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For the Benefit of All: Fiscal Policies and Equity-Efficiency Trade-offs in the Age of Automation

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Abstract

Many studies predict massive job losses and real wage decline as a result of the ongoing widespread automation of production, a trend that may be further aggravated by the COVID-19 crisis. Yet automation is also expected to raise productivity and output. How can we share the gains from automation more widely, for the benefit of all? And what are the attendant equity-efficiency trade-offs? We analyze this issue by considering the effects of fiscal policies that seek to redistribute the gains from automation and address income inequality. We use a dynamic general equilibrium model with monopolistic competition, including a novel specification linking corporate power to automation. While fiscal policy cannot eliminate the classic equity-efficiency trade-offs, it can help improve them, reducing inequality at small or no loss of output. This is particularly so when policy takes advantage of novel, less distortive transmission channels of fiscal policy created by the empirically observed link between corporate market power and automation.

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I. INTRODUCTION

The steady march of automation raises the question how its benefits and costs should be shared by society. Wider use of automation has two effects on the economy. It raises productivity and output, a welcome effect. At the same time, it adversely affects demand for low-skilled labor and the wages of low-skilled workers, exacerbating inequality. Therefore, technological change affects both output and the income/wealth distribution in the economy. Thus, exploring how its benefits and costs could be more widely shared in society is a highly relevant analytical and policy question.

While technological progress has always had supporters and detractors, empirical analyses lean in favor of technology optimists in the long run. For example, investment in robotics raised GDP per capita by 10 percent in OECD countries from 1993 to 2016 (CEBR, 2017). Automation could raise productivity growth globally by 0.8–1.4 percent annually in the long run (McKinsey, 2017). Using industry-level panel data for 17 countries, Graetz and Michaels (2018) find that increased robot use has already raised productivity. Venturini (2019) uses patent data in a sample of industrialized countries in 1990–2014 and finds that automation has so far accounted for 8 percent of the observed productivity increase.

The failure of workers to share in the fruits of the technological progress is also well publicized (Krugman, 2019; Sachs, 2017; Summers, 2016). Empirical studies highlight job destruction and its consequences to income distribution during the long transition period to a new equilibrium. They suggest a double-edged sword feature of the widespread use of automation: improving economic efficiency while raising income and wealth inequality and reducing the labor's share in national income.

These effects are accompanied by increasing market power of large corporations. Empirical studies highlight a correlation between technological progress and market concentration. The observed effects include: widening productivity differences between top ranked firms and others (Andrews et al., 2015); a positive correlation between the speed of technological progress and concentration (Autor et al., 2020); a relatively small number of "superstar" firms in the upper tail of the mark-up distribution (Diez et al., 2018; Stiebale et al., 2020); and a possible contribution of an increase in mark-up to a declining trend of the labor share (Karabarbounis and Neiman, 2014; Kehrig and Vincent, 2021).

The COVID-19 crisis may further strengthen these trends. The crisis directly affects income distribution through reducing demand for some industries/segments of workers. Also, the crisis could cause structural transformation in labor markets that could further adversely affect disposable income of workers, especially during the transition period. For instance:

- *First, the pandemic and the increasing use of automation have already exerted a significant distributional impact on the economy.* Aspachs et al., (2020) used a real-time high-frequency data from bank records on the wages and public transfers in Spain, finding wage inequality

increased by almost 30 percent during the COVID-19 crisis. Data on job losses during the crisis point to a higher job separation rate for unskilled workers (Palomino et al., 2020). Likewise, past pandemics also demonstrate a persistent distributional impact on workers with less than college education (Furceri et al., 2020).

- *Second, the crisis has fostered a wider use of robots/automation.* To keep social distance, the role of robots has recently been increasing rapidly. For example, robots have been used more for: (i) running polymerase chain reaction tests for COVID; (ii) measuring the temperature of a person; (iii) using ultraviolet light to sanitize a toilet; (iv) transporting food to restaurants; (v) spraying disinfectant; (vi) helping elderly people; and (vii) cooking at fast-food restaurants.[2] This would reduce demand for labor even after the pandemic, leading to structural transformation of an economy as well as labor markets (IMF, 2021a).

In view of these developments, this paper analyzes how fiscal policies could mitigate the adverse effects of technological progress while preserving its benefits. Adding the COVID-related impact to the changes due to the rise in automation over the past decades could further complicate income/inequality trade-offs. How to alleviate these effects, while preserving automation-driven productivity growth, is now an acute question for policymakers. We focus on how tax, spending, and non-fiscal measures could help address the adverse effects of technological progress on labor income, employment, and inequality.

While this is a well-defined question, solving it is not simple because of the classic "equity-efficiency" trade-off. Reducing inequality and investing in public goods (e.g., education, infrastructure) generally requires more tax revenue. However, in the absence of large-scale lump-sum taxes, any additional taxation inherently increases economic distortions and may reduce output. Desirable policy packages to effectively mitigate the adverse effect of tecnological progress from automation need to balance this trade-off.

Our contributions to the literature are threefold. First, we study various redistributive and spending policies in the automated economy, focusing on their effects on output and income distribution during the transition period to a new equilibrim. To our knowledge, this is the first paper that studies the effects of comprehensive fiscal and regulatory policy packages to address equity-efficiency trade-offs caused by automation with transition dynamics. Second, we discuss the welfare implications of these packages based on different criteria. Third, we investigate the effects of several fiscal policy packages when market power, modeled as the price mark-up, is endogenous to (depends on) the degree of automation. Our innovation lies in explicitly linking corporations' market power to the degree of their automation. This creates interesting tax policy effects, as taxation of automation––and corporations' excess profits––becomes less distortionary than under perfect competition or exogenous price mark-ups. While the model used in the paper

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[2] https://jp.mobile.reuters.com/news/picture/coronavirus-fighting-robots-and-drones-idJPRTX7HZF6.

is illustrative one, to our knowledge, the paper is the first study to highlight the interactions of tax policy and market power in the context of automation.

Our workhorse model is the dynamic general equilibrium (DGE) model developed by Berg et al., (2018), augmented by mark-up pricing. First, we add an exogenous price mark-up to the model following the formulation of Dixit and Stiglitz's (1977) monopolistic competition model. Then we link the mark-up to the degree of automation in an empirically plausible way to account for the observed correlation between the two developments. We analyze the effectiveness of various revenue and expenditure fiscal measures bundled in policy packages to account for their interactions in a general equilibrium setup.

Our main findings are the following: (i) fiscal policies can improve the equity-efficiency trade-off exacerbated by automation; (ii) the economic costs of taxing productive capital would be substantial in the long run; (iii) taxing automation can reduce inequality but lead to large income losses in the long term; and (iv) when automation increases corporations' market power (the price mark-up), fiscal policy acts through new, less distortionary transmission channels, which could alleviate the efficiency-inequality trade-off, especially by taxing robots and excess profits from the mark-up.

The paper is organized as follows. The next section briefly summarizes the recent literature on the impact of automation on employment and income distribution, and fiscal policies to mitigate the adverse distributional effect of technological progress. Section III introduces the DGE model and policy packages. Section IV presents the transitional dynamics between the two equilibrium states, including the impact of policy packages. Section V compares the welfare impact of the policy packages. Section VI presents the impact of selected policy packages in the extended model, in which the corporate power depends on the degree of automation. After sensitivity analysis in Section VII, policy implications will be discussed in the concluding Section VIII. Technical details of the models and their calibration are summarized in Online Annex I.

II. LITERATURE

A. Empirical Studies on the Impact of Automation on Employment and Income Distribution

Empirical studies highlight job destruction and its consequences for income distribution during the transition period to the new equlibrium. For example, job disruption by automation has contributed to rising income inequality in the past (Mckay et al., 2019), and it may take decades for the adjustment to get completed, with substantial increases in unemployment in the interim (Furman and Seamans, 2019). Acemoglu and Restrepo (2020) use U.S. labor market data to find: one more robot per thousand workers reduces employment by 0.2–0.35 percentage points and wages by 0.25–0.5 percent. Several studies find that the "winner-take-all" feature of automation technology may lower labor share and raise the share of top one percentile income (Guellec and Paunov, 2020; Autor et al., 2020). Bessen (2016) finds: (i)

computer use is associated with major workforce dislocation; and (ii) low wage occupations tend to lose jobs while high-wage occupations gain, raising inequality. Also, displaced workers' earning losses have increased since the mid-1990s (Farber, 2010). Gardberg et al., (2020) find that education reduces the risk of suffering from automation.

Forward-looking studies anticipate further substantial job loss before completing transition. For instance, McKinsey (2017) reports that about half of today's work activities could be automated by 2055 or earlier. In addition, 14 percent of jobs are at high risk of automation and 32 percent are likely to see significant changes in the next 15–20 years (OECD, 2019). Frey and Osborne (2017) find that 47 percent of total US employment is at high risk of losing jobs owing to computerization; however, Arntz et al., (2017) put that figure at 9 percent when job-level heterogeneity of tasks is accounted for. Dengler and Matthes (2018) find that 15 percent of German employees are in jobs that face high risk of automation.

B. Impact of the COVID-19 Crisis on Employment, Income Distribution, and Market Power

The COVID-19 crisis has disproportionaly affected low-income people and raised inequality. Using granular data, Chetty et al., (2020) show that the shock has resulted in a significant job separation for low-income employees. Also, Karpman and Acs (2020) point out that income losses have disproportionately hurt lower income groups. Early evidence from job posting data shows that most of the job cuts have been in low-income areas and areas with greater income inequality (Campello et al., 2020).

Structural transformation triggered by the crisis may further raise corporate power and reduce the share of labor. Adapting the production structure to intensive use of automation could safeguard businesses from economic disruption, such as the one witnessed during the pandemic (Chernoff and Warman, 2020). On the other hand, more intensive use of digitalized technology could raise firms' market power. Bigger firms invest a higher share of their sales in intangibles (Crouzet and Eberly, 2019).

Similarly, network effects are an important driving force behind market structure (Rysman, 2004; Calvano and Polo, 2021). Direct network effects mean that the utility that a user receives from a particular service is directly affected by the number of other users, like telecommunication networks. Indirect network effects arise when the number of users on one side of the market attracts more users on the other market side, like the Amazon platform where more buyers attract more sellers (Haucap and Stühmeier, 2016). An important characteristic of these markets is the intangible capital used in creating and sustaining the platforms. This makes the use of the platforms efficient when achieving larger size of users, which can easily lead to highly concentrated market structures (Weyl, 2010). This in turn has spillovers to a declining labor share (Karabarbounis and Neiman, 2014; Grullon et al., 2019; Autor et al., 2020; Kehrig and Vincent, 2021), which could further raise income inequality.

C. Policy Impact to Address the Trade-off of Automation by Quantitative Models

Given the rapid automation, there is a debate on the necessity and feasibility of fiscal policies to help achieve fair allocation of gains from technological progress.[3] From the viewpoint of the equity-efficiency trade-off, the discussions so far could be divided into three groups: [4] (i) The optimal tax theory based on the Diamond-Mirrlees' (1971) framework, mostly relying on **static models**; (ii) technology optimism, emphasizing the explosive costs of taxing capital/automation in **the long run**; and (iii) a focus on the **transition dynamics** between the old and the new equilibrium in DGE models. These groups reflect multiple dimensions of the trade-off created by automation (e.g., benefits of redistribution vs. distorting production, and short-run vs. long-run distortions).

Studies based on the Diamond-Mirrlees (1971)'s optimal taxation theory advise taxing robots. There have been many studies in this line, including Thuemmel (2018), Stiglitz (2018), Korinek and Stiglitz (2019), Zhang (2019), and Guerreiro et al., (2021). They insist that taxing robots should raise demand for goods substitutable for robots and their factor prices (i.e., unskilled wages). Therefore, imposing a tax on goods substitutable for unskilled workers (i.e., robots) could help address the adverse distributional impact, provided finite tax elasticity of robot demand. For instance, Costinot and Werning (2018) find that optimal tax rate on robots in the U.S. ranges from 1 to 3.7 percent (with labor supply elasticity from 0.1 to 0.5). However, these studies do not discuss income redistribution policies through spending measures.

On the other hand, technology optimists are against taxing robots due to the large long-run costs. Atkinson (2019) and The Economist (2017) stress the benefits (i.e., job creation, productivity increase, and ultimately higher economic growth) of technological progress in the long run. Their emphasis on the explosive costs of taxing robots, including its opportunity costs, is in line with the classic discussion on the zero optimal tax rate on capital in the steady state (Judd, 1985; Chamley, 1986).[5] However, little is discussed about the transition period to the new steady state in the context of automation.

