companies will be negatively affected, since these firms produce new blueprints but they are not allowed to sell them. Note that this policy does not have a direct cost for the Government, but it presents a substantial opportunity cost for society since R&D firms' profits are reduced, negatively affecting the economy's efficiency and GDP per capita growth (as discussed in section 4 below).

The Government seeks to maximize social welfare. Social welfare is defined as a generalized (prioritarian) social welfare function (Jacobs and Thuemmel, 2022; Thuemmel, 2022):

$$SW = \sum_{i=1}^{N} \psi_i U_i \tag{49}$$

where ψ_i is the weight assigned to each individual i based on the Government's preferences for equality.[20] Since this paper focuses on the functional distribution of income, the social welfare function can be rewritten as a function of the utility of three groups of individuals: (i) capitalists (C), i.e. the owners of firms in FG and in R&D sectors; (ii) employed workers (E); (iii) unemployed workers (UN):

$$SW = \sum_{C=1}^{N_F} \psi_C U_C + \sum_{E=1}^{N_E} \psi_E U_E + \sum_{UN=1}^{N_{UN}} \psi_{UN} U_{UN} \tag{50}$$

where ψ_C, ψ_E, and ψ_{UN} are the weights assigned to each of the three groups of individuals, reflecting the relative importance that the groups have according to the Government's preferences. The groups' weights must be such that: $\psi_E + \psi_C + \psi_{UN} = 1$. The vector $[\psi_E; \psi_C; \psi_{UN}]$ thus represents the Government's preferences for equality.[21]

The Government seeks to find a combination of public spending and public revenues that maximizes social welfare (50) subject to the fiscal budget constraint (48). We discuss the Government's problem in further details in section 4.

policies that tackle their negative distributional effects.

[20] In a prioritarian social welfare function, individual weights depend on agents' position in the utility (or income) distribution, such that individuals that are in the lower part of the income distribution get higher weights than those in the upper part of the distribution (Adler and Fleurbaey, 2016; Piacquadio, 2017). Note that, in the special case in which the weights assigned to different individuals (groups) are all equal, the social welfare function becomes a simple utilitarian function, that sums up all agents' utilities without imposing any priority on some individuals or social groups.

[21] Regarding the utility levels of the three groups (U_C, U_E, U_{UN}), in the simulation analysis these are specified as a function of the corresponding income levels (net earnings).

2.7 Equilibrium Level of Labor Share

The model has four market clearing conditions: (i) Total demand for goods and services by households must equal total supply by final goods firms; (ii) Total demand of blueprints by final goods firms must equal total supply by R&D firms; (iii) Total labor supply of skilled workers must equal total labor demand by FG and R&D firms; (iv) The Government's budget constraint is satisfied.

The labor share LS is the main outcome variable of interest in the policy analysis. The labor share is defined as:

$$LS = \frac{TE_E}{GDP} \tag{51}$$

where TE_E is the total earnings of employed workers, and GDP is the total GDP of the economy. Using optimal levels of wage and labor demand, the numerator can be written as:

$$W^*(1-TI)\left\{\sum_{FG=1}^{N_{FG}} L^*_{FG} + \sum_{RD=1}^{N_{RD}} L^*_{RD} + \sum_{PUB=1}^{N_{PUB}} L^*_{PUB}\right\} \tag{52}$$

The three terms on the RHS could also be written using the optimal labor demand conditions derived in the labor market section of the model and hence expressing them as a function of price, productivity and technology parameters (although this is not strictly necessary for the policy analysis). The denominator of (51) can be written as the sum of three sets of terms:

$$\begin{aligned} GDP = &\sum_{i=1}^{N_{FG}} \Pi_{FG} + \sum_{i=1}^{N_{RD}} \Pi_{RD} + \sum_{i=1}^{N_{PUB}} \Pi_{PUB} + \\ &+ W^*(1-TI)\left(\sum_{i=1}^{N_{FG}} L^*_{FG} + \sum_{i=1}^{N_{RD}} L^*_{RD} + \sum_{i=1}^{N_{PUB}} L^*_{PUB}\right) + \\ &+ TSPT + TSPE + TSPRD + TSPRES \end{aligned} \tag{53}$$

The first three terms are the total profits of FG and R&D firms (private and public). The next three terms are the earnings of workers employed in FG and R&D firms (these are exactly the same three terms in the expression for TE_E in (52)). The last four terms represent the public spending components of GDP.

Expressions (52) and (53) point out that the labor share depends, among other things, on the policy package adopted by the Government. In other words, for each combination of public spending and public revenues, there will be a specific equilibrium value of the labor share. Section A3 in the Online Appendix will show how each of the different types of public policies noted above affects the steady state levels of the labor share and the GDP per capita of the economy. In this section, as a benchmark, it is useful to derive the equilibrium level of the labor share for the baseline version of the model used in the simulation analysis, in which public welfare spending is set to zero:

$$LS^* = W^*(1-TI)\left(\sum_{i=1}^{N_{FG}} L^*_{FG} + \sum_{i=1}^{N_{RD}} L^*_{RD} + \sum_{i=1}^{N_{PUB}} L^*_{PUB}\right) /$$

$$/[\sum_{i=1}^{N_{FG}} \Pi_{FG} + \sum_{i=1}^{N_{RD}} \Pi_{RD} + \sum_{i=1}^{N_{PUB}} \Pi_{PUB} + \tag{54}$$

$$+W^*(1-TI)\left(\sum_{i=1}^{N_{FG}} L^*_{FG} + \sum_{i=1}^{N_{RD}} L^*_{RD} + \sum_{i=1}^{N_{PUB}} L^*_{PUB}\right) + TSPRES]$$

Given the market clearing conditions noted above, this equilibrium level of LS is *unique* for the specific policy package adopted in the baseline model.[22]

To study the dynamics of the labor share over time, I take logs and time derivatives of expression (54):

$$\frac{\dot{LS}}{LS} = \frac{\dot{TE_E}}{TE_E} - \frac{\dot{GDP}}{GDP} \tag{55}$$

Using (52) and (53) and assuming that public spending is constant over time, the growth rate of the labor share is given by:

$$\frac{\dot{LS}}{LS} = -\frac{\dot{\Pi}_{FG}}{\Pi_{FG}} - \frac{\dot{\Pi}_{RD}}{\Pi_{RD}} - \frac{\dot{\Pi}_{PUB}}{\Pi_{PUB}} \tag{56}$$

The dynamics of the labor share over time is inversely related to the sum of the growth rates of the total profits of final goods firms, private R&D firms, and public R&D firms (whereas the three terms representing the growth of total earnings noted in (52) cancel out and they therefore do not appear in expression (56)). From (55) and (56) it follows that:

$$\text{If: } \quad \frac{\dot{\Pi}_{FG}}{\Pi_{FG}} + \frac{\dot{\Pi}_{RD}}{\Pi_{RD}} + \frac{\dot{\Pi}_{PUB}}{\Pi_{PUB}} > 0 \quad \Rightarrow \quad \frac{\dot{LS}}{LS} < 0 \tag{57}$$

$$\text{If: } \quad \frac{\dot{\Pi}_{FG}}{\Pi_{FG}} + \frac{\dot{\Pi}_{RD}}{\Pi_{RD}} + \frac{\dot{\Pi}_{PUB}}{\Pi_{PUB}} < 0 \quad \Rightarrow \quad \frac{\dot{LS}}{LS} > 0 \tag{57'}$$

Conditions (57) and (57') point out that the labor share declines (increases) when the total sum of profits of firms increases (decreases). Now, using the profits equations (12) and (33), the growth rate of the labor share may be rewritten as follows:

$$\frac{\dot{Y}_{FG}}{Y_{FG}} - \frac{\dot{L}_{FG}}{L_{FG}} - \frac{\dot{L}_{RD}}{L_{RD}} - \frac{\dot{L}_{PUB}}{L_{PUB}} - \frac{\dot{W}}{W} - \frac{\dot{K}_{FG}}{K_{FG}} \tag{58}$$

[22]Note also that the equilibrium level of LS defined in equation (54) is obtained using the baseline parametrization of the model that assumes, among other things, that the production of new blueprints in the R&D sector does not affect the speed and type of the automation process in FG firms (see sec. 2.3, and footnote 7). Additional simulation analyses not reported here show that if new blueprints also lead to an increase in the number of tasks that can be carried out by workers in the FG sector (i.e. if α_N is positive), then the equilibrium labor share would be higher than what noted in equation (54). This extension is interesting, but I will not consider it further in the policy simulation analysis, because it is not essential to derive the results that will be discussed in sections 4 and 5.

Expression (58) is useful to point out the main mechanisms at stake in the transitional dynamics. When the productivity of R&D grows over time (following the motion equation noted in (29)), the price of new blueprints declines (see equation (30)). This has two contrasting effects on the labor share. On the one hand, the lower price of blueprints increases the amount of blueprints that FG firms seek to purchase, and this raises labor demand in the R&D sector and the wage level, thus raising firms' labor costs (second, third, fourth, and fifth terms of equation (58)). On the other hand, since FG firms purchase and use more blueprints, they will be able to produce and sell a larger amount of final goods (represented by the first term in (58)). In the transitional dynamics, the increase of revenues will be larger than the higher labor costs (otherwise FG firms would not demand more blueprints), so that expression (58) will be positive and the labor share will decline (see condition (57) above). Hence, in the transitional dynamics, the model generates a declining labor share that is driven by increases of R&D productivity and the consequent general equilibrium effects through labor demand, wage and production levels.

However, over time, the rate at which the labor share declines will be lower and lower due to the fact that the higher wage level driven by increased labor demand in the R&D sector will progressively induce lower labor demand in the final goods sector and hence lower production and revenues. In the steady state, the growth rate of the labor share will be zero, and hence the long-run equilibrium level of the labor share will be constant:

$$\frac{\dot{LS}}{LS} = -\frac{\dot{\Pi}_{FG}}{\Pi_{FG}} - \frac{\dot{\Pi}_{RD}}{\Pi_{RD}} - \frac{\dot{\Pi}_{PUB}}{\Pi_{PUB}} = \frac{\dot{Y}_{FG}}{Y_{FG}} - \frac{\dot{L}_{FG}}{L_{FG}} - \frac{\dot{L}_{RD}}{L_{RD}} - \frac{\dot{L}_{PUB}}{L_{PUB}} - \frac{\dot{W}}{W} - \frac{\dot{K}_{FG}}{K_{FG}} = 0 \quad (59)$$

The simulation analysis will study how the steady-state level of the labor share changes for different policy packages, i.e. for different combinations of public spending and fiscal revenues.

3. Empirical Calibration

The model is empirically calibrated for the US (Jaimovich et al., 2021; Berg et al., 2021; Thuemmel, 2022). I define first the calibration moments, i.e. the main outcome variables of interest that I seek to reproduce in the simulation of the model. Then, I calibrate the parameters in order to minimize the difference between these moments and the simulated outcomes. The main calibration moment is the key outcome variable of interest, i.e. the labor share. In the US, this had a value close to 60% of GDP in 2010, and it has declined further in recent years (Hemous and Olsen, 2022; Thuemmel, 2022; Dawid and Neugart, 2023). The baseline version of the model is calibrated such that the simulated labor share has a value that is empirically close to this calibration moment.

Regarding income inequalities within the group of employed workers, as previously explained, this is not a main target variable in the present paper. However, it is important that the empirical calibration leads to plausible values for this variable too. According to Thuemmel (2022), the ratio between the wage of cognitive workers and manual non-routine workers was around 2 in the US in the year 2016. I therefore calibrate the model such that the ratio between the mean wage of high-skill workers is about twice as high as the mean wage of the low-skill employed workers. This ensures that the within-group variation generated by the model for employed workers is empirically plausible.

