Quantifying the Effects of Basic Income Programs in the Presence of Automation*

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Abstract

The trend towards increasing automation and robotization is a challenge for the labor market, especially for the demand for low skilled labor. Concepts of a Universal Basic Income (UBI) are often brought up as potential reforms to current welfare systems which could provide additional insurance against this trend. I develop a quantitative theory of the labor market where firms endogenously decide on their investment in robots, while workers can insure themselves against the risk of automation induced job-loss by obtaining a college degree. This framework allows for an analysis of the interaction between unconditional transfers and automation and reveals a negative relationship between the generosity of the basic income and the investment in robots. Higher transfers reduce the incentives for obtaining a college degree and the reduced output in the college sector also leads to a fall in profits in the automation sector which discourages investment in robots. Concerning worker welfare, my framework highlights a generational conflict: When comparing stationary equilibria, workers would always prefer being born into an economy without a basic income. However, older cohorts who are already alive during the introduction of the basic income can expect welfare gains during the transition to the new equilibrium.

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1 Introduction

The idea of a society in which every individual is guaranteed a basic income without any obligations has been part of philosophical considerations for centuries. In his famous book about the perfect state (Utopia, 1516), Thomas Moore already claimed that the state should provide unconditional subsistence for everyone in order to prevent thievery. In economics, too, the idea is not new and several different concepts have been considered. In his discussion of the role of economic capitalism in a liberal society, Friedman (1962), for example, proposes replacing social security, public housing, and other safety-net programs with a Negative Income Tax (NIT). Later, Atkinson (1995) discussed the replacement of the social security system by a guaranteed basic income which provides transfers to everyone irrespective of their age, income or other personal characteristics.

The concept of such a Universal Basic Income (UBI) or of similar programs is also often brought up in political discussions, especially among critics of current social welfare systems. In 1969, US President Richard Nixon proposed to replace a welfare program aimed at families with children with a guaranteed minimum income for all these families. As a reason he cited the apparent failure of the current welfare system to prevent poverty.[1] Thereafter, four well-known field experiments were conducted in the US analyzing the effects of unconditional transfers in the form of a negative income tax.[2] In an overview of the results, Munnell (1986) states that reductions in work effort were only moderate, while school attendance increased. Others, however, have questioned the results from such experiments as they are not able to capture general equilibrium effects or to provide insights on the effects on the broader population (see, e.g., Zellner and Rossi 1986).

More recently, 2020 former Democratic presidential candidate Andrew Yang proposed a "Freedom Dividend", a guaranteed payment of $\$1,000$ per month to every U.S. citizen aged 18 or older (Yang, 2018). In Switzerland, a national referendum about a basic income was held in 2016 (and rejected by the population[3]) and in Germany, an ongoing experiment provides unconditional cash transfers of $1,200$ EUR to a randomized treatment group to study the effects of a UBI. More examples and a deeper discussion of UBI in advanced countries are provided in the review by Hoynes and Rothstein (2019).

Several key features of UBI make it especially appealing for public and political discussions. First, as a concept it is easy to understand and an adoption appears to be straightforward. Second, since it is an unconditional program aimed at the whole population it would yield a 100 percent coverage and avoid frictions from stigma or eligibility.

[1] In his Address to the Nation on Domestic Programs in 1969 he stated: “Whether measured by the anguish of the poor themselves, or by the drastically mounting burden on the taxpayer, the present welfare system has to be judged a colossal failure.”

[2] Namely: The New Jersey Graduated Work Incentive Experiment, The Rural Income-Maintenance Experiment, The Seattle/Denver Income-Maintenance Experiments and The Gary, Indiana Experiment

[3] Although the text of the initiative did not mention a specific amount of the provided basic income, the initiators advocated a monthly payment of CHF 2,500 for every adult citizen (roughly $1,600 at the time of the referendum).

Lastly, providing an unconditional income is thought to yield a minimum of distortions as it is a lump-sum transfer which avoids problems from bunching below certain costly thresholds.

Besides these appealing features, the concept of UBI programs has also found increasing interest due to several developments in most western countries, which have experienced a recent recession, a stagnation of median wages, a surge in automation and robotization, and a rise in inequality of wealth and income. Also, due to the coronavirus pandemic, several countries in Europe and the US have faced a considerable increase in unemployment rates, while Russia's invasion of Ukraine has caused a surge in inflation rates. The insurance provided by basic income programs is often brought up as a possible means to mitigate the impacts of such crises on the economy and poorer households in particular.

Some of these crises should be only temporary in nature, whereas the rise in robotization is generally thought to remain a major challenge for the labor market going forward. While automation can be both, a complement and a substitute for labor, recent evidence suggests that the substitution effect might be dominant in the short-run. Autor and Salomons (2018), for example, report that the observed decrease in aggregate labor shares in most western countries stem from within-industry movements and that automation displaces employment in the industries in which it originates. Similarly, Kindberg-Hanlon (2021) estimate that a 10 percent technology-driven improvement in labor productivity reduces employment by 2 percent in advanced economies.

These observations lead to an increased fear of job-loss due to the displacement of low skilled workers by the adoption of robots and many believe that programs such as UBI might be necessary to counteract the resulting rise in inequality.[4] A basic income could provide much needed insurance and give people the freedom to learn new skills according to their talents. And since the trend towards increasing robotization is likely to only accelerate in the years to come, understanding the interactions between automation and basic income programs becomes ever more important.

While the literature on the effects of unconditional transfers is already extensive and still growing, studies mostly rely on empirical data or contained field experiments (see, among others, Cesarini et al., 2017 on the effects of lottery wins, or Jones and Marinescu, 2022 on the effects of the Alaska Permament Fund). However, one should be careful before extrapolating the results of such experiments, since their ability to provide insights on general or even partial equilibrium effects for the broader population and other sub-populations is very limited (Zellner and Rossi, 1986). Moreover, such experiments only study the responses from workers, while understanding the reactions of firms and their investment decisions might be just as important. These shortcomings can only be addressed within a model framework which allows for an evaluation of different basic

[4] Andrew Yang's "Freedom Dividend", for example, was also meant to prevent poverty from automation induced job-loss.

income programs and a qualitative counterfactual analysis.