Comprehensive assessment of the effective policies to address the equity-efficiency trade-off requires analysis of the transition dynamics between steady states. Two observations that highlight the different timing of the realization of the benefits and costs of technological

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[3] Numerous studies model the effect of technological progress on income distribution and job destruction, but fiscal policies are absent in many of them. For example, Berg et al., (2018) employ a neoclassical growth model with robot augmented technological progress and find that automation is good for growth and bad for equality due to the fall of real wages. Bessen (2019) points the importance of demand in mediating the impact of automation. Acemoglu and Restrepo (2018, 2019) model automation as the process of machines replacing tasks previously performed by labor to better describe behaviors of the labor share in national income and wages.

[4] Abbott and Bogenschneider (2017) support taxing robots to shift tax burden from workers to firms, given that widespread tax deductions incentivize firms to overinvest in robots (e.g., robots do not pay social security taxes).

[5] Straub and Werning (2020) overturn the conclusion of Chamley-Judd's zero capital income taxation in the long run, proving that the long-run tax on capital is positive and significant when the intertemporal elasticity of substitution of the capitalists is below one (like our setting of this parameter).

progress for workers warrant an extensive analysis of the transition period from the short run to long run. First, job destruction is more rapid than reallocation of displaced workers to newly created tasks/jobs. Second, while redistribution quickly affects workers' disposable income, distortions created by higher taxation, especially slowed capital accumulation, emerge mainly in the long run.

- ***Most of the extant studies only partially cover transition dynamics***. IMF (2018) analyzes the role of education spending to support labor reallocation and redistribution policy in response to technological progress in steady state.[6] Jaimovich et al., (2020) construct a DGE model with a number of fiscal policy instruments (taxes, unemployment benefits, universal basic income, etc.), but focus only on the long-run effect. On the other hand, Gaspar et al., (2017) analyze the growth-inequality trade-off by simulating the social welfare impact of policy packages. But they focus on a relatively short period (one to five years), assuming only idiosyncratic productivity shocks to workers' productivity, rather than sustained technological progress augmented by automation.

- ***Some studies simulate transition dynamics, but they focus on the impact of a single policy measure, rather than comparing different policy packages.*** A group of studies,[7] which use a simple two-period overlapping generations model to analyze a redistribution policy from old to young financed by taxing the old (Sachs and Kotlikoff, 2012; Sachs et al., 2015, Benzell et al., 2018; Prettner and Strulik, 2020).[8] However, in their simulations, each generation is treated as one period, without describing intra-generational transition dynamics. By contrast, Hémous and Olsen (2021) use a representative agent endogenous growth model with automation and innovation in an economy with low- and high-skilled workers. They find that taxing automation innovation increases low-skilled wages in the short run but reduces them in the long run.

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[6] The model treats an increase in the elasticity of substitution between labor (fixed) and other production factors (e.g., capital) or a decline in capital prices as "technological progress."

[7] The studies show that higher productivity is a potential gain for all, conditional on appropriate redistribution from winners to losers. In their framework, all individuals are assumed to start their working life as being low-skilled and may later in life invest in education and physical capital. When exogenous technological advances increase the productivity of machines that substitute for low-skilled labor, young individuals respond by investing less in education reflecting lower wages. Therefore, income redistribution from old to young financed by capital income tax could improve social welfare through higher human capital accumulation and savings.

[8] Prettner and Strulik (2020) show that: (i) innovation in machines leads to more automation and income/wealth inequality; and (ii) raising the income of low-skilled individuals is difficult without severe side effects on growth and welfare by redistribution policies. In the model, technological progress is described as an increase in a variety of machines in the production process.

III. THE MODEL AND POLICY PACKAGES

A. The Model

We add monopolistic competition and a rich set of fiscal instruments to a standard DGE model with automation. The model, based on Berg et al., (2018) features a closed *real* economy with agents blessed with perfect foresight and a set up of no price rigidities (i.e., wages and prices move flexibly to clear the goods and labor markets in every period). Since all households and firms optimize their behavior, the welfare effects, including from policy changes, are well defined and measureable. To this base model, we add monopolitsic competition (a price mark-up), à la Dixit and Stiglitz (1977). The mark-up is constant in the baseline model. Later, we expand our model to make the mark-up endogenously determined, depending on the degree of automation. This extension provides an additional motivation to the firm to expand automation—namely, higher profit margin—and thus opens an additional channel for fiscal policy influence on the model economy (see Section VI). The model is also enriched with several tax instruments, including distortionary taxes on labor income, capital income, robots, and mark-ups.

The model includes three types of household agents (skilled and unskilled workers and owners of capital), a government, and three types of firms, with several assumptions. The assumptions aim to make the problem tractable and clearly highlight the equity-efficiency trade-off between technological progress and fiscal policy (see Online Annex I for details).[9]

- The two types of workers choose their labor supply to maximize their utility, given the after-tax wages.[10] Unskilled workers and robots (the machines brought by automation) are substitutes, while skilled workers and robots are complements. Dividing workers into two types, unskilled and skilled, intends to approximate the higher risk of automation for unskilled workers, including those that have faced "job destruction" during the COVID-19 crisis (Chetty et al., 2020; Aspachs et al., 2020; IMF, 2021a).

- Only owners of capital can save to smooth consumption over time (i.e., workers do not save and owners of capital do not work). Savings are invested in automation and traditional capital stock, suggesting that all firms in the model are held only by the owners of capital.

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[9] A few assumptions could be modified in future work to explore the implications of a more flexible specification. These include: (i) introducing also medium skilled workers, as pointed by Goos et al., (2014). While this could make the model more realistic, as long as the medium skilled workers are substitutable to robots and their income remains below that of the highly-skilled workers, the main messages of the paper do not change; (ii) introducing the entry and exit of heterogenous firms with respect to productivity; (iii) explicitly analyzing the impact of (monopolistic) competition among heterogenous firms to innovation which leads to productivity gains; and (iv) expanding the model to an open economy, which may introduce another trade-off due to tax competition and capital mobility.

[10] As commonly done in the literature, we use the Greenwood-Hercowitz-Huffman preferences to suppress the income effect of wage changes on labor supply.

This seeks to characterize the "winner-take-all" feature of automation as well as "the rise of the top one percent is likely very tied up with technology" (Summers, 2016).

- The government has multiple instruments (taxes and expenditures) to implement fiscal policy, subject to the balanced budget in each period (i.e., no accumulation of debt). Other than the intertemporal budget constraint, the government does not face any implementation problems, like susceptibility to rent-seeking behavior (e.g., lobbying from vested interests).

- On the production side, a competitive firm maximizes its profit by choosing capital, robots, and two types of labor to produce intermediate goods. A wholesale firm buys (homogeneous) intermediate goods and transform them into heterogeneous goods. The wholesale firm has monopolistic power in the intermediate goods market to set the price of intermediate goods, which allows a price mark-up. Retail firms produce final goods by combining a continuum of the heterogeneous goods. The aggregate price is influenced by the degree of monopolistic competition.

- Technological progress is augmented only by automation. In other words, we assume no spillovers from technological progress in robots to productivity of any other factor inputs.

- The interetemporal discount rate is set at 0.5 percent. This rate should be understood as the equilibrium interest rate in real terms. This low value reflects by the trends of low real interest rates observed in many advanced countries, reflecting lower potential growth and abundant savings in recent years, expected to persist in the near future.[11]

B. Policy Packages

The government can implement policy packages as a combination of different policy instruments. The packages intend to mitigate the adverse distributional effect of robot augmented technological progress, which is created by the substitutions of robots for unskilled workers, subject to the equity-efficiency. We compare policy packages to understand their effectiveness to address the problem. Analyzing a package is superior to analyzing isolated policies, as it allows the policymaker to improve the equity-efficiency trade-off more effectively. For example, while a value added tax (VAT) is not itself progressive, using its receipts for social protection purpose could make a package financed by VAT progressive.

The policy packages in this paper have the following distinct features:

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[11] Several robustness checks are conducted with different values of this rate ranging from 0.1 percent and up all the way to 6 percent. While the paper presents only the result of 6 percent discount rate as a sensitivity analysis, the main story is pretty robust to the choice of discount rates (the differences are only in degree, not in kind).

- ***First, there are two types of fiscal policy measures:*** taxes (on capital income, wages, consumption, wealth, robots, and mark-up) and spending (universal lump-sum transfers to all agents, targeted transfer to low-skilled workers, and education spending).

- ***Second, there is no uncertainty or commitment issues in policy implementation.*** Policy parameters (tax rates and spending) are kept constant once they are set—the government is commited to implement these policies—regardless of subsequent dynamics.

- ***Third, we add assumptions that produce a "no free lunch" feature of policy packages.*** They include: (i) almost all taxes are distortionary, as they distort the agent's choice of consumption/saving/work and thus exact an economic toll; (ii) all expenditure cuts have economic costs (i.e., no savings from cutting inefficient expenditure are assumed); and (iii) the budget balances in each period (i.e., there is no debt accumulation).[12]

- ***Fourth, as a corollary of the "no free lunch" feature, the government needs to raise taxes to finance redistribution/additional spending.*** This is done in an environment of increased concentration of income, partly reflecting "winner-take-all" technological progress. The benefit of extra spending relative to the cost of additional taxes determines the effectiveness of policy packages to achieve redistribution.

- ***Fifth, the fiscal policy packages are normalized to allow their comparability.*** Policy packages raise additional tax receipts of one percent of GDP in period one to finance new expenditure.

The simulation packages are divided into the following four groups: (i) The baseline; (ii) a tax-and-redistribution group raises taxes to redistribute the receipts to the people adversely affected by automation; (iii) a tax-and-invest group uses the additional tax receipts to support productive spending (for example, education spending could help some unskilled workers become skilled);[13] and (iv) a non-fiscal measure group intends to directly mitigate the adverse distributional effect of technological progress on unskilled workers' disposable income. For example, fixing the unskilled wage at the initial state may be seen as preserving their disposable income. Also, anti-monopoly regulation could be included in the group, although it is out of the scope of the paper.

The following packages are analyzed in the paper, with their detailed description presented in the Annex.

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[12] This assumption keeps the exercise tractable. Over the long run, it does not materially affect the results as long as all accumulated debt is assumed to be repaid. If debt is allowed to increase and stay elevated, this is tantamount to using up an initial endowment and therefore spending more than what is raised in taxes. Such a development is not subject to our analysis, which focuses on the trade-off created by having to raise money for spending in a distortionary way.

[13] IMF (2018) reports that a 4 percentage points shift from unskilled to medium/high skilled workers costs 1-3 percent of GDP, based on education costs in the U.S. At the midpoint of the range, the implied elasticity is 0.22.

Baseline

- A tax on capital income (factor income from holding of traditional capital and robots as well as income from the mark-up) and taxes on wage income (skilled and unskilled) are set at 13 percent.[14] Tax receipts are evenly transferred to the three households in a lump-sum way (this intends to eliminate distortions related to the use of tax revenue and allow for a clear comparison with the effects of the policy packages).

Tax-and-Redistribute Group

- Raise the tax on capital income to finance targeted transfer to unskilled workers.

- Introduce a wealth tax on holding of traditional capital and robots to finance targeted transfer to unskilled workers.

- Introduce a tax on consumption to finance targeted transfer to unskilled workers.

- Introduce a tax on the stock of robots to finance targeted transfer to unskilled workers.

- Introduce an additional tax on the mark-up (a tax on excess profit due to market power) to finance targeted transfer to unskilled workers. In our model, intermediate goods firms face perfect competition (with zero profits), while wholesale firms face monopolistic competition and earn a mark-up (Online Annex I). We could interpret the tax imposed on the mark-up as a tax on excess profit due to market power.

- Raise the tax on capital income to finance a tax cut on unskilled workers' wage income.

Tax-and-Invest Group

- Raise the tax on capital income to finance education spending to allow a switch from unskilled to skilled jobs.

Non-Fiscal Measure Group

- Rigid unskilled wage—fix the unskilled wage at the initial steady state.

IV. TRANSITION DYNAMICS OF A MODEL ECONOMY WITH POLICY PACKAGES

This section presents the transition dynamics of the model economy driven by technological progress augmented by automation and policy packages aiming to alleviate the attendant adverse effects. We first briefly present the baseline from both the production and income sides. When describing the policy packages, we will focus on the production side of

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[14] The baseline is calibrated to deliver total tax revenue of 13 percent of GDP, consistent with the latest U.S. national accounts data.

the model economy (i.e., growth accounting effects) for each group. The impact of the packages on income distribution will be investigated in the next section to illustrate their welfare implications. Throughout this section, we employ the monopolistic competition model with constant exogenous mark-up.