A second main calibration moment is the unemployment rate. According to the US Bureau of Labor Statistics, the unemployment rate in the US was between 4% and 10% in the period 2010-2020. The baseline version of the simulated model is calibrated such that its steady-state unemployment rate is within this range (the unemployment rate becomes lower when I introduce a re-training policy for unemployed workers).

The third main calibration moment relates to the size of the public sector. In the US, the total Federal Government spending (i.e. excluding State-level and other local Governments' spending) accounts for 18-20% of GDP. This figure includes all types of public spending, including also basic social/welfare spending, which is about 3-4% of GDP. I have therefore calibrated the baseline version of the model so that Government's total spending accounts for 18% of GDP. However, in the simulation policy analysis, I have then increased public spending to finance additional welfare programs targeting unemployed workers so that the total public share of GDP is in becomes larger than 18%.

Regarding fiscal revenues, the model imposes a budget constraint: all public spending must be financed by taxes (or other public revenues). Therefore, the baseline version of the model sets empirically plausible values of tax rates such that total fiscal revenues are able to cover the public spending noted above. Regarding labor taxes paid by employed workers, in the US, these are progressive and range between 0.137 and 0.27 (Jaimovich et al., 2021; Costinot and Werning, 2023; Jacobs and Thuemmel, 2023). In the baseline model, I have set a linear tax rate of 0.15 that provides fiscal revenues that account for 9% of GDP. In additional policy experiments, I have then introduced non-linear (progressive) income taxes that have higher rates for high-income workers.

As for profit taxes that are paid by companies, figures for the US indicate a flat basic tax rate of 0.21 in addition to different corporate income taxes that are imposed by some States. In the baseline model, I have set a profit tax rate to 0.25, which provides fiscal revenues that account for about 9% of GDP. Finally, regarding the R&D tax, I set it to 0 and disregard this tax in the baseline version of the model. Then, in some of the policy experiments (see next section), I have introduced an R&D tax of 5% that generates additional fiscal revenues accounting for 1% of GDP. In summary, in the baseline model, fiscal revenues come from labor taxes and profit taxes that generate fiscal revenues that account for 18% of GDP, which is precisely the amount of resources that the Government needs in order to finance its public spending.

Shifting the focus to other parameters and variables, these were calibrated by using empirically plausible values based on empirical evidence and prior literature and/or by setting values that lead to a good fit between simulated variables and the related moments. I briefly discuss them here, and Table A4 presents an overview of the values of parameters and variables (initial values) in the baseline version of the model. The population is composed of 1000 households (Prettner and Strulik, 2020). In the simulation model, there are 100 final goods firms and 25 R&D firms. Hence, the share of firms' owners (or capitalists C) in the population is 12.5% (in line with Dawid and Neugart, 2023).

As for the households, the parameter representing the constant labor supply elasticity (ϵ) is defined as positive, and in empirical calibrations in the literature, it usually takes values between 0 and 1. For instance, Thuemmel (2022) sets $\epsilon = 0.3$; and Costinot and Werning (2023) set $\epsilon = 0.5$. In my simulation model, households have an elasticity of labor supply equal to 1, as in Jaimovich et al. (2021). I have, however, carried out simulation analyses to study how variations of this parameter affect the model's outcomes (see footnote 13). The skill distribution of agents is governed by a uniform distribution, and S_i is defined in a numerical range between 0 and 25.

Regarding the task-based production function in the final goods sector, the productivity variables (AL, AK and ALK) are initially set to 1, in line with Acemoglu & Restrepo (2018: 1500, corollary 1) and calibrations in Costinot and Werning (2023) and Dawid and Neugart (2023). The elasticity of substitution between K and L is also set to 1 (as in Acemoglu and Restrepo, 2018: footnote 10, corollary 1, and appendix A and B). I also assume that at the beginning of the model run the share of tasks done by skilled labor and the share of tasks done by capital are both equal to 0.5, and these shares then change over time as explained in section 2.3. As for the rental rate of capital (R), this usually takes values between 1% and 5% (see, e.g., Jaimovich et al., 2021; Prettner and Strulik, 2020). I have set this parameter equal to 1% and carried out additional simulations to analyze effects of variations in this parameter on the model's outcomes. The price of machines has an initial value of 1 (similar to Dawid and Neugart, 2023), and its value then adjusts to its steady-state value after some model runs.

Shifting the focus to the R&D sector, the baseline version of the model has private companies only; I then introduce public R&D companies in the policy simulation analysis. R&D firms have a mark-up parameter (parameter β in the model) equal to 0.2, which is in line with mean values for the US (see Aghion et al., 2019; Berg et al., 2021). The inter-temporal knowledge spillovers parameter is set to 0.5, and the technological opportunities parameter (i.e. the mean probability that a blueprint is found as a consequence of R&D investments) is set to 0.5. There are no standard empirical indicators to calibrate these two parameters, so their values are chosen in order to have a reasonable calibration of the productivity of the R&D sector and the pace of technological change. Specifically, the model is calibrated such that the total number of new blueprints produced every year (ΣB_{RD}) grows linearly at a constant annual rate between 2% and 4%, which corresponds to the average annual growth rate of the patent stock observed in the US between 1988 and 2008 according to USPTO data. In additional simulations (not reported here), I have analyzed how changes in the inter-temporal knowledge spillovers parameter and the technological opportunities parameter affect the model's outcomes.

Finally, regarding the social welfare function, the baseline version of the model assigns the same weight (0.33) to the three social groups of interest: capitalists (C), employed workers (E), and the unemployed (UN). This means that the three groups weigh equally in the calculation of aggregate social welfare. In the policy simulation analysis (see next section), I have then analyzed how changes in these three weights affect the model's outcomes and the costs and benefits of adopting different policy packages. Table A4 in the Online Appendix provides a list of all model's parameters and their calibration values.

4. Comparing Entrepreneurial State and Standard Welfare Policies

This section shifts the focus to the main question analyzed in the paper. How do different public policies that address the inequality effects of innovation affect the trade-off between efficiency and equity – and among these, what are the best policies? To address this question, I reformulate social welfare (see equation (50)) as the weighted sum of the two main objectives that the Government seeks to maximize: labor share (equity) and GDP (efficiency). Hence, the Government seeks to maximize the following objective function:

$$O_{(\mathrm{PP})} : \chi\, LS_{(\mathrm{PP})} + (1-\chi)\, GDP_{(\mathrm{PP})} \tag{60}$$

Compared to the standard formulation of social welfare in terms of sum of agents' income (see equation (50)), objective function (60) is useful because it highlights the two main policy objectives of the Government (equity and efficiency), and the trade-off between them. Parameter χ represents the Government's relative preferences for the two objectives. This section considers the case in which the two objectives have the same relevance ($\chi = 0,5$), and the next section will then generalize to the non-utilitarian case.

To maximize (60), the Government must choose among several different *policy packages* (PP). A PP is a combination of additional spending (welfare and redistribution schemes) and additional fiscal revenues (that are necessary to finance the new welfare and redistribution schemes). The various policy instruments that compose a PP are those noted in section 2.6. All PP implemented by the Government are subject to the budget fiscal constraint previously formulated in equation (48). Formulating the Lagrangian function (L) for the constrained optimization problem expressed by (60) and (48), the optimality condition is:

$$\frac{\partial L}{\partial PP} = \chi \frac{\partial LS}{\partial PP} + (1-\chi) \frac{\partial GDP}{\partial PP} = 0 \tag{61}$$

which can be written as:

$$\frac{\partial TE_E}{\partial PP} - \frac{TE_E}{GDP} \cdot \frac{\partial GDP}{\partial PP} + GDP \cdot \frac{\partial GDP}{\partial PP} = 0 \tag{62}$$

Optimality condition (62) points out that each policy package PP will affect the labor share and GDP of the economy in three ways: (1) it will affect the amount of net earnings of employed workers; (2) it will directly affect GDP; (3) it will indirectly affect the labor share by affecting the GDP. Note, though, that each policy package PP is not a scalar but a vector (composed of a spending dimension and a fiscal revenue component), so that there exist several possible policy packages (i.e. different combinations of spending and fiscal revenues) that satisfy the Government's budget constraint. This means that optimality condition (62) does not allow a closed form solution. Therefore, I have studied this problem and compared different PPs through simulation analysis.

4.1 The Policy Packages

Specifically, I set up 14 distinct policy packages, which represent all possible combinations of the policy instruments noted in sec. 2.6. Each policy package (PP) is defined according to the following three criteria. First, it entails welfare policies that come in addition to the other public spending that is already considered in the baseline version of the model. Hence, a PP must be regarded as an additional policy scheme that is specifically meant to address income inequalities effects of innovation. Second, when a PP requires additional public spending (e.g. a new welfare scheme), this will necessitate additional fiscal revenues to be financed. Thus, the Government's fiscal constraint must be satisfied in all packages. Third, the PPs must be normalized to allow their comparability (Berg et al., 2021). This means that each PP accounts for the same share of GDP. Specifically, the simulation scenarios that I build up posit that the size of the increase of fiscal revenues and public spending for any given package accounts for 1% of GDP, so that the size of the public sector's share of GDP will increase from 18% (baseline model) to 19% (policy scenarios).[23] The 14 policy packages that I study in the simulation analysis are the following.

[23]Each policy simulation has been repeated 50 times. The reason for repeating each simulation experiment several times is that the model has two random variables (the skill distribution of workers, and

Standard Policy Packages

1. *Tax and educate*: This policy approach increases taxes and makes use of the additional fiscal revenues to finance a training policy for the unemployed. Fiscal revenues can be obtained through different types of taxes, each of which is considered in a different policy package:
1.A: Increase income tax rate (linear taxes).
1.B: Increase rate of progressivity of income tax (non-linear taxes).
1.C: Increase profit tax rate.
1.D: Introduce a tax on R&D.

2. *Tax and transfer*: Similarly to the previous packages, this approach increases taxes in order to finance a new welfare scheme that provides spending transfers to the unemployed:
2.A: Increase income tax rate (linear taxes).
2.B: Increase rate of progressivity of income tax (non-linear taxes).
2.C: Increase profit tax rate.
2.D: Introduce a tax on R&D.

Entrepreneurial State Policy Packages

3. *Public R&D and educate*: This policy approach makes use of the profits obtained by public R&D firms that commercialize innovations in order to finance a training scheme for the unemployed (analogous to that noted in packages 1). This approach may also be combined with a different type of policy: technology regulation that targets R&D firms. Hence, I set up two distinct packages that implement this policy approach:
3.A: Without technology regulation.
3.B: With technology regulation.

4. *Public R&D and transfer*: This fourth approach makes use again of the profits obtained by public R&D firms that commercialize innovations but uses them to finance spending transfers to the unemployed (i.e. the same welfare scheme considered by packages 2). The two packages that implement this approach are the following:
4.A: Without technology regulation.
4.B: With technology regulation.

5. *Public R&D and public R&D procurement*: This fifth approach is based on the same funding logic as packages 3 and 4 (i.e. using the profits of public R&D firms) but instead of increasing welfare spending, it uses these public resources to finance public procurement of R&D (which is a way to direct innovative investments in specific technological trajectories of high societal relevance). This approach may also be augmented by technology regulation:
5.A: Without technology regulation.
5.B: With technology regulation.

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the probability that R&D firms discover new blueprints), and different realizations of these may lead to somewhat different results. The results presented below are therefore based on average values of the outcome variables across the 50 repetitions.