In the macroeconomic literature, however, UBI and similar concepts have only recently received more attention. Lopez-Daneri (2016) provided the first quantitative assessment of a Negative Income Tax within a general equilibrium setting. Concerning UBI, quantitative studies are still scarce but notable working papers include Conesa et al. (2021), Luduvice (2021) and Chang et al. (2021). While all these papers are highly complementary, they mostly focus on different aspects of how UBI would affect macroeconomic outcomes and none of them consider the interaction with endogenous automation decision.

The aim of this paper is therefore to add to the discussion about the effects of basic income programs by endogenizing the interaction between the provision of unconditional transfers and firms' decisions to automate jobs. In doing so, I am providing a new model framework in which basic income programs and similar policies can be analyzed quantitatively to address some of the open questions regarding macroeconomic effects. I introduce a segregated labor market in which workers have to decide between participating in one of two sectors. One sector will feature endogenous automation, allowing firms to invest in robots instead of hiring a worker. Workers in the second sector do not face this additional job risk, but need to acquire a college degree. Additionally, labor market frictions are incorporated via Nash-Bargaining which determines work contracts. This setup allows for an inexpensive evaluation of basic income programs when automation decisions are endogenous.

The model is calibrated to the US economy and the results show that a reform towards a basic income program has strong effects on firms' automation decisions: higher transfers actually increase the demand for labor while decreasing the investment in automation. A more generous UBI leads to less labor force participation by low skilled workers. Consequently, firms are more likely to be matched with high skilled workers on the labor market. This leads to a situation where expected profits on the labor market rise relative to the adoption of a robot and thus, the rate of automation in the economy decreases. Regarding welfare of workers, effects are mostly negative even though some of the modeling choices can be seen as generally favorable towards policy intervention and UBI. The losses experienced by high income earners are not offset by the gains from low income earners. Instead, firm owners experience higher profits and higher consumption.

This paper is organized as follows. The next section describes relevant literature and highlights the contributions to the ongoing discussion. Section 2 then presents the model setup, while the parameterization, calibration strategy and relevant statistics of the benchmark economy are described in Section 3. In Section 4 I discuss the general effects of different UBI policies of varying generosity, while Section 5 provides a deeper analysis of a specific UBI proposal. Section 6 briefly analyses an optimal tax and transfer system. Section 7 concludes.

1.1 Related Literature

This paper contributes to several strands of the literature. First, this paper is most closely related to the growing quantitative macroeconomic literature on the evaluation of welfare reforms. The first quantitative assessment of a basic income program was conducted by Lopez-Daneri (2016), who studied the impacts of a Negative Income Tax (NIT) as a revenue-neutral reform of the U.S. income tax and welfare system. Lopez-Daneri (2016) uses a life-cycle economy with individual heterogeneity and uninsurable idiosyncratic labor risk to show that an NIT can lead to considerably welfare gains for households born after the introduction of the reform. Also, regarding labor market outcomes, the author finds an increase in labor supply measured in efficiency units, as well as an increase in the number of hours worked. Section 6 of this paper brings forth similar results and therefore partially confirms previous findings.

Recently, similar model environments have been used to assess the consequences of UBI. Luduvice (2021), for example, introduces on-the-job learning and child-bearing costs and finds that the introduction of a UBI leads to a growth in output and capital due to higher precautionary savings, while labor market responses by households are only moderate. Daruich and Fernández (2021) incorporate human capital accumulation and endogenous intergenerational links and find mostly negative effects for younger households and future generations. The authors also address the concern of higher job separations due to a rise in automation by simply increasing the proportion of workers in their model setup who receive an out-of-work shock. While their analysis suggests possible gains from UBI in an environment with rising risk of job-loss, their model is not designed to understand automation decisions and consequently, misses some important general equilibrium effects. In this paper, however, automation decisions are endogenous and their interaction with the generosity of the unconditional transfers is shown to have important quantitative impacts on the welfare results

Another related paper is Conesa et al. (2021) which focuses on the distinction between basic and non-basic consumption goods. With their model setup the authors can show that a generous UBI together with a progressive tax on consumption could lead to ex-ante welfare gains. However, current households would face high welfare losses during the transitional phase. Finally, Chang et al. (2021) use the standard Aiyagari (1994) economy with endogenous labor supply to compare a UBI to an NIT, finding that both programs can provide identical economic incentives, while differing vastly in other aspects such as required funding. In this paper, the focus lies more on the interaction between endogenous automation decisions and occupational choice by workers. Consequently, the results of this paper are complementary to the existing literature and provide insights into new channels through which basic income programs affect the economy.

Next, the model setup in this paper allows for a labor-substituting technology and therefore draws from existing literature on the substitution of labor by investment in automation. Models in which robots and workers compete in the production of different tasks include Acemoglu and Autor (2011) and Acemoglu and Restrepo (2018), among others. Empirical evidence of such labor-substituting innovations is provided by Autor and Salomons (2018), who look at four decades of harmonized cross-country and industry data and find that automation displaces employment in the industries in which it originates. Also, using evidence from structural vector autoregressions on a large global sample, Kindberg-Hanlon (2021) find that the substitution effect of new technologies dominates the complementary aspect in most economies. Leduc and Liu (2021) incorporate these insights into a quantitative general equilibrium model, where the threat of automation weakens workers bargaining power. This paper extends this framework by introducing two sectors which differ in their possibility of automation and by introducing additional frictions on the labor market to analyze the interactions that may arise from the introduction of a UBI policy. Lastly, this paper is in spirit very similar to the analysis by Jaimovich et al. (2021), but differs in some important aspects. For example, in this paper there is no ex-ante distinction between low-skill workers and high-skill workers. Hence, the selection between markets occurs endogenously. Also, workers face income risks over their life-cycle and matching frictions occur in all sectors, not only in the automation sector.

Furthermore, this paper relates to recent studies on the role of UBI in the discussions about welfare reforms. Banerjee et al. (2019), for example, study the role of UBI in developing countries by gathering information from different pilot studies. Hoynes and Rothstein (2019), in contrast, discuss the potential role of different universal transfer systems in advanced countries and find that UBI policies would generally direct larger transfers to childless and middle-income rather than poor households. They assert that a UBI large enough to increase transfers to low-income families would be enormously expensive, about twice the cost of all existing transfers in the US. Hence, the distributional effects of UBI crucially hinge on the source of new funding and its interaction with other macroeconomic factors. This paper contributes to these existing studies by providing a new quantitative theory which can shed light on some of the advantages as well as the challenges of UBI policies, while also assessing the distributional effects within a general equilibrium framework.