A.   Baseline

Productivity gains augmented by automation raise overall output. Technological progress (total factor productivity (TFP) is marked as green in Figure 1 raises robot investment, which is marked as gray). More accumulation of robots leads to increased demand for skilled labor (blue) and raises their wages. Traditional capital accumulation (orange) falls during the first ten years, due to the shift of investment toward robots to seek the benefits of their increased productivity. Replacing unskilled workers by more productive robots reduces both their employment (yellow) and wages. In the long run, more accumulation of robots begins to raise demand for traditional capital, sufficiently offsetting the initial shift of investment toward robots.

However, windfalls from the technological progress mainly benefit the owners of capital, while adversely affecting unskilled workers' disposable income. Figure 2 shows the evolution of disposable income of the three agents over time. Owners of capital (gray) are unquestionably the big winner. Skilled workers (blue) also benefit from technological progress in the long run, as they combine with both robots and traditional capital, which rebounds in the long run. In contrast, unskilled workers' disposable income (yellow) declines, reflecting the lower demand for their services.

Figure 1. Growth Accounting: Baseline
(Deviation from the initial steady state, percent)

Figure 2. Disposable Income Decomposition: Baseline
(Deviation from the initial steady state, percent)

Source: IMF staff calculations.
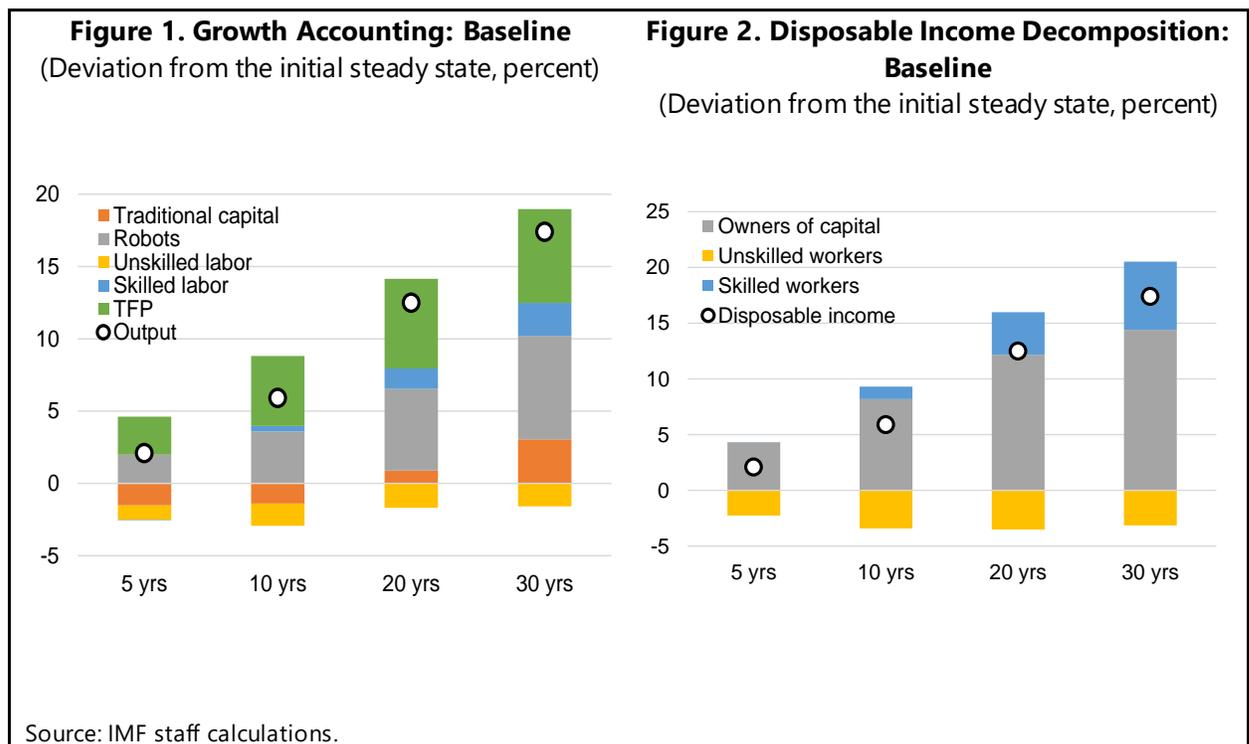
B. Tax-and-Redistribute Group of Policy Packages

This group of policy packages redistributes additional tax receipts (one percent of GDP) to unskilled workers. The rationale for such a policy is to redistribute more widely the gains from automation––generally, from the winners to the losers as highlighted by the baseline. Conceptually, all the packages in the group face the equity-efficiency trade-off. Raising a distortionary tax to generate additional revenue adversely affects resource allocation in the production process, especially capital accumulation. This distortion has to be compared against the positive effects of redistribution toward unskilled workers (see Section V). Throughout the paper, <u>the dynamics are presented as deviations from the dynamics under the baseline</u>. This allows us to focus on the effects of the policy interventions.

- ***Raising the capital income tax or the wealth tax leads to a notable output and employment loss in the long run*** (Figures 3 and 4). The increased tax burden on capital reduces the after-tax return of investment, weighing on both robot (gray) and traditional capital (orange) accumulation. Lower capital accumulation weakens demand for skilled labor (blue) and their wages. Since the only wealth in our model comes in the form of productive capital (traditional and robots), it is not surprising that both taxes have similar economic consequences.[15]

- ***Raising the consumption tax is less harmful for investment and output than others but no panacea.*** A consumption tax affects capital accumulation only at the time of its introduction. It still reduces labor supply of both types (Figure 5) as it changes the relative price of consumption goods to wages (note that our model does not include the income effect for labor supply). The adverse effect on output is much smaller than any other redistribution packages so far, in line with the well-documented less distortionary nature of consumption taxes relative to direct taxes on capital and labor.[16]

- ***A robot tax effectively contains the substitution of robots for labor, with a large long-run output cost.*** While its operational feasibility is still unclear, it is an interesting intellectual exercise to introduce a robot tax. Such tax should address the output-equity trade-off not only through an income transfer of the proceeds but also by containing the substitution from unskilled labor to robots. Much slower robot accumulation (gray in Figure 6) raises demand for unskilled workers (yellow) as well as investment in traditional capital (orange) in the short run. However, in the long run, lower robot accumulation reduces the productivity of

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[15] It is worth noting that the negative effect of the wealth tax stems directly from the assumption that it is levied on productive capital. Indeed, Kocherlakota (2005) argues against wealth taxes in a dynamic optimal taxation framework based on similar considerations. Taxing wealth that does not directly participate in the production process (e.g., real estate, expensive art, cars, yachts etc.) would not generate adverse effects on investment.

[16] The positive contribution of TFP reflects substitution from unskilled labor to robots with much higher productivity (and increasing over time). In this case, the substitution raises the share of robots. Since technological progress is augmented only by robots, the higher share of robots means more contribution of TFP.

traditional capital and skilled labor (blue), weakening demand for them.[17] This reflects the complementarities between robots and skilled labor (and, to a lesser extent, traditional capital).

- ***The mark-up tax demonstrates smaller efficiency costs compared to those of a capital income tax.*** This package could be thought as introducing a tax on the "excess profit" due to market power. Since the mark-up is set constant in the model, this tax does not directly affect capitalists' rate of return on savings. Rather, the tax indirectly affects capital accumulation through reducing available resources for investment, i.e., savings of the owners of capital. This feature (a tax on rent) makes the efficiency costs of this tax much smaller than the costs of raising the tax on capital income (see Figure 7 vs. Figure 3).

- ***The unskilled wage tax cut shows short-term gains and long-term costs.*** The package raises the supply of (and demand for) unskilled labor (yellow in Figure 8), reducing the accumulation of robots (again, the impact may be increased by the assumption of no income effect for labor supply). This, together with increased investment in traditional capital (by shifting investment from robots), raises output in the short run. However, as time passes, the larger share of unskilled labor, less productive than robots, weighs on the productivity of (and thus demand for) traditional capital (orange) and skilled labor (blue). As a result, output is lower than the baseline in the long run.

C. Tax-and-Invest Group

The adverse effects of automation could also be tackled by using public spending to raise output and employment. Productive public spending can in principle expand the production frontier and provide better employment and wage opportunities to workers.

Education spending can partially mitigate the adverse effects of automation.[18] Higher supply of skilled labor (blue) as a result of education spending raises the return of investment to traditional capital (orange) and robots (gray). Reduced supply of unskilled labor (yellow) further raises demand for automation. Accumulation of robots remains strong, very close to the baseline, while accumulation of traditional capital is less adversely affected by the tax on capital income than in other scenarios (Figure 9).[19] On net, output is still lower than the baseline due to distorted capital accumulation by the additional tax on capital income, but higher in the medium/long run than the tax-and-redistribution package.

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[17] The negative contribution of TFP reflects a smaller share of robots under the robot tax than in the baseline.

[18] Raising education spending by 1 percent of GDP shifts 2.2 percent of total population from the unskilled to the skilled group. This is calibrated based on IMF (2018). See also Footnote 13.

[19] In this policy package, the positive contribution of TFP reflects: (i) the larger share of robots; and (ii) productivity gains by shifting unskilled to skilled workers, where the latter have higher productivity.

Error! Bookmark not defined.**Figure 3.
Raising Tax on Capital Income**
(Accumulated change relative to the baseline,
percentage points)
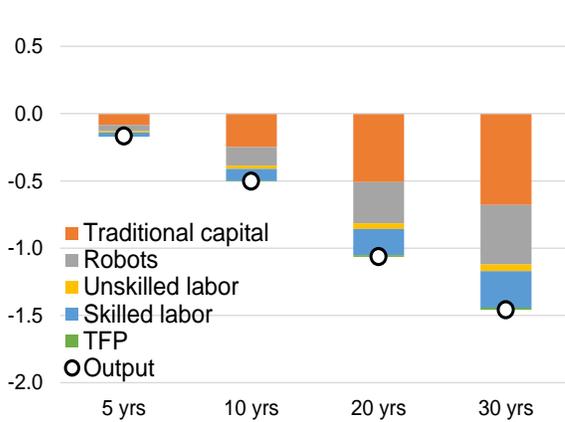
Figure 4. Wealth Tax
(Accumulated change relative to the baseline,
percentage points)

- Traditional capital
- Robots
- Unskilled labor
- Skilled labor
- TFP
- Output
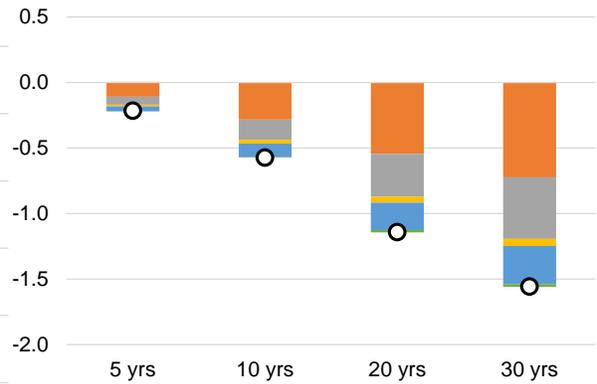
Figure 5. Consumption Tax
(Accumulated change relative to the baseline,
percentage points)
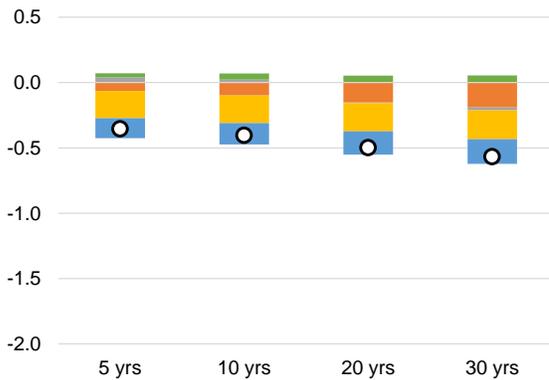
Figure 6. Robot Tax
(Accumulated change relative to the baseline,
percentage points)
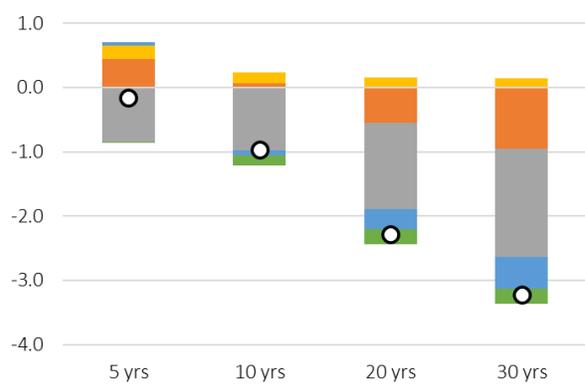
Source: IMF staff calculations.