Table 1: Policy packages: calibration values of policy parameters in the simulation analysis.

	Policy Packages	**TI**	**ΔTIH**	**TP**	**TRD**	**1 - τ**	**SPP**	**θ**	**j**	**SPE**	**REG**	**Public GDP**
0	Baseline	0.15	0	0.25	0	0	0	0	0	0	0	18%
1.A	Tax & educate: Increase linear taxes	0.18	0	0.25	0	0	0	0	0.01	5	0	19%
1.B	Tax & educate: Increase progressive taxes	0.17	0.01	0.25	0	0	0	0	0.01	5	0	19%
1.C	Tax & educate: Increase profit taxes	0.15	0	0.28	0	0	0	0	0.01	5	0	19%
1.D	Tax & educate: Introduce R&D taxes	0.15	0	0.25	0.04	0	0	0	0.01	5	0	19%
2.A	Tax & transfer: Increase linear taxes	0.18	0	0.25	0	0	0	0.20	0	0	0	19%
2.B	Tax & transfer: Increase progressive taxes	0.17	0.01	0.25	0	0	0	0.20	0	0	0	19%
2.C	Tax & transfer: Increase profit taxes	0.15	0	0.28	0	0	0	0.20	0	0	0	19%
2.D	Tax & transfer: Introduce R&D taxes	0.15	0	0.25	0.04	0	0	0.20	0	0	0	19%
3.A	Public R&D and educate (no regulation)	0.15	0	0.25	0	0.06	0	0	0	0	0	19%
3.B	Public R&D and educate (cum regulation)	0.15	0	0.25	0	0.06	0	0	0	0	0.10	19%
4.A	Public R&D and transfer (no regulation)	0.15	0	0.25	0	0.06	0	0.20	0	0	0	19%
4.B	Public R&D and transfer (cum regulation)	0.15	0	0.25	0	0.06	0	0.20	0	0	0.10	19%
5.A	Public R&D and procurement (no regulation)	0.15	0	0.25	0	0.06	1	0	0	0	0	19%
5.B	Public R&D and procurement (cum regulation)	0.15	0	0.25	0	0.06	1	0	0	0	0.10	19%

Legend: Policy parameters: **TI:** income tax rate; **ΔTIH:** additional tax rate paid by high-wage workers; **TP:** profit tax rate; **TRD:** R&D tax rate; $1-\tau$**:** public R&D firms as a share of total number of R&D firms; **SPP:** share of public R&D firms' profits that are used to finance public R&D procurement; θ**:** spending transfer: generosity of the welfare system; **j:** probability that an unemployed worker finds employment after attending a re-training scheme; **SPE:** Education and re-training policy: unit cost per unemployed worker; **REG:** technology regulation: share of new blueprints that are regulated.

4.2 Comparing the Effects of Different Policy Packages

To compare the effects of these policy packages and assess the benefits and costs of different policy approaches, I have carried out a simulation analysis of each scenario (50 repetitions) and recorded the mean values of the key outcome variables in the long-run.[24] I have then calculated percentage deviations of the outcome variables for each scenario *vis-à-vis* the corresponding variables in the baseline scenario, in order to study the extent to which each policy package increases (or decreases) a given outcome variable in comparison to the situation in which this new policy is not introduced (i.e. the baseline scenario). The results of this comparison are presented in Table 2 and Figure 1.

Standard Welfare Policies

Regarding the first two **policy packages (1.A and 1.B)**, the education policy for unemployed workers leads to an increase in the employment rate in the long run. However, financing this policy through an increase in labor tax leads to a reduction in the economy's total efficiency (GDP per capita) since the higher fiscal burden on employed workers negatively affects their net earnings and consumption (Peretto, 2007). If the progressivity of the labor tax increases too (package 1.B), the reduction in efficiency is even stronger as lower consumption of high-wage workers slows down aggregate demand and, relatedly, the revenues and profits of FG firms. As for the labor share, this decreases substantially *vis-à-vis* the baseline scenario, enlarging income inequalities between C and E, driven by the increase in labor tax for the latter group. In summary, these policy packages have contrasting effects on social welfare. While the reduction of the unemployment rate is a positive result of this welfare scheme, this approach has substantial costs in terms of lower GDP per capita as well as higher inequalities between C and E. In short, this approach is quite costly for the society and worsens the relative position of employed workers.

The next two scenarios **(packages 1.C and 1.D)** finance the same training policy for unemployed workers through increased profit taxes or the introduction of an R&D tax, respectively. The simulation results indicate that both of these packages lead to an increase in total efficiency *vis-à-vis* the baseline situation. This is because the higher employment rate that the policy determines in the long run fosters consumption and aggregate demand.[25] Hence, firms' total profits increase despite the higher fiscal burden that capitalists are subject to in this policy approach. Employed workers' total earnings increase too in these scenarios. As a result, the economy's GDP per capita grows, but the labor share is not significantly different from the baseline (as both C and E have improved their position compared to the baseline scenario). In summary, this policy approach is better than the previous in terms of overall efficiency, but it does not represent an effective way to reduce inequalities between C and E.

Shifting to the next policy approach, **packages 2.A and 2.B** provide spending transfers to unemployed workers which are financed through higher labor taxes (linear and progressive taxes, respectively). This welfare scheme is primarily meant to improve the relative position of the unemployed, who may use the transfers to increase their consumption, thus fostering aggregate demand. However, this positive effect is entirely offset by

[24]The long-run values of the outcome variables refer to $t = 300$. The model converges swiftly to the steady state, so an assessment of the outcomes at $t = 300$ is more than sufficient to study the long-run properties of the model.

[25]For a recent empirical analysis of the multiplier effects of Government expenditures on social protection, see Cardoso et al. (2023).

the fact that higher labor taxes lead to a sizeable reduction in total workers' earnings and consumption (and this reduction is even stronger when the progressivity of labor tax is increased). As a result of these contrasting effects, the steady-state GDP per capita of the economy is lower compared to the baseline scenario, and so is aggregate social welfare. Furthermore, this policy approach negatively affects the labor share as it hits net earnings of employed workers relatively more than those of firms' owners. Hence, similarly to scenarios 1.A and 1.B, policy packages 2.A and 2.B represent costly welfare schemes for society because they reduce the economy's total efficiency while also worsening the relative position of the group of employed workers.

Alternatively, spending transfers for unemployed workers may be financed through an increase in profit taxes or the introduction of an R&D tax **(packages 2.C and 2.D)**. Similarly to the previous, this policy approach would increase aggregate demand by fostering consumption activities of unemployed workers. However, in this case, the increase in aggregate demand would not be offset by a reduction of consumption of employed workers. On the contrary, the increase in total consumption would lead to higher revenues and profits of FG firms (despite the higher profit taxes) and therefore an increase in GDP per capita. The simulation results also show that the relative increase in workers' earnings would be higher than that for capitalists' profits so that the labor share will slightly increase. On the whole, this policy approach increases aggregate social welfare. It improves the relative position of unemployed workers; it increases substantially the efficiency of the system (via aggregate demand effects); and it also improves slightly the relative position of E versus C.

Entrepreneurial State Policies

Turning to the set of policy packages that resemble some of the characteristics of Entrepreneurial State policies, let us consider first the policy scenarios in which public R&D firms invest in innovation and sell blueprints, and their profits are then used to finance welfare policy schemes such as those noted above. Specifically, **policy packages 3.A and 3.B** envisage that these additional public revenues finance an education and training policy scheme for unemployed workers (as the one considered in packages 1.A to 1.D above). These policy scenarios lead to a substantial increase in the efficiency of the economy as the higher employment rate induced by the education policy for unemployed workers fosters consumption, aggregate demand, and the profits of FG firms. At the same time, this expansion of aggregate demand and the resulting growth of GDP per capita are not offset by a higher fiscal burden imposed on employed workers or on companies, as it was the case in the previous scenarios, because the education policy is now financed by using the profits of public R&D companies. Hence, policy package 3.A results in a substantial increase in efficiency as well as a sizeable increase in the labor share. The reduction in income inequalities between C and E is due to the fact that total earnings of employed workers increase relatively more than firms' profits, driven by the increase in employment, wage level, and aggregate demand. In short, the Entrepreneurial State policy package 3.A represents an effective policy approach that increases the economy's efficiency, decreases the unemployment rate, lowers inequalities between C and E, and therefore substantially increases social welfare. If we consider a version of this policy package that introduces technology regulation too (package 3.B), this would lead to a lower growth of GDP per capita (because the regulation of technology negatively affects the profits of R&D firms and the dynamics of the R&D sector) but also a higher increase in the labor share. In other words, technology regulation would increase the trade-off between efficiency and equity effects of welfare policies.

Policy packages 4.A and 4.B are based on the same overall idea as 3.A and 3.B and lead to similar results. In these scenarios, the welfare policy is a standard spending transfer provided to unemployment workers (exactly as in packages 2.A to 2.D above), but this additional public spending is not financed through higher taxes but rather by using the profits of public R&D firms (as in packages 3.A and 3.B). The direct effect of the spending transfers is that unemployed workers increase their consumption level. In turn, this fosters aggregate demand, firms' profits, and employed workers' earnings (via an increase in the wage level). Hence, the steady-state GDP per capita increases substantially *vis-à-vis* the baseline scenario. Regarding firms' profits, these increase in absolute terms following the expansion of aggregate demand. However, the labor share increases as the growth of employed workers' total income is higher than the growth in private firms' profits. In short, package 4.A represents a quite effective policy: it improves the relative position of unemployed workers; it increases the economy's efficiency (GDP per capita); and it reduces income inequalities between C and E. Regarding the policy package that also introduces technology regulation (3.B), its effects are quite similar to scenario 4.A, the main difference being that the profits of R&D companies are negatively affected by the regulation policy. This has two effects. On the one hand, it hampers technological dynamics and GDP growth and hence the economy's overall efficiency. On the other hand, it increases the labor share even further. Hence, compared to scenario 4.A, policy package 4.B presents a stronger trade-off between its effects on efficiency (weaker) and functional income inequalities (stronger).

Finally, **policy packages 5.A and 5.B** posit that an Entrepreneurial State uses the profits of public R&D companies to finance public procurement of R&D. Differently from all previous scenarios, this approach does not introduce any welfare scheme to support unemployed workers but instead seeks to foster public R&D in specific trajectories that are considered of high societal relevance. The efficiency effects of this policy approach are positive, although slightly lower than in scenarios 3 and 4. Public procurement of R&D fosters technological change and GDP per capita growth, which in turn increases firms' profits as well as total earnings of employed workers. However, the effects of this policy on functional income inequalities are weaker than in scenarios 3 and 4. The labor share increases only marginally *vis-à-vis* the baseline scenario. Therefore, policy package 5.A, while it fosters the economy's efficiency by supporting the dynamics of the R&D sector, does not have any positive effect on the income distribution – i.e. it does not improve either the position of unemployed workers nor that of employed workers *vis-à-vis* firms' owners. As for the policy package that introduces technology regulation in addition to public procurement (5.B), its effects are similar to what was previously noted. Since technology regulation negatively affects the profits of R&D firms, this has two contrasting effects on efficiency and inequalities. First, it partly offsets the positive effect of public R&D procurement on GDP per capita growth, so that the efficiency effects of 5.B are weaker than 5.A. Second, it decreases the private profit share and therefore increases the labor share much more than was the case in the corresponding scenario 5.A.