Lastly, assessing UBI policies also relates to the empirical literature concerning the effects of unconditional transfers. Beginning in the end of 1960s, four pilot studies using a negative income tax were conducted in the US and showed only moderate reductions in work effort in response to the treatment (see, e.g., Munnell, 1986). The long term effects of one of these experiments[5] were studied by Price and Song (2018). The authors caught up with participants four decades after the program and found that reductions in earnings in response to the cash assistance were mainly related to retirement. Similar

[5] Namely, the Seattle-Denver Income Maintenance Experiment

modest results were found more recently in studies exploiting lottery wins. Cesarini et al. (2017), for example, used evidence from Swedish lotteries to show that a monetary win only leads to a moderate reduction in earnings, while the uncompensated labor supply elasticity is close to zero. Similarly, Jones and Marinescu (2022) exploit data from the Alaska Permanent Fund, which pays a yearly dividend to all residents, and find no effect on employment. While all these empirical studies provide partial insights on the effects of a guaranteed income, their results cannot simply be extrapolated on a broader population, as mentioned by Zellner and Rossi (1986), among others. Such low-scale experiments cannot provide insights on general equilibrium effects as they only focus on the responses of a small sub-population, while ignoring reactions by firms. Moreover, they often even fail to explain partial equilibrium effects, since they do not capture decisions over the whole life-cycle. Hence, this paper provides a quantitative framework to test these results within a model setup which allows for the analysis of general equilibrium effects and the evaluation of counterfactual policies.

2 Model Setup

Time is discrete and there are two types of agents: Capitalists who own firms and hire labor, and workers who provide this labor. There exist two segregated markets which differ in labor demand while sharing the same capital stock. Intermediate goods are produced in one-wokrer firms and are used in the competitive final goods production.

2.1 Workers

There is a measure 1 of workers who do not save, but use all their labor income for consumption. They live for J periods, are ex-post heterogeneous with respect to their labor productivity and seek to maximize expected life-time utility

$$\mathbb{E}\left(\sum_{j=1}^{J}\beta^{j-1}u(c_j,h_j)\right),$$

where preferences are based on consumption, c, and labor supply, h. Per-period utility is described by

$$u(c,h)=\frac{c^{1-\sigma}}{1-\sigma}-\phi\frac{h^{1+\frac{1}{\gamma}}}{1+\frac{1}{\gamma}}, \tag{1}$$

where σ denotes the risk aversion parameter, γ the Frisch elasticity and ϕ a multiplicative constant which is used to match average hours worked in the economy. Also, note that workers can be unemployed, in which case h measures the effort put into finding a new job.

The labor market is segregated as there exist two types of jobs. An agent's decision which market to enter is made in the first model period depending on whether or not a college degree is obtained. Both markets share the same capital stock and produce intermediate goods for final production. In the first market, which does not require a college degree, workers can be replaced by robots, while production in sector 2 always requires labor input.

Skills. A worker enters the model with an idiosyncratic productivity level z and taste for college z_c. Taste for college is only relevant in the first model period by influencing the decision to join sector 2 which requires a college degree. Going to college yields a disutility in the first model period of $\delta_c z_c$. The productivity level z follows a first-order Markov process.

Labor Market. The matching process in the labor market closely follows the specification in Landais et al. (2018), with the exception that in this paper there exist two segregated markets. There is a measure one of heterogeneous workers who can enter one of two markets, $m \in \{1, 2\}$. Initially, all workers are unemployed and search for a job with individual search effort h, while firms can post vacancies to recruit workers. Based on the aggregate search effort in each market, $\mathcal{H}_m$, and open vacancies in that market, v_m, the matching function $\mathcal{M}(\mathcal{H}_m, v_m)$ determines the number of worker-firm matches formed at the beginning of the model period. The function $\mathcal{M}$ has constant returns to scale, is differentiable and increasing in both arguments, and satisfies $\mathcal{M}(\mathcal{H}_m, v_m) \leq 1$. The labor market tightness, θ_m, of each market is given by the relation between open vacancies and aggregate search effort, i.e. $\theta_m = v_m/\mathcal{H}_m$. Due to the properties of the matching function, the labor market tightness determines the probability with which a worker who exerts search effort h finds a job and probability that an open vacancy is filled. The job-finding probability per unit of search effort is given by $f(\theta_m) = \mathcal{M}(\mathcal{H}_m, v_m)/\mathcal{H}_m = \mathcal{M}(1, \theta_m)$, so that an individual who exerts effort h finds a job with probability $h \cdot f(\theta_m)$. An open vacancy is filled with probability $g(\theta_m) = \mathcal{M}(\mathcal{H}_m, v_m)/v_m = \mathcal{M}(1/\theta_m, 1)$. Also, existing matches are separated with exogenous probability ψ, which is the same in each market.

Employed Workers. Workers who find a job are paid a wage rate, w, per unit of effective labor supply. Thus, gross income of employed workers is given by $\tilde{y} = whze_j$, where the wage rate is multiplied by productivity z, nominal labor supply h and an age-specific experience premium e_j. Wage rate and labor supply are determined by Nash-Bargaining when an open vacancy is matched with an unemployed worker. Gross income is then subject to a progressive income tax given by

$$T(\tilde{y}) = \tilde{y} - \lambda_0 \tilde{y}^{1-\lambda_1}, \tag{2}$$

where the parameter λ_1 determines the degree of progressivity, while λ_0 shifts the tax function and determines the average level of taxation in the economy. This specification has been introduced into dynamic macroeconomic models with heterogeneous agents by Bénabou (2002) and allows for closely mimicking existing tax systems with only two variables. Net income, y, is then given as $y = \tilde{y} - T(\tilde{y}) = \lambda_0 \tilde{y}^{1-\lambda_1}$. Also, note that this specification does not provide transfers for unemployed, since $T(0) = 0$. Unemployment benefits are described below and subsection 2.5 discusses the possible forms of UBI.

The decision which market to enter has already been made upon entering the model and cannot be changed thereafter. Hence, from period 1 onward the state of a worker can be summarized as $s = (z, z_{-1}, m, j, u)$, with z_{-1} being last period's productivity (which influences unemployment benefits), $m \in \{1, 2\}$ the market, j age and $u \in \{0, 1, 2\}$ the unemployment status (0 meaning employed, 1 indicating short-term unemployment and 2 denoting long-term unemployment). Also, note that wages and labor supply will be decided by Nash-Bargaining and are therefore functions of s, $w = w(s)$ and $h = h(s)$.