Figure 7. Raising Tax on Mark-up
(Accumulated change relative to the baseline
percentage points)
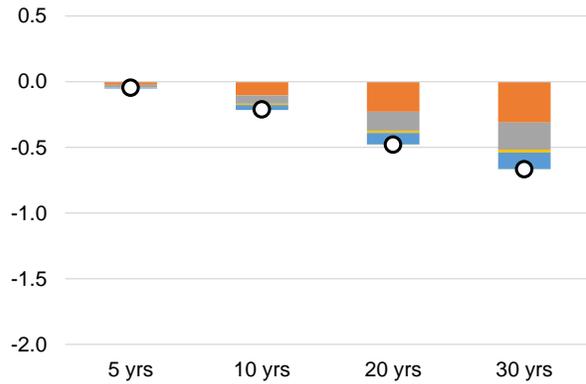
**Figure 8. Growth Accounting: Lowering Tax
on Unskilled Wage**
(Accumulated change relative to the baseline,
percentage points)
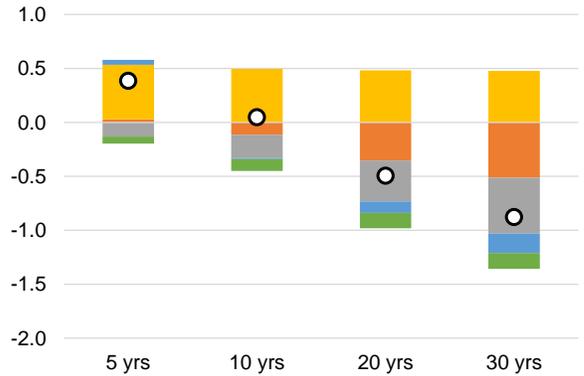
**Figure 9. Raising Tax on Capital Income for
Education Spending**
(Accumulated change relative to the baseline,
percentage points)
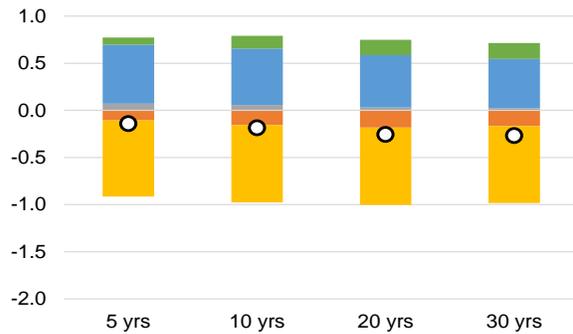
**Figure 10. Growth Accounting: Rigid
Unskilled Wage**
(Accumulated change relative to the baseline,
percentage points)
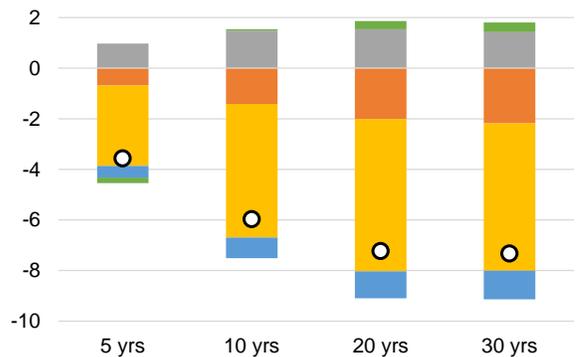
Source: IMF staff calculations.

D. Non-Fiscal Measure Group

This policy seeks income redistribution by directly intervening into the distribution of market income, without relying on fiscal policy instruments. For example, since automation substantially reduces the unskilled labor wage under the baseline, fixing the unskilled wage at the initial level may be seen as a way to preserve their disposable income.

However, a rigid unskilled wage severely hurts production efficiency (Figure 10).[20] As the rigid unskilled wage is set at the level higher than the "market clearing wage", demand for unskilled labor declines sharply and the speed of automation increases relative to the baseline. Furthermore, the scarcity of unskilled workers weighs on the return of traditional capital and thus on demand for skilled workers despite the faster automation. In sum, while depending on the level at which unskilled wage is fixed, output under the package is much lower than the baseline and any other packages.[21]

V.   COMPARING WELFARE ACROSS POLICY PACKAGES DURING TRANSITION

Welfare comparison requires yardsticks to compare how well different policy packages address the equity-efficiency trade-off.[22] This is a difficult political economy question, given the wide spectrum of ways to define social welfare and the different weights attached to higher overall income vs. higher equality (which comes at the expense of losing some income in the aggregate).

We compare the welfare effects of different policy packages with four different criteria. We think they could highlight the challenges that the policy packages face to address the equity-efficiency trade-off deepened by technological progress. Note that we are not searching for the optimal policy, but rather assessing the performance of the chosen policy packages against the baseline.

- *Criterion 1. Equity vs. efficiency: average income and inequality.* For a given level of average income (per capita disposable income), a package with lower inequality than the baseline can be interpreted as a better policy package. We use the Gini coefficient as a proxy for inequality.

- *Criterion 2. The evolution of disposable income of the two types of workers.* The first criterion, focusing only on an aggregate inequality indicator, may mask the developments of workers' disposable income—the main concern of the paper. With this second criterion, social welfare improves when both types of workers, skilled and unskilled, have higher

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[20] Positive TFP contribution reflects the larger share of robots with rigid unskilled wage than the comparator, driven by the substitution effect.

[21] The very large adverse impact reflects the level of wage frozen at the initial state (which is more than 10 percent higher than the market level of unskilled wage under the baseline).

[22] Given the severe adverse impact of the rigid unskilled wage policy package, as clearly demonstrated in the previous section, this package is not explicitly discussed in this section. Intuitively, the unskilled wage is fixed at the initial steady state level, which is now above the marginal productivity of unskilled workers, unskilled labor employment declines much more than under the baseline, reducing the total disposable income of the group of unskilled workers. Also, the additional efficiency cost due to reduced employment of unskilled workers substantially hurts output. Additional robots cannot sufficiently offset the negative impact from the reduced unskilled labor, because of their much smaller share relative to unskilled labor in the production technology. As a result, output declines and inequality of disposable income distribution increases considerably.

disposable income. Omitting the disposable income of the owners of capital can be justified, because small changes in their consumption are unlikely to have a significant effect on social welfare due to both capitalists' very small population share and their high level of consumption.

- ***Criterion 3. Equally Distributed Equivalent Income (EDEI).*** The paper follows the discussion in IMF (2017). The EDEI provides the summary of the welfare impact of policy packages, depending on the degree of inequality aversion. EDEI is defined as the level of income per person that–if equally distributed–would enable society to reach the same level of welfare as the existing distribution. Intuitively, for any two sets of income distribution with the same average income per capita, the one with less dispersion of disposable income across agents delivers better social welfare. The difference in the two EDEIs increases as the degree of inequality aversion—the concavity of the social welfare function (SWF)—rises.

- ***Criterion 4.*** **Social welfare based on each agent's utility function**. Online Annex II discusses social welfare based on the present value of the utility of each agent, aggregated using population weights in Online Annex I. We use the utility function proposed by Greenwood et al., (1988), which is commonly used in the literature to mute wealth effects. It implies that the labor supply will only depend on real wages and not on consumption.

A. Income and Inequality

This criterion compares the policy packages focusing on their impact on the average income and inequality. The horizontal axis of Figure 11 shows the aggregate income (GDP) per capita and the vertical axis shows the group Gini coefficient. Both are expressed as deviations from the baseline. Points in the southeast quadrant reflect combinations of lower inequality with higher income level (i.e., a clearly better outcome than under the baseline). Accordingly, points in the northwest quadrant indicate an inferior outcome (higher inequality and lower income). Points in the other two quadrants involve trade-offs between inequality and income. More generally, points to the south-east of other points dominate the latter, as they reflect more desirable combinations of income and inequality. Each arrow shows the evolution of output and inequality under each policy package. Four different types of dots correspond to years 5, 10, 20, and 30, respectively.

Figure 11. Exogenous Mark-up: Income and Inequality

(GDP per capita, relative to the baseline, percentage points)

Source: IMF staff calculations.
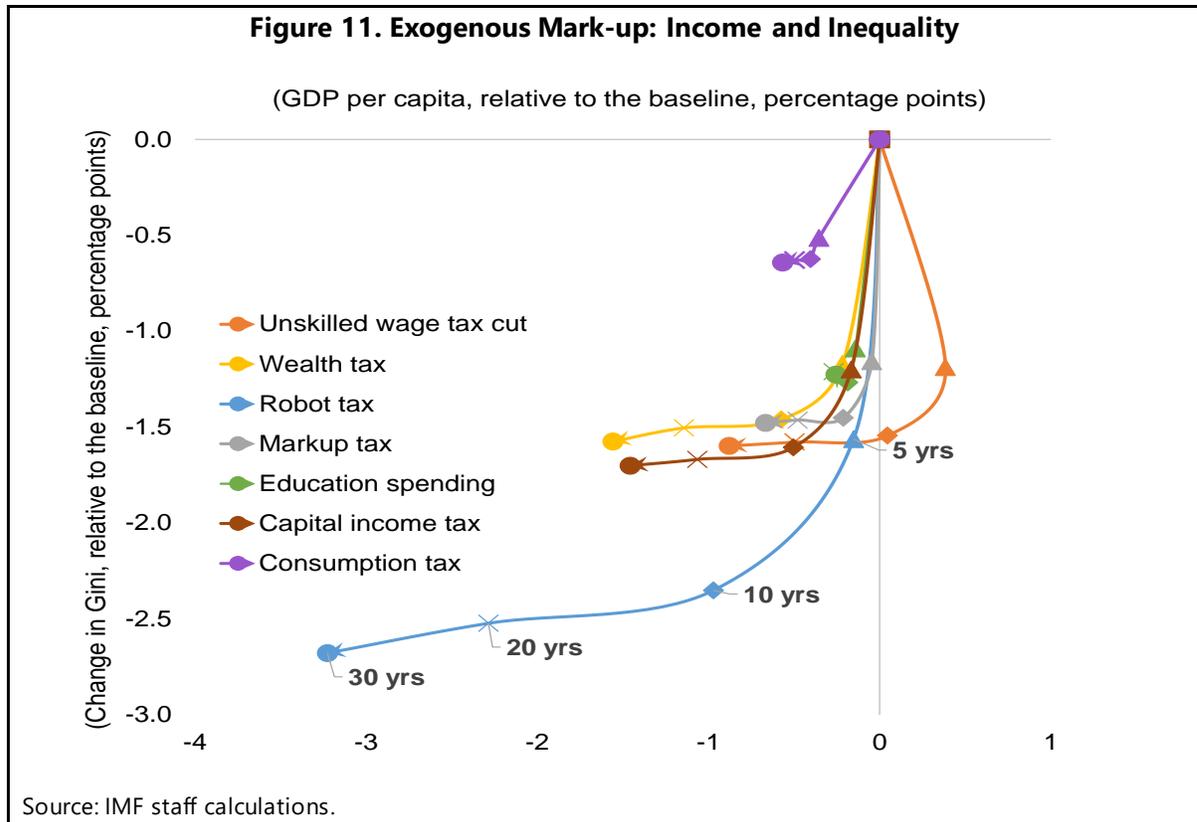
Policy packages show a trade-off between addressing income level and inequality. The trade-off reflects the cost (lower output) of extra taxation and the gain of transferring extra income to the lower-income agents to reduce inequality. At a five-year horizon, the policymakers' choice should be between the unskilled wage tax cut and the robot tax, as these two dominate the others but not each other. The unskilled wage tax cut both increases the disposable income of unskilled (low-income) workers and stimulates their labor supply, resulting in higher output than the baseline (and the robot tax package). The robot tax, however, reduces inequality by slightly more because its incidence and the additional production distortion created by taxing robots more directly affect the disposable income of the owners of capital. Also, the wage tax cut raises labor supply and unskilled disposable income more than the transfer of the proceeds of the robot tax to the unskilled workers. Starting with the 10-year horizon, however, other packages become "admissible" as well. For example, a 3 percent loss in income per capita after 30 years, created by the robot tax (relative to the rising baseline) may be well justified to reduce inequality (the Gini) by 2.5 percentage points, depending on societal preferences. But other choices, with smaller decline in income level and less improvement in inequality, are still acceptable (i.e., not dominated by the robot tax) from the view of the trade-off. Without information on the society's preference over income and inequality, we cannot further shorten the list.