Summary and Comparison

Figure 1 shows a useful illustration of the 14 policy packages and their relative effects on efficiency (GDP per capita; X-axis) and the labor share (Y-axis) *vis-à-vis* the baseline scenario. The diagram enables us to investigate the key question: if policymakers seek to improve the functional distribution of income (i.e. increase the labor share) while avoiding high social costs in terms of efficiency losses, what are the best policy approaches? Figure 1 shows that Entrepreneurial State policy approaches – and specifically policy packages 3 and 4 – represent the first best. This approach achieves substantial increases in the labor share while also fostering the efficiency of the system through GDP per capita growth. In other words, these policy scenarios are Pareto efficient as they increase both efficiency and equity compared to the baseline. Similar considerations apply also to policy approach 5, which is, however, less effective at reducing the labor share than the corresponding scenarios 3 and 4. As noted above, the reason why the three Entrepreneurial State policy packages perform better than the other packages considered in this simulation analysis is that they finance welfare and redistribution policies by retaining and leveraging the profits of public R&D companies, instead of increasing taxes. Hence, this policy approach has at the same time redistributive and (demand-led) growth effects without incurring in distortionary impacts that tax increases would lead to.

Regarding the more standard policy approaches that use tax increases to finance welfare schemes for the unemployed, the second-best policy approach is the one that raises profit taxes paid by companies and/or introduces an R&D tax (i.e., policy packages 1.C, 1.D, 2.C, and 2.D). This approach, despite the higher fiscal burden on firms, leads to an expansion of aggregate demand and has multiplier effects that drive GDP per capita growth. In terms of income inequalities, this approach improves the relative position of the unemployed but does not significantly strengthen the position of employed workers.

Finally, Figure 1 shows that the policy approach that performs worse than the others is the one that raises labor taxes to finance welfare schemes for the unemployed (packages 1.A, 1.B, 2.A, and 2.B). This policy imposes the costs of welfare schemes entirely on employed workers. By hitting net earnings of employed workers, this approach negatively affects the labor share but also reduces consumption, aggregate demand, firms' profits, and the economy's efficiency. Table 3 reports results of *t-tests* of the significance of differences among the three groups of policy packages noted here and highlighted in Figure 1, showing that the three types of packages lead to statistically different outcomes in terms of efficiency (GDP per capita), labor share, and social welfare.

Discussion

It is important to make some clarifications to assess these results further. Let us first discuss the empirical relevance of these findings. First, regarding the size of the effects of the policy packages in our simulation analysis, as indicated in Table 2 and Figure 1, the magnitude of these effects (i.e., their change *vis-à-vis* the baseline) ranges between -5% and +10% for the GDP per capita and between -4% and +4% for the labor share. In terms of absolute size, a deviation of the labor share of, say, +4% means that this would increase from 50% to 52% after the implementation of the welfare policy. Although this is a relatively small size effect in terms of income distribution, it is important to emphasize that this result is obtained by assuming in the simulation analysis that each policy package only accounts for 1% of GDP. This means that if the Government seeks to achieve a stronger reduction of income inequalities, it could implement the same policy package on a larger scale (i.e. using public resources that account for more than 1% of the GDP).

Second, although the simulation analysis has outlined and studied 14 policy scenarios, in a more realistic policy setting, one could well imagine implementing a variety of other additional scenarios that mix and combine together some of the characteristics of the 14 policy packages. For instance, public revenues could be obtained by means of a mix of higher income taxes, profit taxes, and profits of public R&D firms; and public spending could entail a combination of subsistence transfers, education policy, and public procurement of R&D. However, this simulation analysis has not considered all these possible combinations because its main purpose has been to highlight the main characteristics, costs, and benefits of stylized policy packages that represent different policy approaches.

Third, the main result pointed out in section 3.2 is that the first-best policy framework is an Entrepreneurial State approach that makes use of public R&D firms' profits to finance welfare schemes for the unemployed. It is worth noticing that this result is obtained by building up a rather conservative set of policy scenarios in which only a relatively small share of R&D firms (6%) are public (see Table 2). Hence, the policy packages that resemble an Entrepreneurial State approach should indeed be regarded as *realistic* scenarios, in the sense that they would not require a major expansion of the role of the Government in the R&D sector (which would arguably be not feasible in the short-run and hard to implement in most countries in which economic policy is based on a neoliberal tradition).

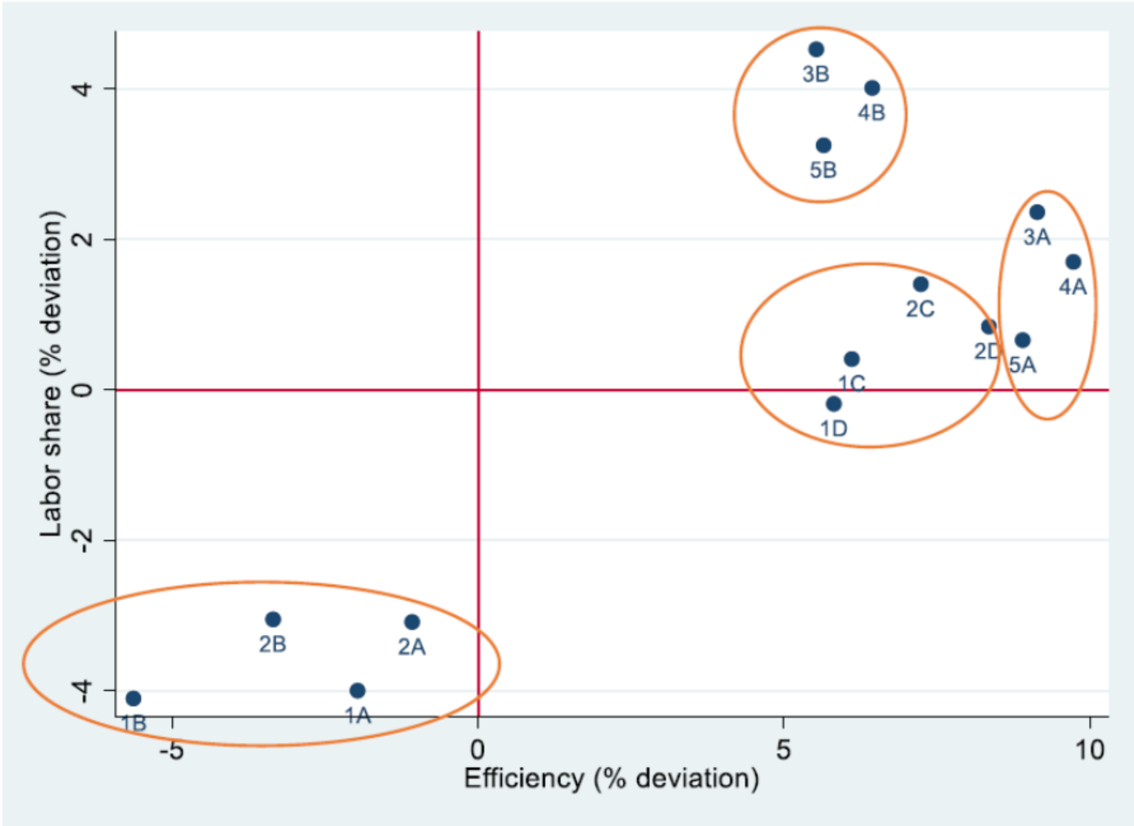
Further, let us briefly note two clarifications on the model parametrization that has generated these results, and some extensions of it. First, the simulation results presented in figure 1 are based on a calibration of parameters that for simplicity sets the same productivity for private and public R&D firms. However, these results can be generalized to the case in which public R&D firms are less productive than private R&D firms (a possibility that was briefly discussed in section 2). This case is investigated by one of the analytical properties of the model (see proposition 2B in the Online Appendix). If the productivity level of public R&D companies is lower than that of private firms, there will be two effects on the steady-state outcomes of the model: (1) the GDP per capita will be slightly reduced; (2) the profit share will be lower (and so the labor share will be higher; see figure A5 in the Appendix). The latter effect is due to the fact that public companies, if they are less productive than private firms, must hire more R&D workers in order to satisfy a given demand for blueprints, thus pushing up mean wages (hence net earnings of workers). In short, if there are inefficiencies in public R&D production, an Entrepreneurial State policy approach will be even more effective in terms of redistribution (compared to scenarios 3, 4 and 5 represented in figure 1), although it will increase GDP per capita slightly less than in the case in which public and private firms have same productivity levels.

Second, although the simulation analysis has focused on outcomes in terms of the functional distribution of income (i.e. income shares of capitalists, employed workers, and unemployed individuals), which is the main dimension of interest in this paper, I have also repeated the same policy comparison looking at a distinct dimension of income inequalities, namely wage inequalities within the group of employed workers. These additional simulation results (available upon request) are closely in line with those noted above for the labor share. The first-best policy to reduce wage inequalities between high-income versus low-income workers is to make use of the innovation profits of public R&D companies in order to finance an education and training scheme for unemployed workers. Such a policy package would at the same time increase GDP per capita (through employment and demand effects) as well as decrease wage inequalities among employed workers more than other policy packages would be able to do.

Table 2: Comparing the effects of different policy packages: % deviations *vis-à-vis* the baseline scenario. All values reported in the table are % deviations from the corresponding variables in the baseline scenario.

Packages	Avg. earnings C	Avg. earnings E	Tot. earnings C	Tot. earnings E	GDP per capita	Profit share	Labor share	Social welfare
1.A	1.69	-9.90	1.69	-4.07	-1.97	1.77	-4.00	-1.97
1.B	-3.19	-12.69	-3.19	-7.04	-5.63	-0.14	-4.10	-5.63
1.C	4.66	0.43	4.66	6.94	6.11	-1.72	0.41	6.11
1.D	5.39	-0.40	5.39	6.06	5.81	-0.81	-0.19	5.81
2.A	0.97	-4.07	0.97	-3.94	-1.08	1.87	-3.09	-1.08
2.B	-2.21	-5.69	-2.21	-5.69	-3.35	0.53	-3.05	-3.35
2.C	3.71	7.24	3.71	7.37	7.24	-2.06	1.40	7.24
2.D	6.30	7.27	6.30	7.69	8.35	-0.47	0.84	8.35
3.A	4.10	1.17	4.10	9.11	9.14	-2.33	2.36	7.28
3.B	-4.35	0.78	-4.35	8.58	5.53	-7.92	4.53	3.87
4.A	3.88	8.29	3.88	8.22	9.73	-2.38	1.70	7.87
4.B	-4.28	8.01	-4.28	8.05	6.44	-7.86	4.01	4.77
5.A	5.34	8.04	5.34	7.95	8.90	-1.77	0.66	7.00
5.B	-3.13	7.75	-3.13	8.00	5.65	-7.38	3.25	3.94

Figure 1: Comparing the effects of different policy packages: trade-off between efficiency (GDP per capita) and labor share.



Legend: The values reported in the figure are % deviations from the corresponding variables in the baseline scenario. **Packages 1.A, 2.A, 1.B, 2.B:** Welfare spending financed by higher labor taxes. **Packages 1.C, 2.C, 1.D, 2.D:** Welfare spending financed by higher profit taxes. **Packages 3.A, 4.A, 5.A, 3.B, 4.B, 5.B:** "Entrepreneurial State" policies.

Table 3: Statistical significance of differences among main groups of policy packages (*t-tests* on simulated data).

Policy packages	Efficiency	Labor share	Social welfare
Welfare spending financed by higher labor taxes	30.41***	45.39***	30.21***
Welfare spending financed by higher profit taxes	10.87***	1.63*	10.71***
"Entrepreneurial State" policies	9.61***	28.44***	9.68***

t-values reported in the table. Number of observations: 700 (14 policy packages times 50 repetitions). ***: 1% significance level; *: 10% significance level.