Then, a worker's decision problem is given by

$$\begin{aligned} W(s) = &\max_{c \geq 0} \; u(c, h) + \beta \mathbb{E}\Big[(1-\psi)W(s') + \psi U(s')\Big] \\ &s.t \quad y(s) \geq (1 + \tau_c)c \end{aligned} \tag{3}$$

with $W(\cdot)$ being the value function of employed workers, $U(\cdot)$ the value function of a worker who becomes unemployed, ψ the exogenous separation rate and τ_c the tax on consumption.

Unemployed Workers. Unemployed workers do not earn income, but receive benefits from the government. Workers who are unemployed for the first period ($u = 1$) receive benefits, b_j, based on their past productivity and the average wage rate in their respective sector. Hence, $b_j = \varrho \bar{w}_m z_{j-1} e_{j-1}$, where $\bar{w}_m$ is the average wage rate in sector m and ϱ the replacement rate. Long-term unemployed workers ($u = 2$), i.e. workers who are unemployed for two or more consecutive periods, receive only a subsistence level of benefits, $\bar{b}$, which is independent of previous productivity and $\bar{b} \leq \min\{b_j\}$. Also, workers who are unemployed in the very first model period do not have a past productivity and thus only receive the subsistence level $\bar{b}$.

Unemployed workers have to exert effort, h, to find a job. The probability of being matched with a firm in market m with market tightness θ_m is given by $h \cdot f(\theta_m)$. Let s again denote the worker's state, then the decision problem for an unemployed workers is

$$\begin{aligned} U(s) = &\max_{c \geq 0, h \in [0,1]} \; u(c, h) + \beta \mathbb{E}\Big[h f(\theta_m) W(s') + (1 - h f(\theta_m)) \bar{U}(s')\Big] \\ &s.t \quad b(s) \geq (1 + \tau_c)c \end{aligned} \tag{4}$$

where $\bar{U}(\cdot)$ denotes the value function of long-term unemployed. Note that $b(s) = \bar{b}$ if $u = 2$.

Market Decision. It is assumed that workers who enter the model for the first period have been exerting the maximum amount of effort for finding a job. Thus, the probability of being employed in the very first model period is simply given by $f(\theta_m)$. With $W_1(z,m)$ denoting the value function of an employed worker in the first period and $U_1(z,m)$ denoting the value function of being unemployed in the first period, the expected lifetime utility of a worker entering market m with taste for college z_c and productivity z is given as

$$V(z, z_c, m) = f(\theta_m) \cdot W_1(z,m) + (1 - f(\theta_m)) \cdot U_1(z,m) - \delta_c z_c \cdot \mathbb{1}_{m=2},$$

with $\delta_c z_c$ being the disutility from college education if the worker chooses to enter the college sector.

Hence, a worker decides to enter sector 2, iff

$$V(z, z_c, 2) > V(z, z_c, 1). \tag{5}$$

In equilibrium, the fraction of workers in both sectors stays constant and is determined by cut-off values for z and z_c.

2.2 Capitalists and Production

The final good Y is produced using the output from the two sectors as intermediate goods. Let y_1 and y_2 denote the output from sector 1 and sector 2, respectively. Intermediate goods are produced according to a Cobb-Douglas technology

$$y_m = k^{\alpha} n^{1-\alpha}$$

where $n = hze_j$ is effective labor supply and $\alpha \in [0,1]$.

Alternatively, firms in sector 1 can ivest in robots with productivity ζ and produce according to

$$y_1 = k^{\alpha} \zeta^{1-\alpha},$$

where the productivity of the robot, ζ, follows an idiosyncratic first-order Markov process.

The final good Y is then produced using the intermediate goods as input:

$$Y = y_1^{\mu} y_2^{1-\mu}$$

with $\mu \in [0,1]$.

The final goods producing sector is competitive and prices of the intermediate goods are determined by their marginal product.

One-Worker Firms. All firms in sector 2 as well as those firms in sector 1 who do not adopt a robot are randomly matched with unemployed workers in their respective market. The value of a job filled with a worker in state s in sector m is given by

$$\begin{aligned} J(s,m) = \max_k \; & p_m \cdot k^{\alpha}(hze_j)^{1-\alpha} - (r+\delta)k - whze_j \\ & + \frac{1}{1+r}\Big[\psi J_m^v + (1-\psi)\mathbb{E}\Big(J(s',m)\Big)\Big], \end{aligned} \tag{6}$$

where p_m denotes the prices for intermediate goods in sector m and J_m^v denotes the value of an open vacancy in sector m. Again the capital input does not influence next-periods profits and consequently, the firms' first-order conditions imply that

$$k^* = zh\left(\frac{r+\delta}{\alpha p_m}\right)^{\frac{1}{\alpha-1}}$$

Value of vacancies. To post a vacancy the firm has to pay a flow cost κ_m^v, which potentially varies between markets, and since the matching process is random, the firm can be matched with every unemployed worker. With $g(\theta_m)$ being the probability of being matched with a worker in sector m and with $J(s,m)$ being the value of a job filled with a worker in state s and sector m, the value of posting a vacancy is given by

$$J_m^v = -\kappa_m^v + \frac{1}{1+r}\bigg(g(\theta_m)\mathbb{E}\Big(J(s,m)\Big) + \Big(1-g(\theta_m)\Big)J_m^v\bigg), \tag{7}$$

where the expectation is formed with respect to the worker state s. Since there is free entry in both markets, in equilibrium firms will continue creating new vacancies until the value of a new vacancy is zero, i.e. until $J_m^v = 0$

Automation. Firms in the automation sector ($m = 1$) can decide to invest in robots instead of searching for a worker. Adopting a robot requires an investment x^a which is drawn from the iid distribution $G(x^a)$ and firms will create automated jobs if $x^a < x_t$ for some cut-off value x_t which could change between periods. Hence, in every period t the fraction of newly automated jobs is given by $q_t = G(x^a < x_t)$. At the same time, existing robots can become obsolete or break down with probability δ^a. Therefore, the stock of automated jobs evolves according to

$$A_t = (1-\delta^a)A_{t-1} + q_t$$

In the stationary equilibrium, with $A_{t-1} = A_t = A^*$ and $q_{t-1} = q_t = q^*$, we get

$$A^* = \frac{q^*}{\delta^a}$$

A robot which is used for production necessitates flow costs κ^a. Thus, the value of automation with a robot of productivity ζ is given by

$$J^a(\zeta) = \max_k \; p_1 \cdot k^\alpha \zeta^{1-\alpha} - \kappa^a - (r+\delta)k + \frac{(1-\delta^a)}{1+r}\mathbb{E}\Big(J^a(\zeta')\Big), \tag{8}$$

where p_1 denotes the price for the intermediate good in sector 1. Note that the capital input does not influence next-periods profits. Therefore, the firms' first-order conditions imply that

$$k^* = \zeta \left(\frac{r+\delta}{\alpha p_1}\right)^{\frac{1}{\alpha-1}}$$

The threshold cost x_t up until which automation occurs is simply pinned down by the value of adopting a robot: Firms will automate jobs as long as they can expect the value from automating being higher than the adoption costs. Hence, automation occurs if and only if,

$$\mathbb{E}(J^a) - x_t > 0,$$

where the expectation is formed with respect to the productivity of the robot.