B. Disposable Income of the Two Types of Workers

The second criterion focuses on the evolution of the disposable incomes of the two types of workers over time. The horizontal axis of Figure 12 shows per capita disposable income of unskilled workers and the vertical axis shows that of skilled workers. Here ponts in the north-east quadrant are unambiguously better than the baseline (marking higher income for both types of workers), and points in the south-west quadrant—clearly worse. More generally, any policy that moves the outcome toward the northeast constitutes an improvement, as it raises the income of both types of workers.

Figure 12. Exogenous Mark-up: Disposable Incomes

(Unskilled workers, relative to the baseline, percentage points)

Source: IMF staff calculations.
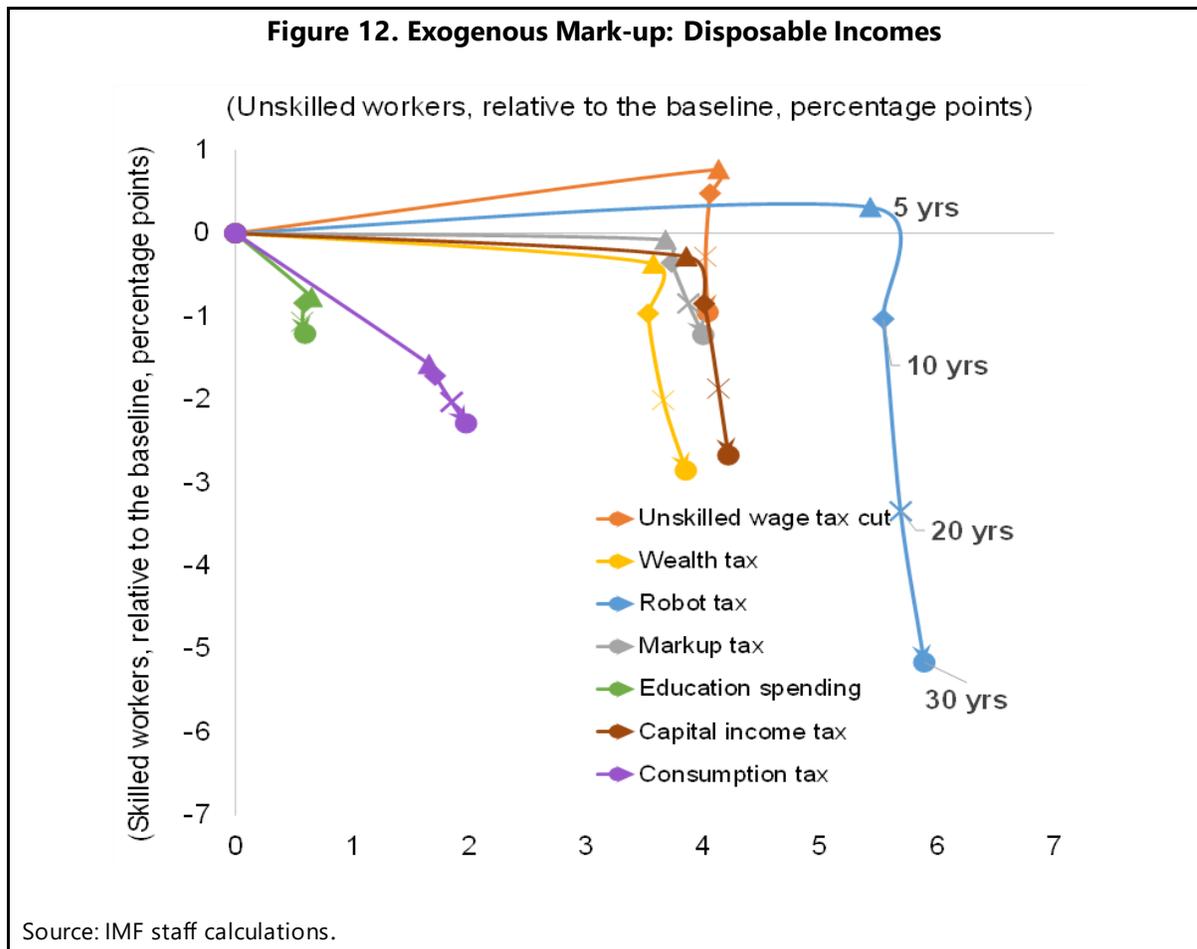
Most packages still involve trade-offs beyond 10 years, reflecting the distortions caused by higher taxes needed to finance transfers to unskilled workers. At a 5–10 year horizon, the unskilled wage tax cut and robot tax dominate the other packages (and the baseline), delivering superior combinations of disposable incomes for both types of workers. At longer horizons, however, this criterion "admits" many packages involving trade-offs between the dynamics of disposable incomes of the two types of workers (see Figure 26). Further information on the society's preference over income and inequality is needed to shorten the list, as in the case of average income vs. inequality.

C. Equally Distributed Equivalent Income (EDEI)

Next, we compare the welfare effects of the packages based on the EDEI. The EDEI expresses how much society is willing to give up of the current average income to be in a world where everyone is certain to receive the same average income. Thus, a positive change in the EDEI signals welfare improvement. The effectiveness of policy packages, measured by an improvement in the EDEI relative to the baseline, depends on the society's preference on income inequality relative to output level (inequality aversion). A higher EDEI indicates higher level of social welfare. Since estimates of inequality aversions range widely and may differ across countries and over time, we consider point estimates in the range between 0.2 and 3, spanning from very low to very high degrees of inequality aversion.[23]

Figure 13. Equally Distributed Equivalent Income

NPV of Equally Distributed Equivalent Income (EDEI) of Policy
Packages, Different Inequality Aversion
(Deviation from the Baseline, Discount rate = 0.5 percent, percent)

Source: IMF staff calculations.
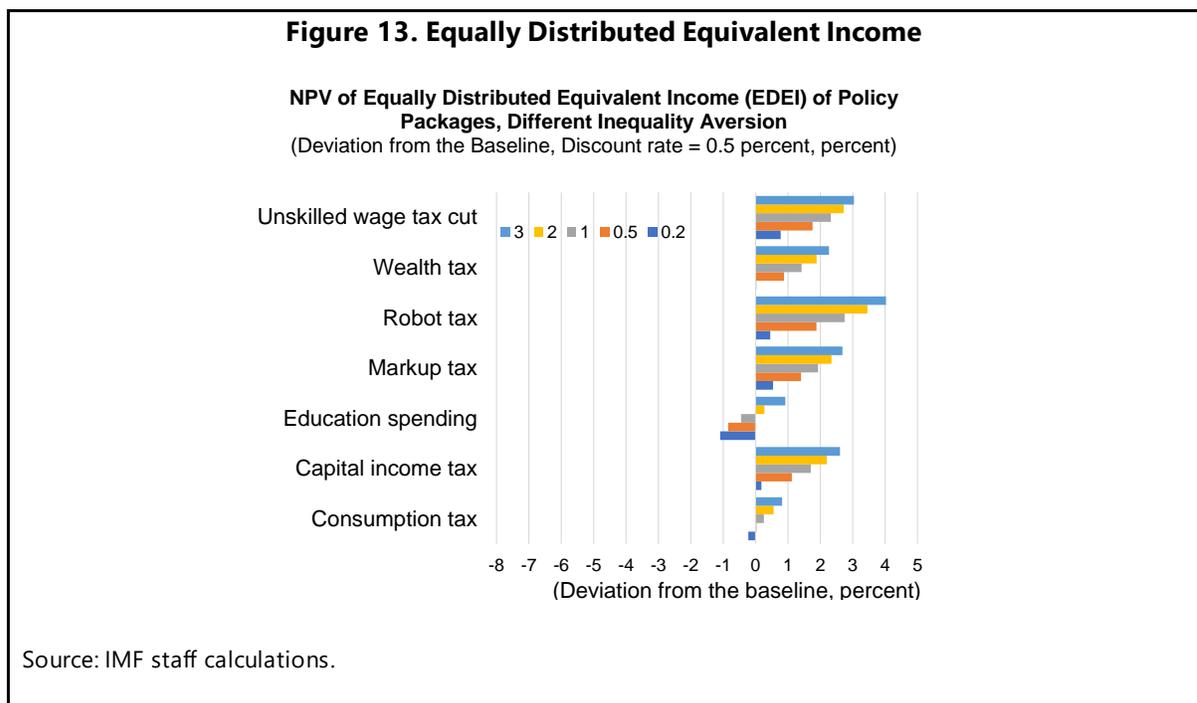
The results using the EDEI measure contrast starkly with the previous results using the other two welfare indicators. Figure 13 presents the net present value of the EDEI, discounted by 0.5 percent per year.[24] As inequality aversion increases, or the society puts more weight on reducing inequality along the equity-efficiency trade-off, packages that address inequality more aggressively come to achive higher EDEI than the baseline. This is well highlighted by a sharp improvement in the EDEI of the robot tax as the aversion increases above 0.5, relative to other

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[23] Gaspar et al., (2017) argue that the inequality aversion in advanced economies may be close to the low end of this range. Estimates suggest that the degree of inequality aversion accepted by the society is less than 0.5 in the U.S., and Finnish experimental data indicate that the median inequality aversion lies below 0.5 t here. However, in view of recent evidence of societal preferences leaning toward more progressive taxation (IMF, 2021b), the paper examines much larger inequality aversion cases too.

[24] The present value of the EDEI is computed over 30 years, to maintain consistency with the first two criteria.

packages. The unskilled wage income tax cut, which hurts production efficiency less but also reduces inequality less than the robot tax, is the best package when the inequality aversion is very low. On the other hand, packages leaning toward addressing efficiency (e.g., education spending and consumption tax) show a lower welfare effect than most others for all levels of inequality aversion.

D. Social Welfare Based on Utility Function

Social welfare, defined as the present value of the weighted average of utility of all household agents shows the robot tax as the best policy package, followed by the mark-up tax and the capital income tax.[25] We use a traditional specification, in which utility is derived from consumption and leisure. As explained above, the robot tax and the mark-up tax increase the employment––and thus income/consumption––of unskilled workers relative to the baseline; the effect is strengthened further through the ineqiality-reducing redistribution of the receipts. The capital income tax raises welfare primarily through the redistribution of the receipts. On the other hand, the unskilled wage tax cut is slightly inferior to the above-mentioned three packages. This reflects the disutility of working, which was not included in the previous three criteria.[26]

Figure 14. Social Welfare Function

Social Welfare of Policy Packages
(Deviation from the Baseline, percent, discount rate = 0.5 percent annually)

(Deviation from the baseline, percent)
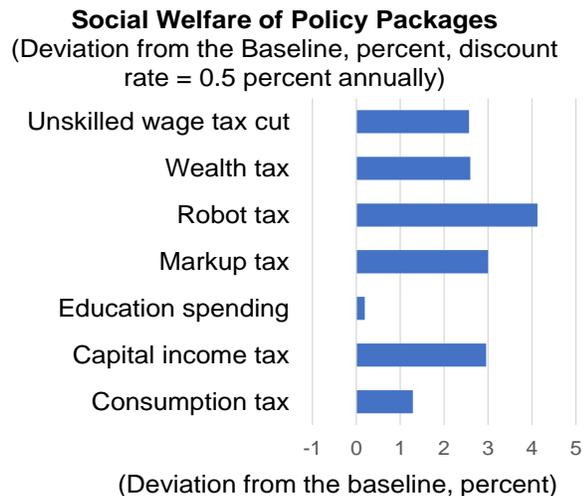
Source: IMF staff calculations.

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[25] See Online Appendix II for fuller elaboration of social welfare analysis for each policy package. The present value of the social welfare is computed over 30 years. However, extending the computation period did not affect the main story.

[26] This effect is strengthened by the assumption of no income effect on labor supply.