5. The Role of Policy Maker's Distributional Preferences

As noted in section 2, the model defines social welfare as a weighted average of the utility (income) of the three focal groups studied in this paper: capitalists (C), employed workers (E), and the unemployed (UN). The weight assigned to each group reflects the latter's importance for society according to the Government, so that the vector of weights reflects the policy-maker's distributional preferences. The simulation results presented in the previous section were based on a standard simple utilitarian definition of the social welfare function that assigns equal weights to the utility of the three groups. In this section, I study how the results of the policy analysis change if I specify instead a generalized (or prioritarian) social welfare function, which assigns different weights to the three groups. The rationale is to analyze how different distributional preferences of the policy-maker affect the results of the policy comparison.

To do so, I have repeated the simulation analysis and comparison of policy packages for different values of the distributional parameters, i.e. varying the weight for C between 0.1 and 0.9, and correspondingly varying the weight for E between 0.9 and 0.1. This simulation analysis was repeated for two different values of the weight for UN: $U = 0$ (representing a hypothetical case in which the utility of unemployed workers does not matter at all for social welfare); and $U = 0.9$ (denoting a situation in which the policy-maker considers the utility of unemployed workers very important for social welfare).

The results of this exercise are summarized in Figure 2, which reports aggregate social welfare (Y-axis) as a function of the weight assigned to C (X-axis; note that the X-axis also represents the weight assigned to E since this is defined as 1 *minus* the weight for C). Intuitively, the left-hand side of Figure 2 represents distributional preferences that consider the welfare of employed workers more important than that of capitalists, whereas the right-hand side represents the preferences of a Government for which the utility of capitalists matters more than that of employed workers. Instead of reporting all 14 policy packages, Figure 2 shows the results for a few selected packages that represent the first-best, second-best, and worst-performing policy approaches according to the results presented in the previous section. The selected policy packages are sufficient to illustrate the key point that I discuss in this section.

Considering the first-best policy approach, i.e. the policy packages in which public R&D firms' profits are used to finance welfare schemes (see scenario 3B in Figure 2), this leads to progressively lower values of social welfare for increasing (decreasing) values of the weight assigned to C (E). This policy induces an increase of social welfare of about 8% (compared to the baseline situation) when profit owners C are not considered very important by the policy-maker (left-hand side of Figures 2a and 2b), whereas the same policy reduces social welfare by around 3% when the C group is regarded as very important by the Government (right-hand side of the diagrams). In other words, the Entrepreneurial State policy approach based on the introduction of public R&D firms becomes less and less appealing if aggregate social welfare is defined in such a way to reflect the interests of C more than the utility of E, because the costs of this policy for the society (in terms of loss of efficiency and lower profits of private R&D firms) become so high that they overturn the benefits in terms of lower income inequalities.

The policy approach that increases profit taxes to finance welfare schemes was pointed out as a second-best policy approach in the previous section. However, when I increase the weight assigned to C (and decrease the corresponding weight assigned to E), social welfare declines by about 2 percentage points (see scenario 1C in Figure 2a and 2C in Figure 2b). This means that taxing firms' profits to finance redistribution programs becomes more costly and less appealing for the society when policymakers consider the welfare of capitalists relatively more important than that of employed workers.

By contrast, the policy approach that raises labor taxes to finance welfare schemes (see packages 1A and 2A in Figure 2) leads to higher levels of social welfare as policymakers assign higher weights to capitalists versus employed workers. Hence, increasing labor taxes becomes a more appealing policy strategy for Governments whose distributional preferences are more oriented towards firms and profit owners.[26]

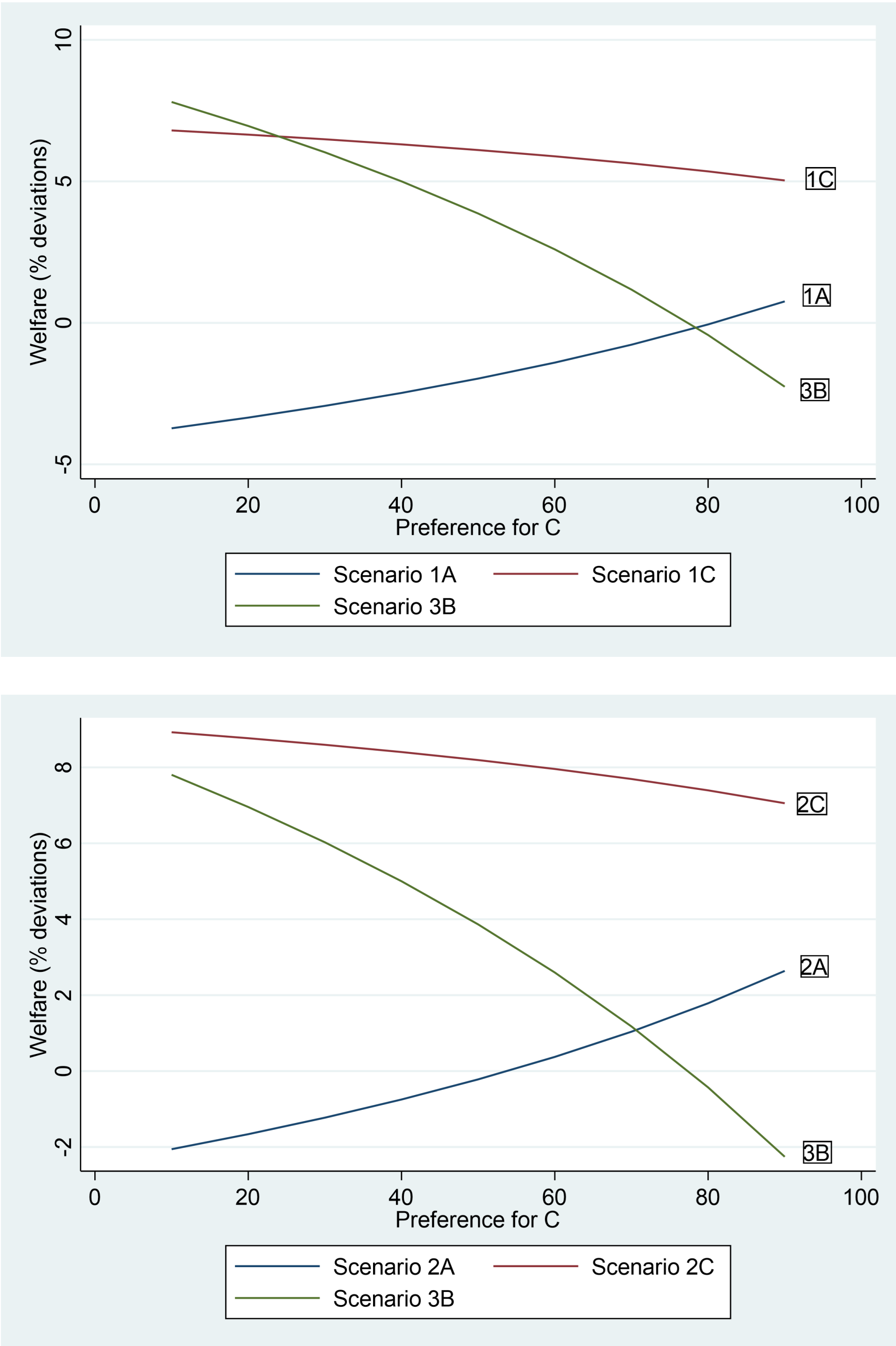
Now, if we seek to compare and rank the three policy approaches based on the impact they have on social welfare, the results of the comparison largely depend on the weights assigned to the three groups. For high values of E and low values of C and U (Figure 2a), the Entrepreneurial State policy approach is the first-best in line with the results presented in the previous section. However, for values of the weight for C > 0.25, the policy approach that raises profit taxes leads to the strongest increase in social welfare, and it becomes the first-best policy among those that I have considered. As for the policy approach based on higher labor taxes, this negatively impacts social welfare and performs worse than other policies for values of the weight of C lower than 0.8 (Figure 2a) or 0.5 (Figure 2b). However, for very high values of the C weight, this policy turns out to have a positive impact on social welfare, and it even performs better than the Entrepreneurial State policy (package 3B).

In summary, the key point of this exercise is to illustrate that changing the parameters that represent the distributional preferences of the policy-maker does indeed affect the relative effectiveness of different policies and their impact on social welfare. This means that ranking different welfare policies and choosing among them is a complex task that largely depends on the policymakers' preferences for different social groups. These social preferences should, to the extent possible, be made explicit in order to provide a clear conceptual basis to discuss the benefits and costs associated with different policy approaches.[27]

[26] For a similar exercise to study the effects of welfare policies for automation, see Loebbing (2019).

[27] An alternative and complementary interpretation of this exercise is that the different weights assigned to the three social groups do not simply represent the policy maker's distributional preferences for the three groups, but also the *feasibility* of different policies given the political support or opposition that these groups provide to the Government (in line with the concept of "government support function", see Pelzman, 1976; Hillman, 1982). According to this interpretation, our results would suggest that an Entrepreneurial State policy approach to address inequalities would not be feasible if the Government is

Figure 2: Effects of selected policy packages on social welfare for different distributional preferences for C, E, and U. *Upper panel*: weight for U = 0. *Lower panel*: weight for U = 0.9.



subject to strong political pressures from the C group, which make it hard to implement redistribution policies in favor of the E and/or UN groups.

6. Conclusions

The paper has investigated an important question that has so far been neglected in extant research. Since innovation drives economic growth, while also fostering income inequalities, how should public policies address this trade-off? The work has presented a model in which innovation fosters the profits of R&D firms, leading to productivity and GDP per capita growth as well as increasing income inequalities between firms' owners, employed workers, and the unemployed. I have empirically calibrated the model for the US economy and carried out a simulation analysis to investigate the impacts of a range of different public policies that seek to address the inequality effects of innovation. Specifically, the simulation analysis has compared two distinct policy approaches: a standard welfare policy approach in which welfare schemes are financed through higher taxes, and a new Entrepreneurial State policy approach in which welfare programs are funded by using the profits of public R&D firms that develop innovations.

The results of this policy analysis are twofold. First, if aggregate social welfare is defined in terms of a simple utilitarian function (as is the case in most innovation and growth literature), the Entrepreneurial State policy approach is superior to all other policy packages considered in the analysis because it leads at the same time to an improvement in the relative position of unemployed workers, lower inequalities between employed workers and capitalists, as well as higher efficiency and GDP per capita growth. The main reason why the new policy approach performs better than the standard approach is that, since welfare schemes are financed by means of retained profits of public R&D companies, economic growth is not penalized by distortionary effects related to tax increases. Hence, the new approach enables to strike a better balance between redistribution and growth objectives.

Second, though, when I define social welfare as a generalized (or prioritarian) welfare function that assigns different weights to the three groups (capitalists, employed workers, and the unemployed), the benefits and costs of the different policy approaches vary with the policymakers' distributional preferences. In this more general setting, the Entrepreneurial State policy approach becomes progressively less appealing and more costly for society if the group of capitalists (employed workers) is regarded as more (less) important for national social welfare. In short, the policymakers' distributional preferences largely determine the first-best policy that the Government should implement in order to reduce the inequality effects of innovation.