Wage determination. When a firm is matched with a worker, a contract specifying the wage rate w and labor supply h is determined through Nash-bargaining. There is no long-run commitment, contracts are set every period. With $U(s)$ denoting the value function for an unemployed agent in state s and $W(w,h,s)$ the value function for an employed worker in state s with wage rate w and labor supply h, the bargaining solution is given by

$$(w,h) = \underset{w\geq 0, h\in[0,1]}{\arg\max} \Big(W(w,h,s) - U(s)\Big)^{\xi} \cdot \Big(J(w,h,s) - J^v\Big)^{1-\xi}, \tag{9}$$

with ξ representing the worker's bargaining power which is the same in both sectors.

The Timing of Events. At the beginning of a model period idiosyncratic productivity of workers and robots are realized as well as investment costs for automation. Based on the investment costs a fraction of firms invests in the adoption of robots in sector 1. At the same time, open vacancies are randomly matched with unemployed workers, while ongoing work relationships are terminated with exogenous probability ψ. Matched firms and workers then decide on wages and labor supply through Nash Bargaining. Lastly, firms who enter a relationship with a worker or adopted a robot make an investment decision and final goods are produced with intermediate inputs from both sectors. Households consume all their income. The timing of events is illustrated in Figure 1.

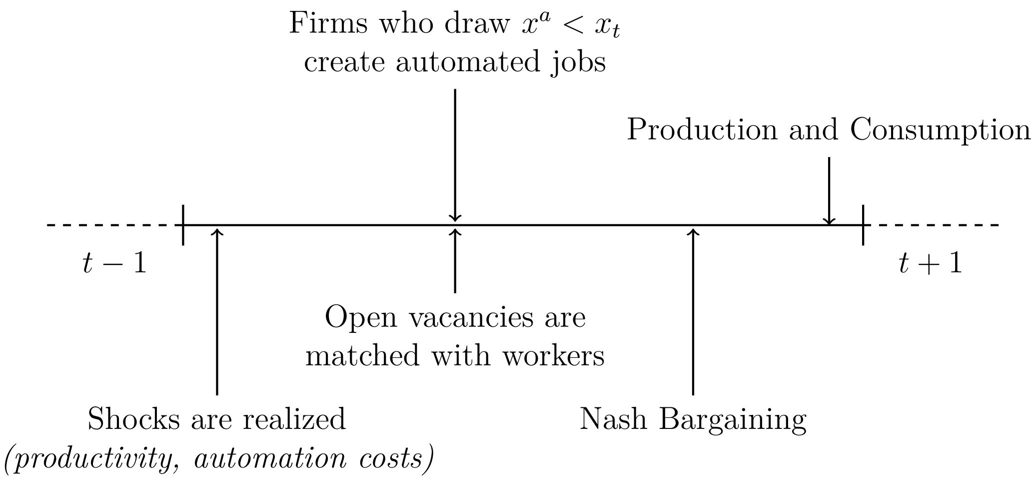


Figure 1: The timing of events in period t

The representative capitalist. Let Π_t denote the total profits from all one-worker firms and all automated jobs in period t. The supply of capital evolves according to

$$(1+r-\delta)K_t^s + (1-\tau_a)\Pi_t - \kappa^v v_t - \bar{x}q_t - (1+\tau_c)c_t^{\text{cap}} = K_{t+1}^s \tag{10}$$

with $\kappa^v v_t$ being the total costs of vacancies, $\bar{x}q_t$ the costs of newly automated jobs, τ_a a tax on profits and c_t^{cap} the consumption of capitalists.

The decision problem of the capitalists can be thought of as the decisions of a representative capitalist who perfectly diversifies. With Φ and A denoting the distributions over employed workers and automated jobs, the value function of this representative capitalist is given by

$$\begin{aligned} V^C(K_t, \Phi_t, A_t) = & \max_{c_t, v_t, A_{t+1}, K_{t+1}} \quad u(c_t) + \frac{1}{1+r}\mathbb{E}\Big[V^C(K_{t+1}, \Phi_{t+1}, A_{t+1})\Big] \\ & s.t \quad (1+r-\delta)K_t + (1-\tau_a)\Pi_t - \kappa^v v_t - \bar{x}q_t - (1+\tau_c)c_t^{\text{cap}} = K_{t+1}. \end{aligned}$$

In a stationary equilibrium, where capital stock, K, and distributions over states, Φ and A, are constanst, $V^C = u(c^*)\left(\frac{1+r}{r}\right)$.

2.3 Government

The government taxes labor income, consumption, and profits and uses the revenue to finance welfare transfers and public consumption G. Public consumption is given as an exogenous fraction of GDP, $G = gY$, and does not enter the utility of households.

Tax revenues from labor income, R_ℓ, consumption, R_c and profits, R_π, are given by

$$
\begin{aligned}
R_\ell &= \int_S \tilde{y}(s) - \lambda_0 \Big(\tilde{y}(s)\Big)^{1-\lambda_1} \,\mathrm{d}\Phi(s), \\
R_c &= \tau_c \cdot \int_S \tilde{c}(s) \,\mathrm{d}\Phi(s) + \tau_c \cdot c_{cap}, \\
R_\pi &= \tau_a \cdot \Pi,
\end{aligned}
$$

while payments to unemployed are given by

$$
B = \int_S b(s) \,\mathrm{d}\Phi(s),
$$

where $b(s) = 0$ for employed workers ($u = 0$) and $b(s) = \bar{b}$ for long-term unemployed workers ($u = 2$).