VI. ENDOGENOUS MARK-UP—AN ILLUSTRATIVE EXAMPLE

A. Relationship Between Automation and Price Mark-up

We introduce a positive relationship between automation and the price mark-up. As discussed in Section II and Section III-A, this exercise is motivated by recent observations of a positive correlation between automation and market concentration, or increased mark-up, (e.g., Acemoglu et al., 2020). While this story is intuitively sensible, there has been no concrete theoretical model to characterize the link between automation and mark-up from first principles. Here, as an illustrative exercise, we postulate a positive correlation between the price mark-up and the usage of robots in an ad-hoc but empirically plausible way (details of the extended model are presented in the Online Annex I). Further work can substantiate the link between automation and market power and put it on theoretically sound foundations.

Specifically, we assume that the mark-up increases as robot density (robots per worker) increases. That is,

$$markup_t = \frac{1}{\theta_t} = \frac{(rd_t)^x}{m_0}, rd_t = \frac{Z_{d,t}}{S_{d,t} + L_{d,t}}$$

where θ_t is the inverse of mark-up (the price of the intermediate goods), m_o is a fixed parameter that pins down the level of mark-up in the initial state, rd_t is robot density defined by demand for robots $Z_{d,t}$ divided by the sum of demand for skilled labor $S_{d,t}$ and demand for unskilled labor $L_{d,t}$, and $x > 0$ is the elasticity of mark-up with respect to robot density. The concept of robot density is widely used in the literature, which makes it easier to calibrate the parameters of mark-up function.[27] One possible story to explain such positive correlation is network effects: large firms (e.g., Big Tech companies) can take advantage of owning the platform and other digitalization-related networks (which make marginal costs lower than average costs), because costs to construct such network would be an entry barrier for other companies, leading to both high market shares and large mark-ups (Kenney and Zysman, 2020). The owners of capital internalize this positive correlation when they select savings, and investment to robots and traditional capital in their optimization problem.

We examine most of the packages discussed in the previous sections to illustrate whether and how the results change when the mark-up depends on automation. The selection aims to highlight important features of the fiscal policy. The packages include: (i) the baseline; (ii) raising the tax on capital income and use its receipts for targeted transfers to unskilled workers; (iii) raising the tax on mark-up and use its receipts for targeted transfers to unskilled workers; (iv) introduce a robot tax and use its receipts for the targeted transfers; (v) raising the tax on capital income and use its receipts to reduce the tax on unskilled wage income; and (vi) raising the tax

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[27] We use the mark-up elasticity calculated from the U.S. time series data. The parameter is calibrated to match the data on mark-up level, 1.19, estimated by Barkai (2020), in the initial steady state.

on capital income to finance education spending to switch unskilled workers to skilled workers (spending measure to seek more efficiency). As in the previous sections, all results show the deviation from the baseline.

B. Impact of Endogenous Mark-up on Production Efficiency: Two Additional Transmission Channels

Allowing an endogenous mark-up introduces an additional transmission channel of fiscal policy. Recall that so far we have discussed two traditional channels of fiscal policy transmission: (i) through (distortionary) taxation, it *affects relative prices* between the factors of production; and (ii) it also engages in *direct income redistribution by taxation/transfers*. Now we have a third channel: as the price mark-up depends on the stock of robots relative to labor inputs, policy packages that slow the accumulation of robots also reduce the mark-up (excess profits) and thus expand the production frontier. This *efficiency gain channel* is not present in the model with an exogenous mark-up, which is not affected by taxation.

The new transmission channel creates notable differences in the impact of policy packages under the endogenous mark-up model compared to the exogenous mark-up case. The robot tax and the mark-up tax can clearly highlight these differences:

- *Efficiency gains from reduced mark-ups mitigate the efficiency cost of the robot tax*. (Figure 15). The reduced mark-up helps raise output relative to an economy with an exogenous mark-up.

- *Similarly, the mark-up tax increases output in the short run by reducing inefficiency* (Figure 16). The mark-up tax has an additional adverse effect on robot investment in the model with endogenous mark-up, because the tax affects the marginal return of robot investment. Therefore, imposing the mark-up tax reduces robot investment and the size of mark-up (i.e., improves economic efficiency). This raises both demand and supply of unskilled workers through the substitution effect and the higher marginal return of supplying unskilled labor. As a result, output increases in the short-run. However, reduced robot investment also reduces the benefits of robot-augmented technological progress, weighing on output in the long run.

- *Interestingly, the endogenous mark-up makes the robot tax less harmful to output compared to the case with the exogenous mark-up; the difference is negligible for the mark-up tax.* Since the price mark-up depends on the robot density, direct robot taxes have a stronger impact on the level of the mark-up, which in turn affects the efficiency losses of the policy package. On the other hand, the impact of the mark-up tax on the mark-up itself is of second order, because the distortion is modified by the marginal conditions of robots, skilled labor, and unskilled labor as the robot density is defined by these three factor inputs (the mark-up tax is irrelevant for the marginal condition for traditional capital).

Figure 15. Robot Tax
(Accumulated change relative to the baseline, percentage points)

Figure 16. Raising Tax on Mark-up
(Accumulated change relative to the baseline, percentage points)

Source: IMF staff calculations.
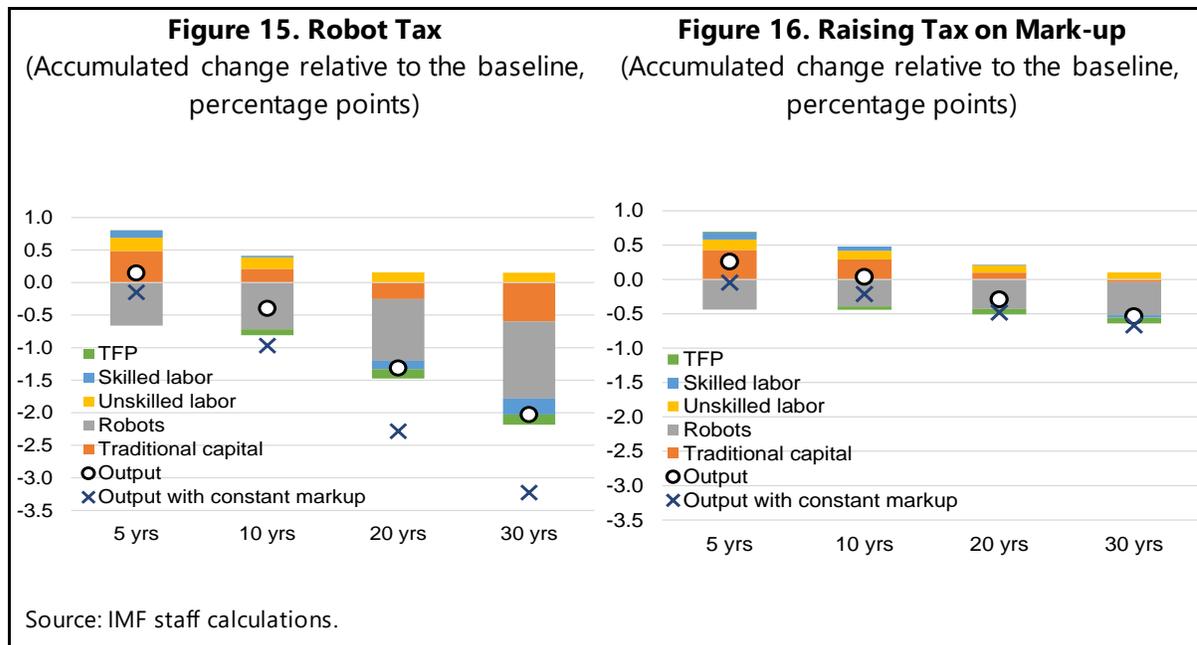
C. Welfare Implications of the Endogenous Mark-up

The endogenous mark-up, according to the first two criteria (output vs. inequality, and disposable income of the two types of workers), shortens the list of "admissible" policy packages. The benefits the robot and mark-up taxes generate by reducing the mark-up are particulalry prominent in the short run.

- For *output vs. inequality*, at a 5-10-year horizon, the robot tax, the mark-up tax and the unskilled wage tax cut (only five-year) are "admissible" packages, in the sense that they dominate the rest but not each other. Interestingly, different from the model with exogenous mark-up, the robot tax and mark-up tax continue to be "admissible" in the long run, while only higher education spending financed by a capital income tax hike emerges as another "admissible" policy package.

- On the other hand, for the criterion of *disposable income of the two types of workers*, the robot tax is a clear winner at the five-year horizon, although the mark-up tax and the unskilled wage tax cut can raise disposable income of both workers relative to the baseline too. These three packages are the "admissible" packages at 10-year horizon. However, the unskilled wage tax cut is no longer an "admissible" package after that, reflecting its efficiency cost relative to the other two packages.

In the long run, however, the positive effect of the lowered mark-up is dominated by distortions stemming from additional taxes on capital income. The equity-efficiency trade-off reemerges (between income and inequality in Figure 17 and disposable income of unskilled and skilled workers in Figure 18). The efficiency gain from a lower mark-up is not sufficiently powerful to offset the efficiency costs of additional taxes in the long run, while it helps shorten

the list of the "admissible" set. This is because the burden of the additional taxes is ultimately born by robot accumulation (relative to other input factors), whose long-run ouput cost is sizable in the automated economy.

Figure 17. **Endogenous Mark-up: Income and Inequality**

Figure 18. Endogenous Mark-up: Disposable Incomes

Source: IMF staff calculations
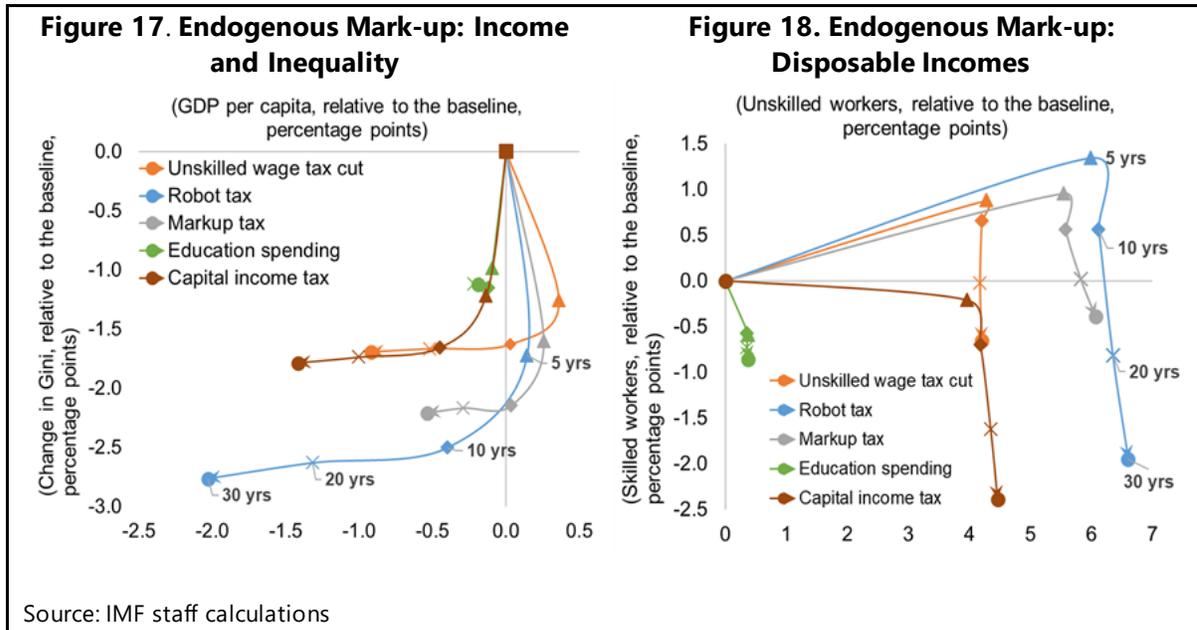
The EDEI shows the mark-up tax and the robot tax as winners (Figure 19)**.** It is not surprising that the mark-up tax, a tax on an economic rent, performs best when the inequality aversion is low. But as the inequality aversion increases, the robot tax's ability to reduce income inequality begins to dominate the mark-up tax. However, the difference between the robot tax and the mark-up tax is much smaller than in the model with exogenous mark-up. This reflects the offsetting force of the efficiency gain by the robot tax through lowering the mark-up—relative to the exogenous mark-up model, the output loss by the robot tax with an endogenous mark-up is smaller. Finally, like in the analysis of the first two criteria, the unskilled wage tax cut follows the two packages.