On the whole, the paper combines insights from, and it contributes to, two distinct strands of research. First, research on innovation and income inequalities has recently attracted much scholarly attention. This literature is based on models and empirical analysis of innovation, skill-bias and automation (e.g. Acemoglu and Autor, 2011; Acemoglu and Restrepo, 2018; Aghion et al., 2018). The present work shifts the focus to the analysis of the normative implications of this theme, and it considers a variety of different policy approaches that may be implemented to reduce the inequality effects of technological change, studying not only standard welfare schemes, but also a new approach that is inspired by the Entrepreneurial State literature.

Second, the paper is also related to this recent literature. The Entrepreneurial State approach has so far focused on how public policies can steer the rate and type of technological change in order to address major societal challenges (Mazzucato, 2013; Dosi et al., 2023). Increasing income inequalities is indeed a major challenge for the society, but this important 'mission' has not been explicitly considered yet in the Entrepreneurial State literature. Specifically, the present work puts forward the idea that if public R&D companies invest in innovation alongside private R&D firms, some of their profits could be used to finance welfare programs for the unemployed. The extension of the Entrepreneurial State approach to the study of income inequalities is relevant because it opens up a new dimension in the current debate. The idea proposed in this paper implies that the mission-oriented approach is not only important because it discusses the directionality of the economic system, but it may also create new sources of public revenues that can be used to improve the relative position of the losers of the process of creative destruction, and therefore foster innovation capabilities for all. If an Entrepreneurial State contributes to creating a more equal and more inclusive society, this approach would turn out to be more relevant than if it is only meant to steer the directionality of the system.

The model presented in this paper could be refined and extended in a number of ways. In particular, two possible future extensions are worth noting. One relates to the time horizon of the policy impacts. This paper has focused on steady-state outcomes of the model and how various policies affect these. However, it would be reasonable to think that the effects of some policies may take time to manifest, so that there might be differences and possibly trade-offs between short-term and long-term impacts of welfare policies (Castellacci, 2023). Future extensions of the analysis presented in this paper could therefore investigate how the policy effects on efficiency and equity vary along the transition path, pointing out relative benefits and costs of different policy approaches in the short-run and in the long-run.

The other aspect refers to the role of uncertainty. The present model has largely neglected this dimension for the sake of simplicity. Basically, the model has assumed that at any time t the policy-maker knows what the effects of innovation on efficiency and income inequalities will be at time $t + s$, so that various policy options can be assessed and compared to each other *ex-ante*. However, in a more realistic setting, the uncertainty dimension should play a more important role in this conceptual framework because innovations that are introduced at present can sometimes have unintended spillover effects in the future, such as radically new applications in different domains and sectors that are indeed hard to predict when an innovation is first commercialized. In the presence of uncertainty, the attitude and strategy of the policy-maker turn out to be crucial. Public authorities may take an optimistic stand in the belief that a new technological trajectory will turn out to have some social benefits in the long-run; or they may be more adverse to risk and decide to monitor and regulate the development of new innovations until their socio-economic effects will be known with more certainty. Therefore, policy-makers' attitudes toward technological uncertainty and their different strategies to cope with it represent an important dimension that future extensions of this research could investigate.

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ONLINE APPENDIX

A1: Related models: overview of main features

Model's features	**Aghion et al. (2019)**	**Loebbing (2019)**	**Prettner & Strulik (2020)**	**Jaimovich et al. (2021)**
Firms and sectoral structure	Final goods & intermediate goods sectors	Final goods & intermediate goods sector	Final goods, intermediate goods & R&D sector	Final goods sector only
Workers' heterogeneity	Homogenous workers	Heterogeneous workers (continuum of skills)	Heterogeneous workers (high- vs low-skilled)	Heterogeneous workers (cognitive, routine, manual)
Production function (final goods)	Cobb-Douglas and CES (one type of labor; no capital)	CES (special case)	Cobb-Douglas (two types of labor; robots and capital)	CES (three types of labor; capital; robots)
Type of innovations	Vertical innovations that increase productivity of final goods production	Horizontal innovations in intermediate goods that increase the quality of capital	Blueprints that increase variety of robots employed in production	Automation
R&D production function	Linear	Not specified. R&D input is fixed. R&D output is new varieties of capital	Linear	Not specified
Dynamics of R&D productivity	Increasing (see footnote 10)	Not specified	Function of R&D stock, spillovers and congestion effects	Not specified
Type of technological change	Labor-augmenting	Directed technical change (skilled vs unskilled-bias)	Automation	Automation
Public policies	Not considered	Progressive labor tax	Robot tax; spending transfers; education subsidies	Retraining programs; spending transfers; progressive labor tax
Type of inequalities	Functional income distribution	Wage inequalities	Wage inequalities and functional income distribution	Wage inequalities and functional income distribution

Model's features	**Berg et al. (2021)**	**Thuemmel (2022)**	**Guerrero et al. (2022)**	**Costinot & Werning (2023)**
Firms and sectoral structure	Final goods, wholesale & intermediate goods sectors	Final goods & intermediate goods sector (the latter produces capital including robots)	Final goods & intermediate goods sector (the latter produces robots)	Final goods & intermediate goods sector (the latter produces robots)
Workers' heterogeneity	Heterogeneous workers (skilled, unskilled, capitalists)	Heterogeneous workers (cognitive, routine, manual)	Heterogeneous workers (routine vs non-routine)	Heterogeneous workers (continuum of skills)
Production function (final goods)	Nested CES (two types of labor; capital; robots)	Nested CES (three types of labor; three types of capital)	Task-based CES (two types of labor; robots; no capital)	Cobb-Douglas (labor and capital)
Type of innovations	No R&D and innovation; technical change is represented by prices of robots	No R&D and innovation; technical change is represented by prices of robots	No R&D and innovation; technical change is productivity in robots production	No R&D and innovation; technical change is productivity in robots production
R&D production function	Not specified. Wholesalers produce new varieties of goods	Not specified. Robots and other capital are produced linearly	Not specified	Not specified
Dynamics of R&D productivity	Not specified	Not specified. Analysis of effects of decreasing costs of robots	Not specified. Analysis of increased productivity in robots production	Not specified. Analysis of increased productivity in robots production
Type of technological change	Automation	Automation	Automation	Automation
Public policies	Several policy packages combining welfare spending and increased taxes	Robot tax; progressive labor tax	Robot tax	Robot tax; progressive labor tax
Type of inequalities	Wage inequalities	Wage inequalities	Wage inequalities	Wage inequalities

A2: List of variables and parameters in the model

AGENT-SPECIFIC VARIABLES

Households

U_i	Utility level of household i
C_i	Consumption of household i
LS_i	Labor supply of household i
W_i	Wage level (after bargaining) of household i
GE_i	Gross earnings (before tax) of household i
NE_i	Net earnings (after tax) of household i
S_i	Skill level of household i
SD_i	Skill dummy for household i
ED_i	Employment dummy for household i

Final Goods Firms

Y_{FG}	Output of production in final goods firm
L_{FG}	Labor employed by final goods firm
K_{FG}	Capital employed in production by final goods firm
Π_{FG}	Profits of final goods firm
B_{FG}	Demand for blueprints by final goods firm
P_{FG}	Price of final goods

R&D Firms

P_B	Price of a blueprint
B_{RD}	Blueprints produced by R&D firms
L_{RD}	Labor employed by R&D firm
Π_{RD}	Profits of R&D firm

AGGREGATE VARIABLES

Households

LS	Total labor supply
N_S	Number of skilled workers
N_{US}	Number of unskilled workers
N_E	Number of employed workers
N_{UN}	Number of unemployed workers
N_{HW}	Number of workers whose wage is above the average wage
N_{LW}	Number of workers whose wage is below the average wage
NE_{MIN}	Minimum (lowest) earnings of employed workers

Final Goods Sector

ALK	Total factor productivity in the final goods sector
AL	Labor productivity in the final goods sector
AK	Capital productivity in the final goods sector
LTS	Share of tasks done by skilled labor in the final goods sector
KTS	Share of tasks done by capital in the final goods sector
I	Automation threshold (number of tasks done by capital)
N	Number of tasks done by skilled labor
LD	Total labor demand of final goods sector
W_{FG}	Wage of final goods firms (sectoral)

PARAMETERS

N_H	Number of households (employed + unemployed = skilled + unskilled)
N_F	Number of firms (final goods + R&D firms)
ϵ	Elasticity of labor supply
N_{FG}	Number of final good firms
σ	Elasticity of substitution between K and L
R	Rental rate of capital
N_{TRD}	Total number of R&D firms
N_{RD}	Number of private R&D firms
N_{PUB}	Number of public R&D firms
α_{ALK}	Elasticity of ALK with respect to $\sum B_{RD}$
α_{AL}	Elasticity of AL with respect to $\sum B_{RD}$
α_{AK}	Elasticity of AK with respect to $\sum B_{RD}$
α_N	Elasticity of N with respect to $\sum B_{RD}$
μ	Technological opportunities (mean of normal distribution)
ρ	Inter-temporal knowledge spillovers
β	Mark-up factor
η	Bargaining effect: Elasticity of wage *wrt* skill level
τ	Fraction of private firms that satisfy demand for blueprints
λ	Productivity discount factor in public R&D firms
j	Education subsidy: Probability that unemployed get a new job
SPE	Education subsidy: Lump sum to each unemployed worker
θ	Spending transfer: Generosity of the welfare system
SPP	Fraction of public R&D firms' profits that finance public procurement
TI	Tax rate on income (linear)
ΔTIH	Increase of tax rate for high-wage workers (progressive taxation)
TP	Tax rate on firms' profits
TRD	Tax rate on R&D
REG	Regulation of new technologies
ψ_C	Government's weight on capitalists' welfare
ψ_E	Government's weight on employed workers' welfare
ψ_{UN}	Government's weight on unemployed workers' welfare

A3. Effects of each public policy on the labor share and GDP per capita

To analyze how changes in public policies affect the steady-state level of the labor share, consider a given public policy instrument, say P, and take the derivative of LS^* with respect to P:

$$\frac{\partial LS^*}{\partial P} = \frac{\partial \left(\frac{TE_E}{GDP}\right)}{\partial P} = \frac{GDP \cdot \frac{\partial TE_E}{\partial P} - TE_E \cdot \frac{\partial GDP}{\partial P}}{GDP^2} \tag{63}$$

If this derivative is positive (negative), the effects of changes in policy P will increase (decrease) the labor share, leading to lower (higher) inequalities between employed workers (E) and capitalists (C). Since the denominator is a squared term, it will always be positive. As for the numerator, it will be positive if:

$$GDP \cdot \frac{\partial TE_E}{\partial P} > TE_E \cdot \frac{\partial GDP}{\partial P} \tag{64}$$

and it will be negative if:

$$GDP \cdot \frac{\partial TE_E}{\partial P} < TE_E \cdot \frac{\partial GDP}{\partial P} \tag{64'}$$

Note that GDP per capita is the variable that I use to measure efficiency in the policy analysis.[28] So, a natural interpretation of conditions (64) and (64') is that when the effect of changes in P is positive (negative), the policy increases the earnings of workers relatively more (less) than the increase in the total efficiency of the economy.

By looking at (57), it is easy to see that the effects of changes in each policy variable on the labor share will go through the following mechanisms. First, a given policy will affect labor demand and/or the wage level, hence affecting the workers' earnings components — both at the numerator and the denominator. Second, the policy will have three distinct effects on the terms that compose the denominator: (i) It will affect R&D firms' profits from sales of blueprints; (ii) It will affect FG firms' profits from sales of final goods induced by higher workers' earnings (i.e. due to a demand effect); (iii) It will also have a direct spending effect on GDP (when the policy implies increased public spending).