The government runs a balanced budget every period, that is

$$
R_\ell + R_c + R_\pi = B + G \tag{11}
$$

2.4 Stationary Equilibrium

At each point in time an agents state is given by $s = (z, z_{-1}, m, j, u)$, with z being persistent productivity, z_{-1} last period's persistent productivity, $m \in \{1, 2\}$ the market, j age and $u \in \{0, 1, 2\}$ the unemployment status (0 meaning employed, 1 indicating short-term unemployment and 2 denoting long-term unemployment). Let the space of possible states be denoted by $S = Z \times Z \times m \times J \times u$.

A stationary equilibrium is an allocation of value functions for employed and unemployed workers, $W(s)$ and $U(s)$, a decision rule for consumption $c(s)$, prices of intermediate goods p_1 and p_2, work contracts over wages $w(s)$ and labor supply $h(s)$, a distribution over states $\Phi(s)$, social transfers and taxes such that:

1. The value functions and the optimal decision rule for consumption $c(s)$ solve the optimization problems of the households (3) and (4) given the factor prizes, bargaining outcomes and initial conditions.

2. The measure of households over states $\Phi(s)$ is constant.

3. Wages $w(s)$ and labor supply $h(s)$ solve the bargaining problem (9)

4. The optimization of capitalists together with the optimal decision rules of workers yields an expectation of 0 for opening new vacancies and the measure over vacancies and automated jobs is constant.

5. Prices of intermediate goods solve the optimization of the competitive final goods

production and are determined by their marginal product, i.e.:

$$p_1 = \mu \left(\frac{y_1}{y_2}\right)^{\mu-1}$$
$$p_2 = (1-\mu) \left(\frac{y_1}{y_2}\right)^{\mu}$$

6. The government runs a balanced budget

$$R_\ell + R_c + R_\pi = B + G$$

2.5 Basic Income

Section 4 will discuss the effects of introducing a basic income which is provided by the government and financed through labor income taxes. There are two concepts of how to provide unconditional transfers to everyone which are often used interchangeably in the public discussion. The first refers to a policy as proposed by Atkinson (1995) and provides a fixed amount of lump-sum transfers to every individual irrespective of their age, income or other personal characteristics. The other is a tax system as discussed by Friedman (1962), where everyone again receives a fixed amount of transfers, but these transfers slowly face out when people start earning income. Within the framework of this paper the first will be referred to as Universal Basic Income (UBI), while the second will be called Negative Income Tax (NIT).

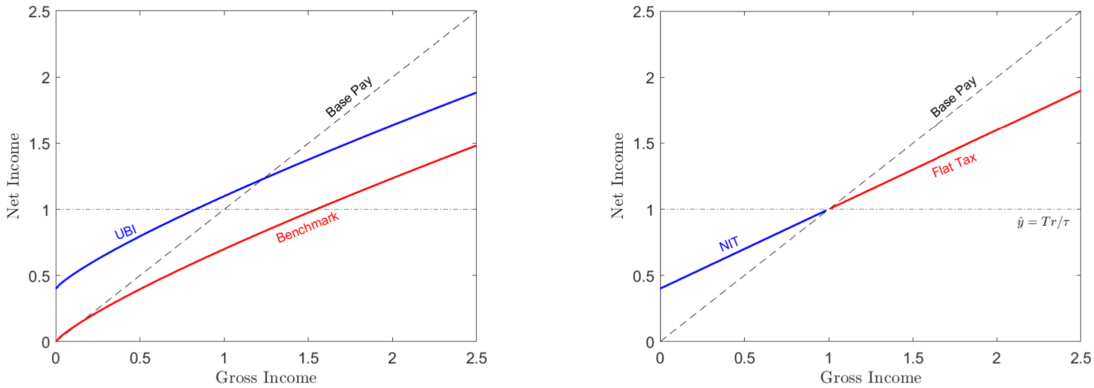
A reform towards UBI simplifies the problem of unemployed workers as they only receive the lump-sum transfer b^{UBI} irrespective of their individual state. However, employed workers also receive this transfer. Hence, with gross income of employed workers being denoted by $\tilde{y}$, net disposable income in the case of UBI is given by

$$y^{disp} = \begin{cases} \tilde{y} + b^{UBI} - T(\tilde{y}) & u = 0 \\ b^{UBI} & u \in \{1, 2\} \end{cases} \tag{12}$$

with $T(\cdot)$ again being tax on labor income.[6] Figure 2a shows how the introduction of a UBI which provides transfers in the amount of median income to everyone would shift disposable income compared to a given benchmark economy with a progressive income tax.

The idea of an NIT is very similar to UBI, as people are guaranteed a basic income, regardless of their employment status, their wealth or their education. The difference, however, is that the transfers face out as households start to earn labor income until

[6]Note that this specification means that the UBI transfers are not subject to taxation. This can potentially lower the marginal tax rates when entering employment, but does not have significant effects on the analysis otherwise.



(a) UBI (b) NIT

Figure 2: Universal Basic Income and Negative Income Tax

they completely vanish above a given income threshold, $\hat{y}$. Therefore, introducing an NIT usually requires less revenue to fund the additional expenses.

In this paper, I study the effects of replacing the taxation scheme and the unemployment benefits from the benchmark economy with a linear negative income tax. With $\tilde{y}$ denoting gross income (0 in case of unemployed), τ denoting the flat tax and Tr the amount of transfers to unemployed, after-tax income is now given by

$$y = \tilde{y} + Tr - \tau\tilde{y}, \tag{13}$$

such that households receive transfers until their income exceeds $\hat{y} = Tr/\tau$.[7] Figure 2b shows an example of how such a tax can look like, when households are guaranteed transfers in the amount of median income and transfers face out at a rate of 40%.[8]

3 Parameterization

This section presents the parameter values used to numerically solve the benchmark economy.[9] I calibrate the model to certain moments of the U.S. economy in order to provide an insightful analysis of the possible effects of different basic income programs. Some parameters are set externally (cf. Table 1), while others are estimated using a Simulated Method of Moments approach to match important labor market outcomes (cf. Table 2). Lastly, Table 3 provides a brief overview of the benchmark economy, before the effects of introducing a basic income are discussed in section 4.

[7]Note that this specification already includes unemployment benefits, since $b(s) = y(0) = Tr$.

[8]I also conducted an experiment with a progressive tax schedule, but the effects did not vary drastically. The rest of this section only presents the results from the flat tax, since its implementation is more straightforward and easier to understand and should therefore be preferred in view of similar outcomes.