Figure 19. Equally Distributed Equivalent Income

Figure 20. Social Welfare Function

Source: IMF staff calculations.
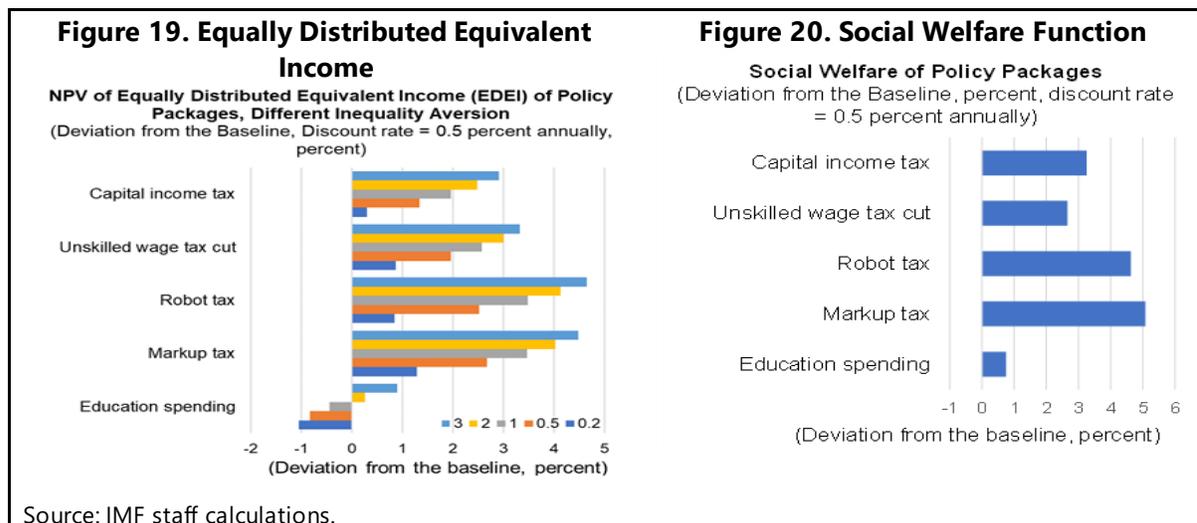
The social welfare function (SWF) shows again a similar story: the mark-up and robot taxes do better. The mark-up tax produces slightly higher social welfare than the robot tax (Figure 20), contrary to the model with exogenous mark-up, as in the case of the EDEI with lower value of inequality aversion. This reflects the same mechanism (the offsetting force by the improved efficiency on income distribution) highlighted in the previous paragraph.

VII. SENSITIVITY ANALYSIS

Like all numerical simulations, the analysis in the paper may be sensitive to the calibration of structural parameters. This section conducts sensitivity analysis of the following four parameters, using the endogenous mark-up model: (i) the elasticity of substitution between unskilled workers and robots; (ii) the elasticity of the price mark-up with respect to robot density; (iii) the size of the robot-augmenting techology shock; and (iv) the intertemporal discount rate; detailed results are presented in Figure 21. The paper uses the baseline policy package to examine the impact of these alternative values of the four parameters on the four welfare criteria: output and inequality (Gini); disposable income of unskilled workers and skilled workers; the EDEI; and the present value of SWF.[28]

- *Lower elasticity of substitution between unskilled workers and robots.* This parameter is set at 2.5 in the model, following Berg et al., (2018). We will examine the impact of lowering its value to 1.9, which is the lower bound of the estimate in DeCanio (2016). Lower elasticity of substitution means robots and unskilled workers are less substitutable.

- *A higher value (0.075) of the mark-up elasticity with respect to the robot density.* The exercises in the paper so far use 0.045, based on the average mark-up elasticity implied by the relation between robot density and mark-up over 20 years, using data from the International Federation of Robotics. The ongoing automation/IT progress may raise the elasticity if companies' profits get even more sensitive to automation.

- *A smaller robot-augmented technological shock.* Berg et al., (2018) examined five cases of robot-augmented technological shocks: 300 percent increase (the baseline in this paper); 200 percent increase; 100 percent increase; 50 percent increase; and 0 percent increase. In this section, we choose the lowest non-zero technological shock from this set.

- *Higher intertemporal discount rate (6 percent) than the assumed rate (0.5 percent).* While it is very difficult to say what is the "right" level of the discount rate, it would be useful to check the impact of a higher discount rate. We utilize here the 6 percent figure used in Berg et al., (2018). A higher discount rate tends to reduce the importance of longer-term effects (mainly distortions caused by higher taxation) in favor of near-term benefits of redistribution policies.

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[28] To maintain comparability, the EDEI and the social welfare value in each period are discounted by 0.5 percent per period.

Figure 21. Evolution of Economic Variables in the Sensitivity Analysis

Unskilled Worker's Disposable Income
(% deviation from the initial steady state)
- Baseline
- Elasticity of substitution 1.9
- Discount rate 6
- Markup elasticity 0.1
- Technology shock 50 percent

Skilled Worker's Disposable Income
(% deviation from the initial steady state)

Capitalist's Disposable Income
(% deviation from the initial steady state)

Output
(% deviation from the initial steady state)

Unskilled Wage
(% deviation from the initial steady state)

Skilled Wage
(% deviation from the initial steady state)

Return on Capital
(% deviation from the initial steady state)

Return on Robot
(% deviation from the initial steady state)

Unskilled Labor
(% deviation from the initial steady state)

Skilled Labor
(% deviation from the initial steady state)

Capital
(% deviation from the initial steady state)

Robot
(% deviation from the initial steady state)

Unskilled Worker's Utility
(% deviation from the initial steady state)

Skilled Worker's Utility
(% deviation from the initial steady state)

Capitalist's Utility
(% deviation from the initial steady state)

Robot Density
(% deviation from the initial steady state)

- **The sensitivity analysis confirms our previous findings, in qualitative terms, regarding the equity-efficiency trade-offs.** Reproducing the charts used for welfare analysis in the previous sections (Figures 22–25) highlights the mechanisms and implications to the welfare analysis clearly, where all measures are presented as deviations from the baseline with the original values of the four parameters.

- *Lower elasticity of substitution between unskilled workers and robots.* With lower elasticity of substitution, the technological progress shock causes: (i) smaller replacement of unskilled workers by robots; and (ii) a shift of savings from robots to traditional capital investment, relative to the baseline. These effects raise the disposable income of unskilled workers. With the assumed values of the structural parameters, output stays slightly above the baseline in the first 10 years, also due to lower mark-up as a result of lower robot investment. However, using more unskilled labor and less robots weighs on productivity and output in the long-run. The equity-efficiency trade-off emerges in the long run. Higher disposable income of unskilled workers improve both the EDEI and social welfare values.

- *Higher elasticity of the mark-up with respect to robot density.* Higher elasticity of the mark-up widens the wedge between the marginal product of robots and their rental cost, raising the required marginal product of robots to satisfy the first-order conditions of intermediate goods firm (see Online Annex I). The higher required marginal product of robots creates a shift of investment from robots to traditional capital and substitution from robots to unskilled labor. As a result, inequality and disposable income of unskilled workers improve in the first five years. However, once robot investment catches up, the larger mark-up caused by the higher elasticity weighs on production efficiency, moving the economy in an unfavorable direction: lower income with higher inequality; and lower disposable income of both types of workers. Welfare gains measured by the EDEI and SWF stay small, or even deteriorate compared to the baseline.

- *A smaller robot-augmented technological shock.* A smaller technological shock reduces growth as well as substitution from unskilled labor to robots. The net result is lower output, lower inequality, and higher disposable income of unskilled workers. In addition, disposable income of skilled workers begin to decline beyond the five-year horizon, reflecting lower growth.[29] We still see clearly the income-inequality trade-off in Figures 22 and 23. It is notable that disposable income of unskilled workers declines beyond 20 years, as lower efficiency due to the lower technological progress dominates the positive effect of slower replacement by robots. The efficiency loss weighs on social welfare measured by the EDEI with low inequality aversion (i.e., with more weight on efficiency). However, as inequality aversion increases, the EDEI improves dramatically, reflecting the very powerful effect of inequality reduction stemming from the higher

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[29] It increases in the short run, reflecting a shift of investment from robots to traditional capital.

disposable income of unskilled workers, as in the case of the SWF (Figures 24 and 25).[30]

- *Higher intertemporal discount rate.* With a higher discount rate, the initial steady state has a lower stock of robots and traditional capital relative to output, because of the higher required marginal product of these factors of production. Therefore, throughout the period, the size of the mark-up with a higher discount rate is slightly lower than the baseline (because the robot density is lower). This moves income, inequality, and disposable income in a favorable direction over the long run (Figures 22 and 23). On the other hand, the higher discount rate (i.e., the equilibrium real interest rate) lowers investment, particularly robot investment, with the effect felt more strongly in the first 5-10 years. The rate of technological progress normalized by the marginal product of the stock of robots is lower with the higher discount rate, as is therefore its impact. However, this effect is dominated by improved disposable incomes of both workers in the long run, raising the social welfare measured by the EDEI and SWF.

Figure 22. Income and Inequality

(GDP per capita, relative to the baseline, percentage points)

Figure 23. Disposable Incomes

(Unskilled workers, relative to the baseline, percentage points)

Source: IMF staff calculations.

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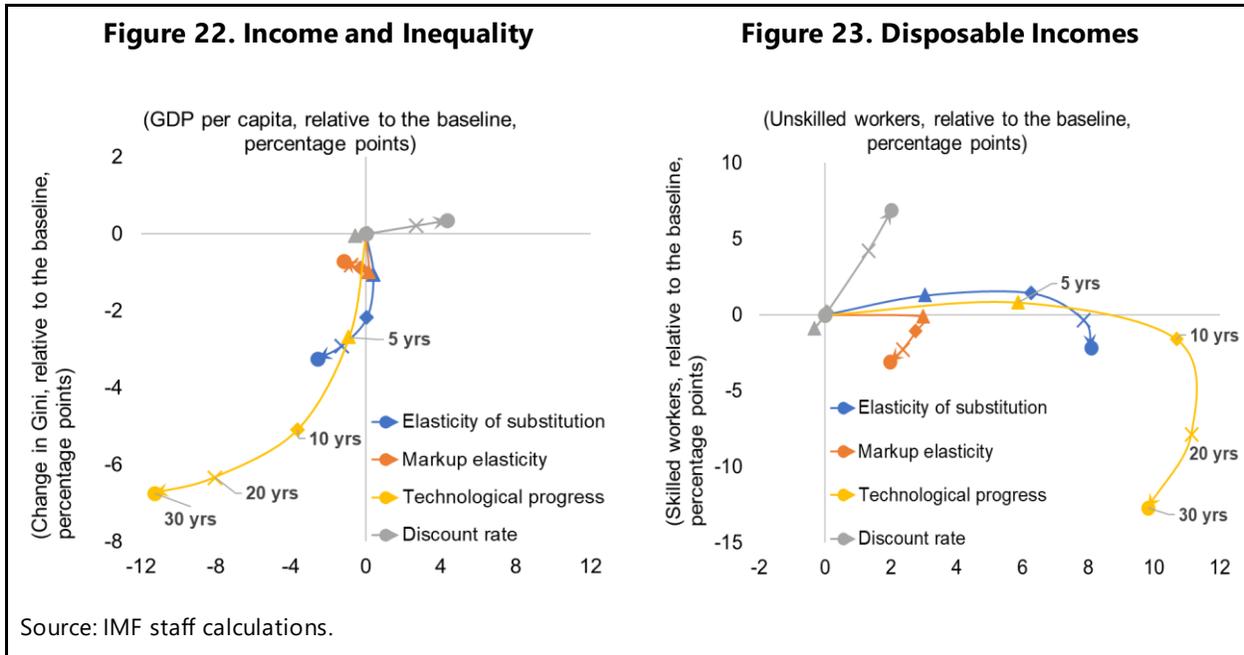
[30] The reader may think that improving the SWF despite lower productivity is counterintuitive. This reflects two issues: (i) the relative risk aversion in the SWF is above 2, suggesting that the SWF puts a large weight on addressing inequality; and (ii) the present value of the SWF and EDEI is computed only using the first 30 years to keep the results comparable to those under the first two criteria (income vs. inequality, and disposable income). If the present value of the SWF is computed for a much longer period, say 100 years, the present value of the SWF is much inferior to others, because the lower technological progress makes the social welfare after year 30 lower than others.

Figure 24. Equally Distributed Equivalent Income

NPV of Equally Distributed Equivalent Income (EDEI) of Policy Packages, Different Inequality Aversion
(Deviation from the Baseline, Discount rate = 0.5 percent annually,

Figure 25. Social Welfare Function

Social Welfare of Policy Packages
(Deviation from the Baseline, percent, discount rate = 0.5 percent annually)

Source: IMF staff calculations.