I will now consider all policies noted in section 2.6 of the paper and, for each of them, I will point out its effects on efficiency (measured by the GDP per capita) and inequality (measured by the labor share). Note that the results noted in propositions 1 to 4 below are based on bivariate simulation analysis in which I study the effects of each policy change on the steady state of the outcome variables, keeping all other model's variables fixed. This means that the following propositions do not consider how a given increase in public spending must be financed by higher public revenues (or, conversely, how a given increase in fiscal revenues can be used to finance additional welfare spending). These propositions, therefore, do not represent the effects of "policy packages", which is the aspect that was discussed in section 4 of the paper.[29]

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[28] Since the size of the population is constant, changes in GDP are reflected in changes in GDP per capita. Hence, these two variables have the same effects on the economy's efficiency.

[29] The exercise presented in this appendix does also represent a useful robustness analysis, that shows how the model's steady-state outcomes change when the policy parameters vary in their entire range. This is also relevant in empirical terms, since econometric evidence suggests that the effects of many public policy programs (such as labor market poly interventions) vary substantially depending on the size of the program and other covariates (see survey in Card et al., 2010).

Proposition 1: Effects of Increasing Public Revenues Through Taxes

P1A: Income Tax. *An increase in the linear income tax rate will decrease the labor share and decrease GDP per capita.*

Figure A1.1 illustrates these relationships using the results of simulation analysis of the model in which the linear income tax rate (TI) takes progressively higher values. An increase in the income tax rate that employed workers pay reduces the total amount of net earnings of workers and their consumption level. This leads to a demand effect that negatively affects profits of FG firms and the GDP per capita in the economy. However, the reduction of net earnings of workers is larger than the reduction of capitalists' profits, so that the labor share declines too, leading to higher inequalities between firms' owners (C) and employed workers (E). Analytically P1A means that:

$$GDP \cdot \frac{\partial TE_E}{\partial TI} < TE_E \cdot \frac{\partial GDP}{\partial TI} \tag{65}$$

The RHS term is a higher negative number than the LHS term, as the derivative of the latter also contains the terms in the derivative of the former (changes in workers' earnings).
Figure A1.2 illustrates the case of a progressive (non-linear) income tax. The effects of a progressive income tax on the labor share and GDP per capita are the same as for the linear tax. However, a progressive tax also has an additional effect: it decreases income inequalities among employed workers (we do not elaborate further on this result because the present paper focuses on income inequalities between C and E, rather than inequalities within the E group).

P1B: Profit Tax. *An increase in the profit tax rate will increase the labor share but reduce GDP per capita.*

Figure A2 shows P1B using simulated data. An increase in the profit tax rate TP that FG and R&D firms have to pay negatively affects these firms' profits, and hence reduces GDP per capita by hitting the supply-side of the economy. Since profits decrease relatively more than GDP, the profit share decreases and the labor share gets larger. Analytically, using condition (64):

$$GDP \cdot \frac{\partial TE_E}{\partial TP} > TE_E \cdot \frac{\partial GDP}{\partial TP} \tag{66}$$

The LHS term is 0, since changes in TP do not affect directly earnings of employed workers; while the RHS term is negative as noted above.

P1C: R&D Tax. *The introduction of a tax on firms' R&D investments will increase the labor share but reduce GDP per capita.*

As illustrated by figure A3, the effects of the introduction of a R&D tax (TRD) are basically the same as those of an increase in the profit tax pointed out by P1B. If R&D companies have to pay an additional tax on the R&D investments they carry out, this tax will lead to a reduction in R&D demand, blueprints, and profits in the R&D sector. This will negatively affect GDP per capita as well as the share of R&D profits (and hence the share of total profits) in the economy. As a consequence, the labor share will increase, so that inequalities between C and E will decrease. In analytical terms, this means that:

$$GDP \cdot \frac{\partial TE_E}{\partial TRD} > TE_E \cdot \frac{\partial GDP}{\partial TRD} \tag{67}$$

Similarly to (66), the LHS term of (67) is 0, since the introduction of a R&D tax does not affect directly the earnings of employed workers; while the RHS term is negative due to the effects of *TRD* on GDP.

Proposition 2: Effects of increasing public revenues through profits of public R&D companies

P2A: Introduction of Public R&D Firms. *An increase in the share of public firms investing in R&D will increase the labor share but reduce GDP per capita.*

Using simulated data, Figure A4 shows that increasing the share of public R&D firms that compete with private R&D companies has two contrasting effects. On one hand, it decreases GDP per capita if public R&D firms are less productive than private firms, since the R&D sector becomes on average less productive, reducing the pace of technological progress and economic growth. On the other hand, if public companies are less productive than private firms, the former will need to hire more skilled workers than the latter in order to produce the same amount of blueprints. Thus, a larger share of public R&D firms in the economy leads to an increase in labor demand, the wage level, and a higher labor share. Hence, P2A formalizes a key idea of this paper: the introduction of public R&D companies is a way to reduce income inequalities between capitalists (C) and employed workers (E), as well as to create additional resources that the Government can use to finance welfare policies (or other spending measures). This new way of financing welfare policies has the advantage that it does not require a raise in tax rates and thus avoids distortionary effects that higher taxes have via decreases in consumption and aggregate demand. Analytically:

$$GDP \cdot \frac{\partial TE_E}{\partial (1-\tau)} > TE_E \cdot \frac{\partial GDP}{\partial (1-\tau)} \tag{68}$$

The left-hand side (LHS) term is 0 because the introduction of public R&D firms has no direct effect on the earnings of employed workers; while the right-hand side (RHS) term is negative as noted above.

P2B: Productivity of Public R&D Firms. *The effects of the introduction of public R&D firms will be magnified when these have lower productivity than private R&D companies.*

Figure A5 shows how variations in the variable measuring public R&D firms' productivity (δ_{PUB}) affect GDP per capita and the labor share. The figure points out that when public R&D firms are substantially less productive than private R&D companies (i.e. for values that lie on the left side of the two graphs in figure A5), GDP per capita will be low, and the labor share will be high. By contrast, the two effects noted in P2A will be less visible when public R&D firms have similar productivity to private R&D companies. Using again condition (64') we have:

$$GDP \cdot \frac{\partial TE_E}{\partial \delta_{\text{PUB}}} < TE_E \cdot \frac{\partial GDP}{\partial \delta_{\text{PUB}}} \tag{69}$$

The LHS of (69) is 0 while the RHS is positive because GDP increases when the productivity of public R&D firms increases.

Proposition 3: Effects of increasing public welfare spending

P3A: Transfers to Unemployed Workers *Public transfers to unemployed workers will increase GDP per capita but also decrease the labor share.*

Shifting the focus from the effects of changes in public revenues to the effects of changes in public welfare spending, P3A points out two contrasting impacts of a standard policy scheme that provides subsistence transfers to unemployed workers (SPT). As shown by Figure A6 with simulated data, this policy will, on the one hand, increase GDP per capita through demand and a multiplier effect. In fact, unemployed workers will use subsistence transfers to finance their consumption activities, which will increase the profits of FG firms. This demand effect will also foster labor demand and the wage level, thus increasing employed workers' earnings. On the other hand, though, this policy will decrease the labor share as the increase of firms' profits will be larger than the increase of employed workers' earnings:

$$GDP \cdot \frac{\partial TE_E}{\partial SPT} < TE_E \cdot \frac{\partial GDP}{\partial SPT} \tag{70}$$

Both the RHS and the LHS are positive, but the former is higher than the latter because the derivative of the term on the RHS also includes the terms in the derivative of the LHS. Further, the RHS also includes the terms referring to profit changes due to demand effects and the public spending component (which is also a component of GDP). Interestingly, P3A points out that this type of welfare policy has contrasting effects on the functional distribution of income: providing transfers to unemployed workers decreases directly income inequalities between UN and the other two groups but at the same time, via demand effects, it increases the gap between C and E (as measured by the labor share).

P3B: Training for Unemployed Workers *Publicly funded training for unemployed workers will reduce the unemployment rate and increase GDP per capita, but also decrease the labor share.*

Figure A7 illustrates simulation results that point out the effects of publicly funded training for unemployed workers. The mechanisms that explain these relationships are twofold. First, this type of policy will over time decrease the unemployment rate. The higher number of employed workers in the economy will increase the total amount of earnings perceived by employed workers and therefore also increase demand for consumption goods and the profits of FG firms. These demand-related effects explain the increase of GDP per capita that is induced by the training policy. Second, the profit share will increase and the labor share will decrease. This is because the increase of profits of FG firms driven by the expansion of demand is larger than the increase of earnings of employed workers; and also because the policy has a direct spending effect that increases GDP and lowers the labor share. Analytically this means that:

$$GDP \cdot \frac{\partial TE_E}{\partial SPE} < TE_E \cdot \frac{\partial GDP}{\partial SPE} \tag{71}$$

Similarly to what noted for condition (70) above, both the RHS and the LHS are positive but the RHS term is larger than the LHS term as the derivative on the RHS contains also the terms included in the derivative on the LHS. In addition, the RHS also includes the terms referring to profit changes due to demand effects and the public spending component of GDP. In summary, similarly to what observed in relation to P3A, a training policy for the unemployed leads to an improvement for the group UN (reducing the number of unemployed workers), while at the same time it fosters income inequalities between C and E.

Proposition 4: Effects of public procurement and technology regulation

P4A: Reinvesting Public R&D Profits in Public Procurement of R&D. *If public firms invest in R&D, using their revenues to finance public procurement of R&D will increase GDP per capita but also decrease the labor share.*

As noted earlier, profits of public R&D companies are publicly owned and they can therefore be used to finance welfare spending and/or reinvested to create further innovations. In the latter case, public R&D firms' profits can finance public procurement of R&D that seeks to develop innovations in specific technological trajectories that have high societal relevance. The effects of this policy are shown in figure A8. Specifically, the impacts on GDP per capita will be positive, since this policy increases the demand for blueprints that accelerate technological progress and productivity growth. Further, higher labor demand in the R&D sector will also increase the wage level, fostering earnings and consumption of employed workers. These productivity and demand effects explain the growth of GDP per capita that is induced by public procurement of R&D. On the other hand, however, the labor share will decrease because the growth of profits will be larger than the growth of workers' earnings:

$$GDP \cdot \frac{\partial TE_E}{\partial TSPRD} < TE_E \cdot \frac{\partial GDP}{\partial TSPRD} \tag{72}$$

The proof of (72) is the same as the one noted for (71). A general implication of P4A in terms of the functional distribution of income is that while the introduction of public R&D companies decreases income inequalities between C and E (see P2A), using public firms' profits to finance further R&D negatively moderates (attenuates) this effect.

P4B: Technology Regulation. *Introducing a regulation that limits the diffusion of (some) innovations will increase the labor share but also decrease GDP per capita.*

Figure A9 uses simulated data to show this proposition. Regarding the effects of this policy on GDP per capita, the introduction of a technology regulation (REG) implies that R&D companies are not allowed to sell newly developed blueprints, and this negatively hits firms' profits in the R&D sector. In turn, this negatively affects GDP per capita as well as the share of R&D profits, and hence the share of total profits in the economy. This means also that the labor share will increase, so that this policy leads to a reduction of income inequalities between the groups C and E. The analytical condition is as follows:

$$GDP \cdot \frac{\partial TE_E}{\partial REG} > TE_E \cdot \frac{\partial GDP}{\partial REG} \tag{73}$$

The LHS term is 0 because technology regulation has no direct effect on the earnings of employed workers; the RHS term is negative due to the policy's effect on GDP through reduced R&D firms' profits.

Figure A1.1: Linear income tax: Effects on the labor share and GDP per capita.