[9]For details on the computational solution method see appendix C.

3.1 Households

Households enter the model at age 21 and die with certainty at age 80. One model period corresponds to six months. There is no formal retirement, but the households' age-dependent experience premium drops after the age of 65. The experience premium is set exogenously and normalized to yield a life-time mean of 1. The evolution of the experience premium is plotted in Figure A1 in appendix A.

Households discount the future with the discount factor $\beta = 0.992$ and per-period utility is described by

$$u(c, h) = \frac{c^{1-\sigma}}{1-\sigma} - \phi \frac{h^{1+\frac{1}{\gamma}}}{1+\frac{1}{\gamma}},$$

where the risk-aversion parameter, σ, is set to 2, which is standard in the literature. The Frisch elasticity γ is chosen to be 0.7 as estimated by Hall (2009). The multiplicative disutility of supplying labor, ϕ, is calibrated endogenously to yield an average labor supply of 40% of total labor endowment, which is in the range of standard values in the literature.

Persistent labor productivity follows a simple AR(1) process where the annual autocorrelation parameter is set to $\bar{\rho} = 0.95$ and the variance of the iid shock chosen to be $\bar{\sigma}^2 = 0.025$. All of these values are within the range of standard literature. To map these values into biannual numbers, I set $\rho = \bar{\rho}^{1/2}$ and $\sigma^2 = \bar{\sigma}^2/(1 + \rho^2)$.

Finally, disutility from college is given by $\delta_c z_c$, where z_c is drawn from a normal distribution with mean 1 and standard deviation 0.1 at the beginning of the first model period. The utility costs, δ_c, are calibrated endogenously to match an average college attendance of 31%.

3.2 Production

The capital share in production of intermediate goods, α, is chosen to match the average of capital income over total income in the U.S. between 1960—2007, which is 0.35 as reported by Lopez-Daneri (2016). Final production uses an equal share of intermediate goods from both markets, i.e. $\mu = 0.5$. The biannual depreciation rate, δ, is set to 0.5% and the biannual nominal interest rate is given by $r = 1/\beta - 1 = 0.8\%$.

Automation. The productivity of a robot, ζ, evolves according to an AR(1) process. For the quarterly autocorrelation, $\hat{\rho}$, and the quarterly standard deviation of the normal innovation, $\hat{\sigma}$, Leduc and Liu (2021) estimate values of 0.86 and 0.029, respectively. I map these quarterly values into biannual values and set $\rho_a = \hat{\rho}^2$ and $\sigma_a = (1 + \hat{\rho}^2) \cdot \hat{\sigma}$.

The costs of automating an open vacancy, x^a, are drawn from a uniform distribution with support $[0, \bar{x}]$. The upper bound $\bar{x}$ determines the probability of automating an open vacancy and is chosen endogenously to match an automation rate in sector 1 of 30% as reported in Leduc and Liu (2021). The probability with which a robot becomes obsolete

Table 1: Directly specified parameters

	Parameter	Value	Target/Source
Preferences			
Risk aversion	σ	2	standard
Frisch elasticity	γ	0.7	Hall (2009)
Discount factor	β	0.992	standard
Labor income			
Autocorr. labor efficiency	ρ	0.95	standard
Variance labor efficiency	σ^2	0.025	standard
Production			
Capital share	α	0.35	Lopez-Daneri (2016)
Intermediate Input	μ	0.5	standard
Depreciation	δ	0.5%	standard
Automation			
Autocorr. efficiency	ρ_a	0.86	Leduc and Liu (2021)
Std. dev. efficiency	σ_a	0.028	Leduc and Liu (2021)
Maintenance costs	κ^a	0.34	see text
Probability of obsolescence	δ^a	0.08	Leduc and Liu (2021)
Labor Market			
Job finding probability	χ	0.97	Krusell et al. (2010)
Elasticity of matching function	η	0.72	Shimer (2005)
Bargaining power workers	ξ	0.72	Shimer (2005)
Government			
Consumption tax	τ_c	7.5%	McDaniel (2007)
Capital income tax	τ_a	25%	McDaniel (2007)
Curvature of income taxes	λ_1	0.137	Holter et al. (2019)

or breaks down, δ^a, is set exogenously to 8%. This leads to a situation in which the average annual life-span of a robot is in line with the data reported by the International Federation of Robotics (IFR) as used in Leduc and Liu (2021). Lastly, following the estimation in Leduc and Liu (2021), maintenance costs of robots are given by $\kappa^a = 0.34$, which yields annual profits of 2% of annual revenue by adopting a robot.

3.3 Labor market.

Workers and open vacancies are matched according to the function $m(u, v) = \chi u^\eta v^{1-\eta}$, as in Shimer (2005). Following Shimer (2005), I calibrate χ by targeting a market tightness of $\theta = 1$ for both sectors and setting χ to match the average probability of finding a job.

Table 2: Jointly calibrated parameters

	Parameter	Value	Target
Disutility of college	δ_c	720	31% college attendance
Investment costs	$\bar{x}$	9.8	33% automation rate
Labor disutility	ϕ	56	Avg. labor hours 0.4
Average taxation	λ_0	0.63	Avg. taxation 22%

As reported in Krusell et al. (2010), a worker finds a job with probability 0.45 per month. Hence, on average the biannual flow arrival rate of job offers equals $1-(1-0.45)^6 = 0.97$ and with an equilibrium market tightness of $\theta = 1$, this pins down the value $\chi = 0.97$.[10]

Next, as estimated in Shimer (2005) the elasticity of the matching function is assumed to be equal to the bargaining power of the workers and hence, $\eta = \xi = 0.72$. Also, the exogenous probability of a job separation, ψ, is set to 4%, which is twice as high as the probability with which a robot becomes obsolete. Finally, the costs of posting a vacancy, κ_m^v, are chosen so that the market tightness of $\theta = 1$ satisfies the equilibrium free-entry condition for posting a vacancy in both markets, meaning that expected profit of creating a new vacancy is 0 in both markets.[11]

3.4 Government

The replacement rate for short-term unemployed is set to be 0.5, while long-term unemployed receive transfers of 40% of median income to assure a subsistence level of consumption. Also, there are three different tax parameters to be chosen. Tax rates on consumption and capital gains for the U.S. are taken from McDaniel (2007), who reports $\tau_c = 7.5\%$ and $\tau_a = 25\%$. The parameter λ_1, which measures the rate of progressivity, is based on Holter et al. (2019) who find an estimated value for the US of 0.137. The parameter λ_0, which shifts the tax function and determines average level of taxation, is chosen endogenously to match an average taxation in the economy of 22% as estimated in McDaniel (2007). The resulting tax revenue will exceed payments for unemployment insurance and this surplus amount will be assumed to be exogenous government consumption G, which will be held fixed in subsequent policy experiments.