VIII. SUMMARY OF THE RESULTS AND POLICY IMPLICATIONS

The paper uses a standard DGE model enriched with monopolistic competition and a set of fiscal instruments to analyze the impact of various fiscal policies on the equity-efficiency effects of automation. We have simulated a number of different policy packages, mainly of the tax-and-redistribute kind, paying special attention to transition dynamics.

Overall, we find that fiscal policies can ameliorate (though not eliminate) the well-known trade-off between rising average income and rising inequality brought by automation. This is due to two fundamental and related features of the modern economy. First, without policy intervention, the gains from automation accrue mainly to the owners of capital and skilled workers, while the costs are borne mostly by the unskilled workers. This calls for policy-driven redistribution of these gains––taxing the owners of capital and transferring the proceeds to the unskilled workers–– which leads to the second feature: taxing capital and capital income is inherently costly in the long run. How much income is society willing to give up for a given reduction in inequality is a key political economy question that critically depends on societal preferences. The job of the economist is to outline and quantify, to the extent possible, the attendant trade-offs. Here we provide a positive analysis of fiscal policies in an economy that features automation.

Figure 26. Desirable Policy Packages [1]/

Source: IMF staff calculations.
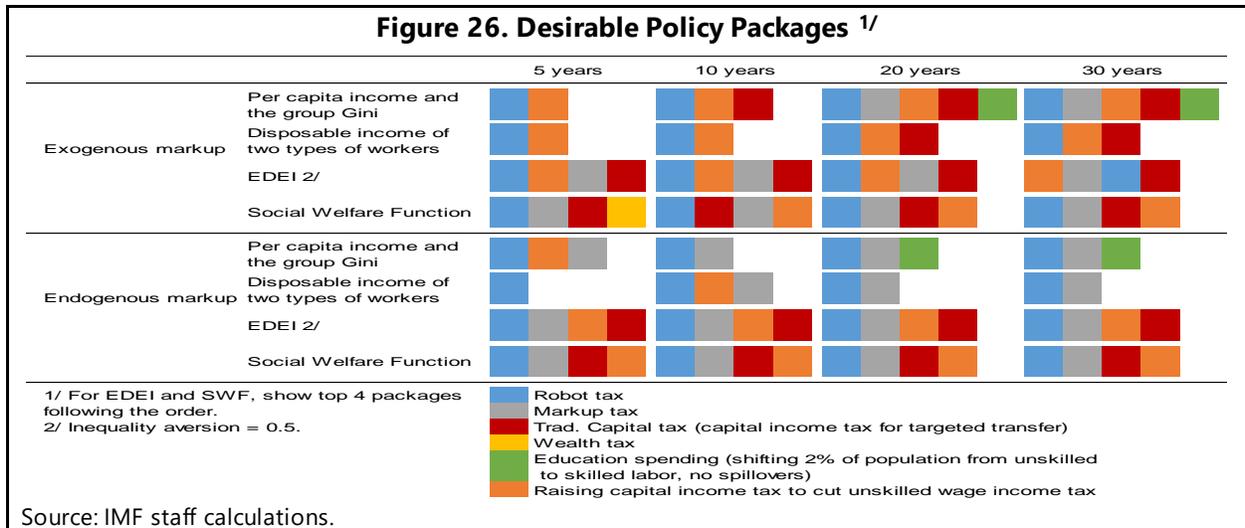
That said, policy design does matter, and our findings provide some guidance on the relative performance of the various policy packages. Figure 26 summarizes the results across different policy packages, time horizons, and trade-offs/welfare criteria. For the two criteria involving trade-offs (i.e., the first two rows in each block), the figure shows the "admissible" packages, which are not dominated by any other (in contrast, the rest of the packages are dominated by at least one of the admisible ones, in the sense that they do worse on both criteria than at least one of the admissible packages. The choice between the "admissible" packages in the first two rows depends on the society's preferences regarding growth and inequality. On the other hand, the next two rows show the top four packages in order, measured by the net present value of EDEI and SWF.

The analysis of the simple trade-offs of equity/efficiency and skilled/unskilled wages provide some important insights:

- *With the exogenous mark-up, mainly the robot tax (blue) and unskilled wage tax cut (orange) are admissible over the first 5–10 years.* In the long run, some other packages join the admissible set, as distortions on capital accumulation caused by the robot tax and unskilled wage tax cut begin to weigh more heavily on economic efficiency. *In other words, the equity-efficiency trade-off binds more strongly in the long run and thus looking for inadmissable packages is less fruitful.*

- *With the endogenous mark-up, the mark-up tax joins the set of admissible packages (together with the robot tax and unskilled wage income tax cut).* Interestingly, the mark-up tax dominates most other packages in the long-run, keeping the set of the admissible packages smaller than in the model with the exogenous mark-up. This suggests that improved efficiency through lowering the mark-up helps ameliorate, to some extent, the equity-efficiency trade-off. This is a somewhat general feature because it turns out to be robust to model assumptions and calibrations, as highlighted by our sensitivity analysis.

To make more progress, however, we need to know more about society's preferences to find the preferred pacakge, as expressed in the EDEI and SWF:

- *The majority of policy packages show improvement relative to the baseline.* This is due mainly to three effects: (i) under some policies, the income of both skilled and unskilled workers––the vast majority of population––increases; (ii) when there is a trade-off, the increase in the income of unskilled workers as a group is larger than the decline in income of the skilled workers; and (iii) for the SWF, the diminishing marginal utility of consumption ensures that the increase in income/consumption of unskilled (lower-income) workers weighs more in utility terms than an equivalent decline in the income/consumption of skilled workers.[31] Second, the top two policy packages––the robot tax and the mark-up tax––remain the same at all time horizons. However, as already presented, the welfare change depends on the degree of inequality aversion (for the EDEI) and relative risk aversion (for the SWF). With rising inequality aversion and/or relative risk aversion, policy packages focusing more on income redistribution––and thus protecting against very low incomes for some––achieve better outcomes.

- *The robot tax performs so strongly across the board mainly because it slows accumulation of robots, raising demand for unskilled workers and their wages.* It also helps skilled workers through (i) increasing the accumulation of traditional capital (some investment shifts from robots to traditional capital); and (ii) reducing the mark-up in the endogenous mark-up setup. These factors raise the marginal product of skilled workers and their wages. All this comes, of course, at the expense of output losses especially in the long run, but in welfare terms the gains in reducing inequality turn out to be more important under the EDEI and SWF with widely used parameters. The operational implications of robot tax, however, need to be studied further.

- *The main advantage of raising the capital income tax and cutting the tax on the unskilled wage is that it makes unskilled workers more competitve vis-à-vis robots and thus reduces their replacement.* It also increases directly their disposable income. While it is never the best performing package, it is always a top contender, and could improve welfare relative to the baseline in the first 5-10 years, mainly through reducing inequality in income distribution. Moreover, compared to the robot tax and the mark-up tax, this package is likely to be operationally less challenging.

- *Why is the package of increased education spending so mediocre*? This reflects its limited scope: the education spending package shifts only 4 percent of the unskilled workers to the skilled group (2.2 percent of total population). Improved productivity from this shift is not sufficiently strong to offset distortions caused by raising the tax on capital income or taxing robots. Also, the extra education spending "helps" only a small fraction of unskilled workers, shifting them to the skilled group. Therefore, the aggregate impact on inequality is modest.[32] The picture would change if investment in education is allowed to raise the productivity of the whole economy;

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[31] The income of capitalists declines under all considered packages. However, as this decline is from a high level, and as the share of capitalists in total population is very low, the social welfare impact of this is negligible.

[32] A sensitivity analysis revealed that plausible changes in the elasticity of the education function do not affect the ranking of the education policy package relative to the other packages.

while intuitively plausible, we have not been able to find reliable estimates of this aggregate effect.

- *However, there are two caveats*: (i) the model does not assume any spillovers of the robot augmented technological progress to other factor inputs since such spillovers would magnify the cost of reducing robot accumulation by the robot tax, undermining its competitiveness; and (ii) the share of unskilled labor that can be replaced by robots is calibrated at 45 percent of workers, following Berg et al., (2018), but there is considerable uncertainty about it in the literature and the real world. If this share is much smaller, the benefits of all tax-and-redistribute packages in terms of reducing inequality would be smaller as well.

Some important policy implications follow from these results.

First, with technological progress driven by automation, inclusive growth is not guaranteed and indeed is not likely to occur without policy interventions. Fiscal policies could soften the adverse distributional impact at the cost of some output loss in the long-run. A fair balance–taking into account political and social preferences—should be sought.

Second, policymakers should consider both the short-term and long-term benefits and costs of policies. What may be seen to work in the short term could be harmful in the long run. In particular, taxing capital income has very different effects on resource allocation over time: little cost in the short run, which enables some packages to reduce inequality without a loss in income, but very large in the long run.

Third, excessively taxing capital and income from capital can be costly in the medium/long run. This suggests the importance of creating fiscal space with minimal additional burden on investment and capital (i.e., without killing the goose that lays the golden eggs).

Fourth, fiscal policy could affect the equity-efficiency trade-off beyond its traditional channels. In an economy where the pricing power of corporations is proportional to their usage of automation, fiscal policy can exploit an additional channel of transmission. Specifically, the harmful effect of taxing automation is mitigated by the attendant improvement in economic efficiency stemming from the reduced price mark-up, a measure of economic rents. This allows fiscal policy to achieve the desired reduction in inequality at lower efficiency costs (or, alternatively, to achieve deeper reduction in inequality for a given economic growth target), an important goal for policymakers concerned about equity-efficiency trade-offs.

Lastly, the post-COVID era could see an acceleration in adoption of automation, making the policy implications of this paper much more prominent. On current trends, inequality would likely rise further and faster in the absence of policy interventions, and policymakers should respond swiftly. The fiscal policy effects and transmission channels highlighted in the paper should give some insights for policymakers when they calibrate policy packages to tackle the equity-efficiency trade-off caused by technological progress and protect people who are vulnerable to its side effects.

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Annex I. Full Description of the Policy Packages

The sequence of simulations is as follows. Year 1 shows the initial steady state with a mark-up value of 1.19 estimated by Barkai (2020). Year 2 is the year when the new tax rates are introduced in each policy package. Year 3 is the year when robot augmented technological progress begins to kick in the model. The calibrated tax rates and assumed expenditure policies in each policy package are summarized below.

Package	Raise	Spend	Explanation
1	Tax rate on capital income to 15.0%	Targeted transfers to unskilled workers	The paper puts this package at the top of the list of the group because taxing the owners of capital (winners) and transferring the receipts to unskilled workers (losers) are likely to be the most straightforward ways to ameliorate the equity-efficiency trade-off created by the robot-augmented technological progress.
2	Tax rate on consumption to 1.5%	Targeted transfer to unskilled workers	This package shows the impact of redistribution policy with the least distortionary tax available (other than a lump-sum tax). This reflects the fact that any different tax on different production inputs causes distortion in production (Diamond and Mirrlees 1971).
3	Tax rate on robots to 0.6% and tax rate on capital income to 14.4%	Targeted transfer to unskilled workers	Taxing robots could take a number of forms—e.g., changing tax for investment in automation in South Korea in 2017, or taxing robots proposed by the European Union, although it was rejected by the European parliament. This paper postulates that the government can directly tax the stock of robots. Slavík and Yazici (2014) study the optimal taxation of two types of capital: equipment and structures. They find that the optimal tax rate is higher for equipment capital, which complements skilled workers, than structures because taxing equipment depresses its accumulation and decreases skill premium, providing indirect redistribution from skilled to unskilled workers. We anticipate a similar mechanism.
4	Tax rate on total physical capital to 0.2%	Targeted transfer to unskilled workers	This is a wealth tax on total physical capital (i.e., traditional capital and robots). This is the form of wealth present in the model.
5	Tax rate on the mark-up to 19.3%	Targeted transfers to unskilled workers	This tax on the mark-up can be interpreted as a corporate income tax on excess profits (rents), generated by the market power of the monopolistically-competitive firms.
6	Tax rate on capital income to 15.0%	A tax rate cut of unskilled workers' wage income to 9.2%	This package seeks income transfer in a way different from the targeted transfer. The package is somewhat similar to employment subsidies suggested by Summers (2016), and Furman and Seamans (2019).
7	Tax rate on capital income to 15.0%	Education spending to switch unskilled to skilled labor	The elasticity of switching workers against education spending is based on information in Box 4 of IMF (2018). Unskilled workers switched to skilled workers are regarded as "skilled" once they switch.