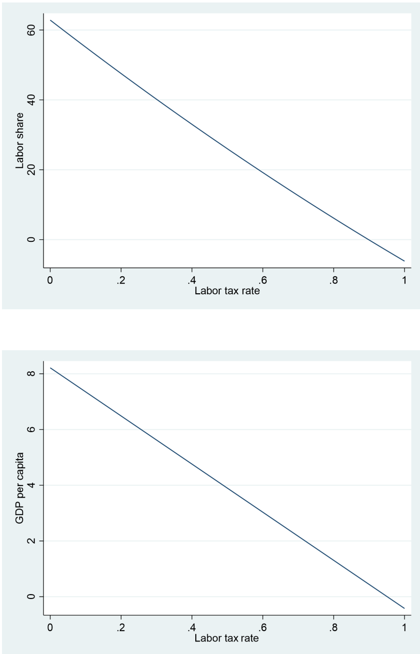


Figure A1.2: Progressive income tax: Effects on the labor share and GDP per capita.

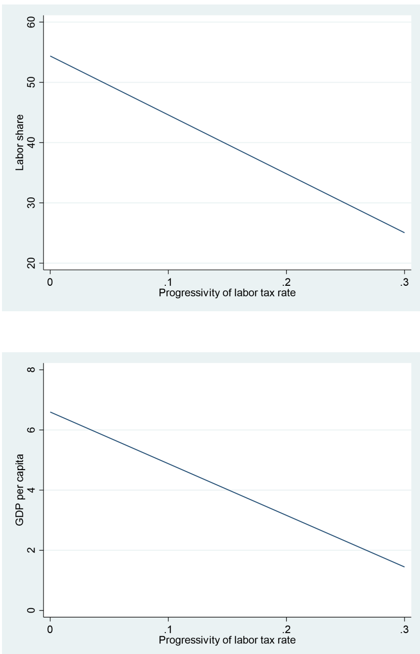
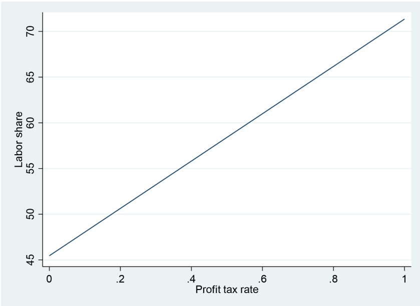


Figure A2: Profit tax: Effects on the labor share and GDP per capita.



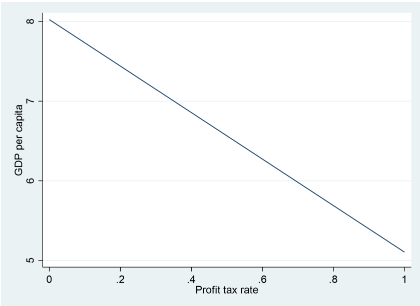
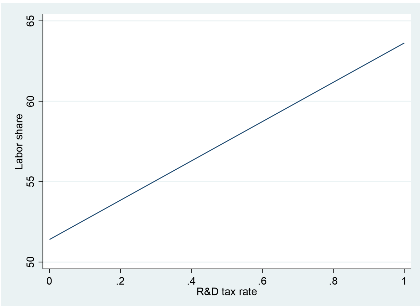


Figure A3: R&D tax: Effects on the labor share and GDP per capita.



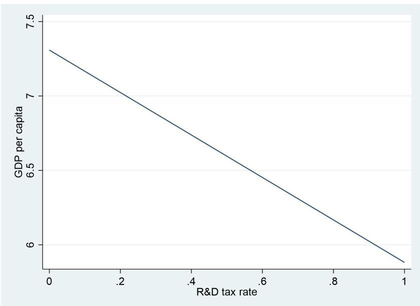


Figure A4: Share of public R&D firms: Effects on the labor share and GDP per capita.

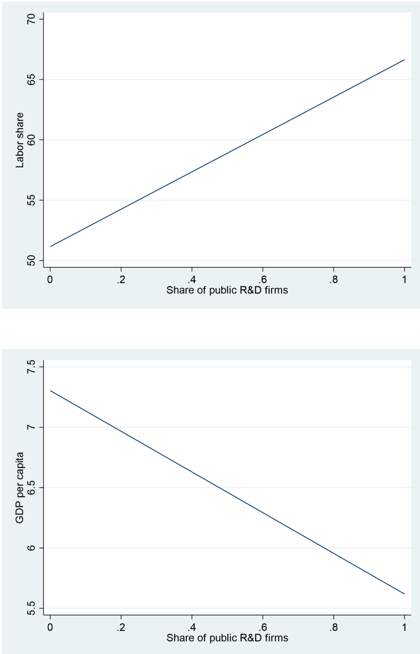


Figure A5: Productivity of public R&D firms: Effects on the labor share and GDP per capita.

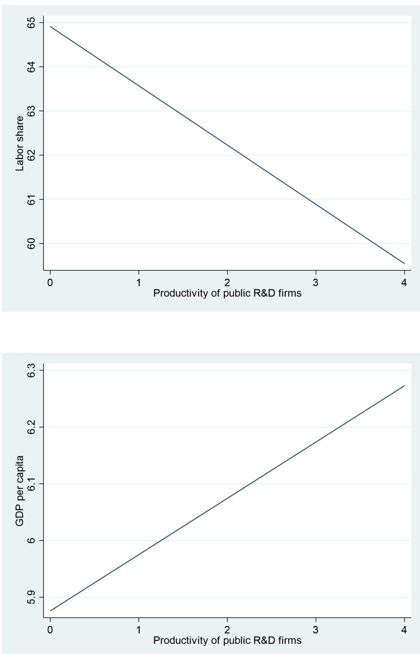


Figure A6: Public transfers to the unemployed: Effects on the labor share and GDP per capita.

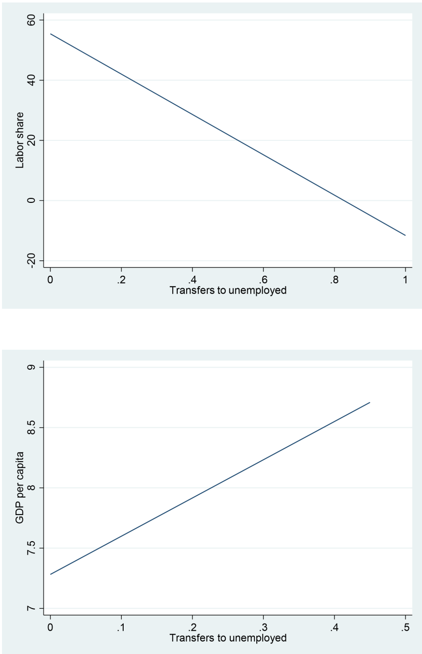


Figure A7: Spending for education (retraining) policy for the unemployed: Effects on the labor share and GDP per capita.

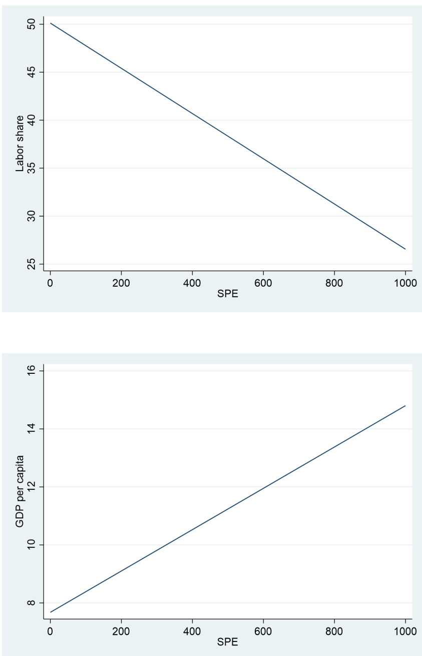
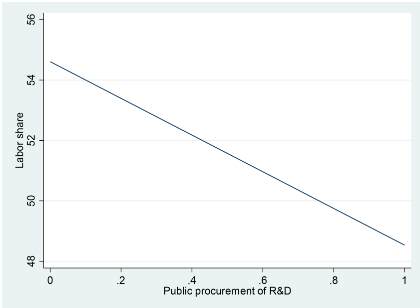


Figure A8: Share of public R&D profits re-invested in public procurement: Effects on the labor share and GDP per capita.



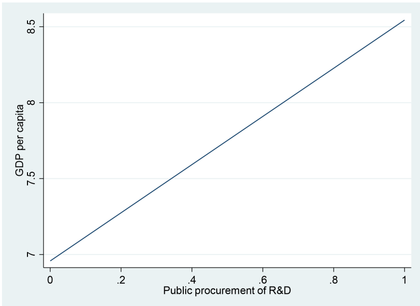
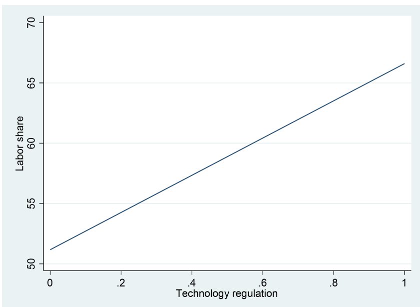
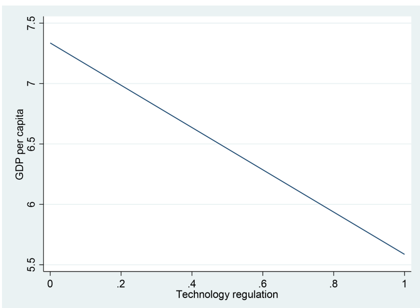


Figure A9: Technology regulation: Effects on the labor share and GDP per capita.





A4: Calibration of Parameters and Initial Values of Variables in Baseline Model

Parameters		
N_H	Number of households	1000
ϵ	Elasticity of labor supply	1
N_{FG}	Number of final good firms	100
σ	Elasticity of substitution between K and L	1
R	Rental rate of capital	1
N_{TRD}	Number of R&D firms	25
α_{ALK}	Elasticity of ALK with respect to $\sum BRD$	0
α_{AL}	Elasticity of AL with respect to $\sum BRD$	0
α_{AK}	Elasticity of AK with respect to $\sum BRD$	0
α_N	Elasticity of N with respect to $\sum BRD$	0
μ	Technological opportunities (mean)	0.5
ρ	Inter-temporal knowledge spillovers	0.5
β	Mark-up factor	0.2
η	Bargaining effect: Elasticity of wage *wrt* skill level	1
χ	Fraction of blueprints that lead to scientific output	0
τ	Fraction of private firms that satisfy demand for blueprints	0
λ	Productivity discount factor in public R&D firms	1
SPP	Fraction of public R&D profits that is reinvested in procurement	0
j	Education: Probability that unemployed get a new job	0
SPE	Education subsidy: Lump sum to each unemployed worker	0
θ	Spending transfer: Generosity of the welfare system	0.5
TI	Tax on income	0.15
TP	Tax on firms' profits	0.25
TRD	Tax on R&D	0
REG	Regulation of new technologies	0
ψ_C	Government's weight on capitalists' welfare	0.33
ψ_E	Government's weight on employed workers' welfare	0.33
ψ_{UN}	Government's weight on unemployed workers' welfare	0.33
P_{FG}	Price of final goods	1
Variables		
ALK	Total factor productivity	1
AL	Labor productivity	1
AK	Capital productivity	1
LTS	Share of tasks done by skilled labor	0.5
KTS	Share of tasks done by capital	0.5
I	Automation threshold (number of tasks done by capital)	0.2
N	Number of tasks done by skilled labor	1
A	Stock of technological knowledge	1
δ	Productivity of R&D	1