[10]Note that this market tightness in the automation sector occurs after the decision of automating open vacancies. Hence, the flow arrival rate of job offers is the same in both markets. However, the additional possibility of automating a job increases the expected profits of keeping a vacancy open, thus leading to less matches for the same number of job offers.

[11]In subsequent policy experiments, these benchmark costs of creating a vacancy will be held constant. In order to still get the equilibrium free-entry condition for posting a vacancy, the market tightness becomes a free parameter and will adjust to again yield zero expected profits of creating a new vacancy.

Table 3: Benchmark Outcomes

College Share	31%
Automation Rate	35%
Unemployment Rate	7%
autom. sector	7.9%
college sector	5.1%
Mean Net Income[1]	1.5
autom. sector	0.94
college sector	2.78
Average Taxation	23%

[1] Note: Average income is given in relation to median income and only includes employed workers.

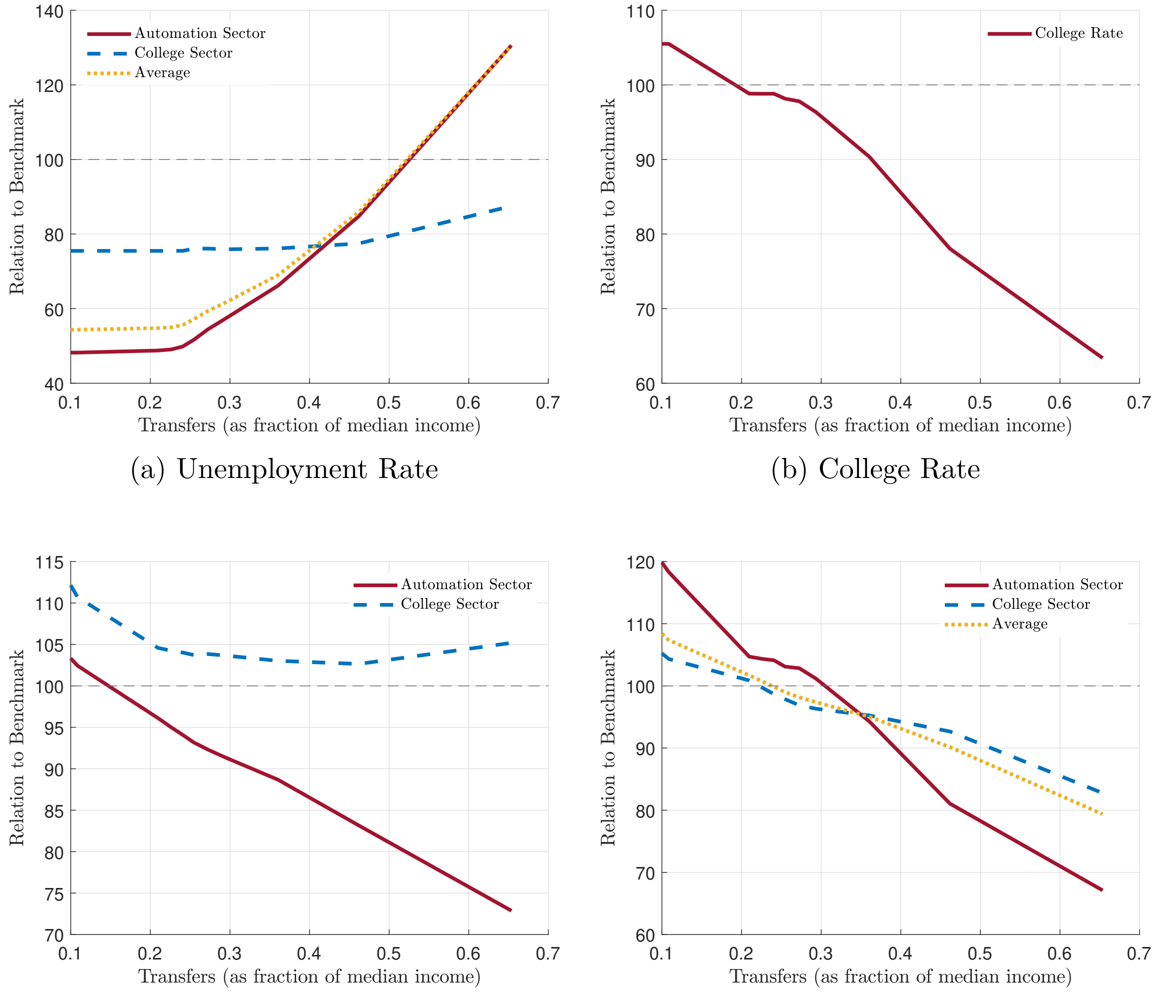
3.5 The Benchmark Economy

Before introducing a universal basic income, Table 3 summarizes the outcome of the benchmark equilibrium with the parameterization as described above. The equilibrium college share is 31% and the the automation sector sees a share of 35% of automated jobs. Also, we can see sizable differences between the markets. While the overall unemployment rate is given by 7%, it is higher in the automation sector than in the college sector with 7.9% against 5.1%, respectively. The probability to invest in robots instead of workers also has implications for wages. Average income is nearly three times higher in sector 2 than in sector 1. Workers who obtained a college degree earn 278% of median income on average, while the average worker in the automation sector only earns 94% of median income. Lastly, employed workers face an average tax rate of roughly 23%,

4 The Effects of a Basic Income

As discussed in subsection 2.5, there exist two popular concepts of how to provide a basic income. This section describes the effects of replacing unemployment benefits with a Negative Income Tax (NIT) as described in Equation 13 and shown in Figure 2b.[12] I vary the generosity of the unconditional transfers and measure them as fraction of median income in the new stationary equilibirum. The flat income tax, τ, which is also the face-

[12] The effects of UBI are briefly discussed in appendix E, but since UBI yields similar results as NIT with a considerable higher need for additional revenue, the rest of this paper focuses on NIT.



(a) Unemployment Rate

(b) College Rate

(c) Average Working Hours

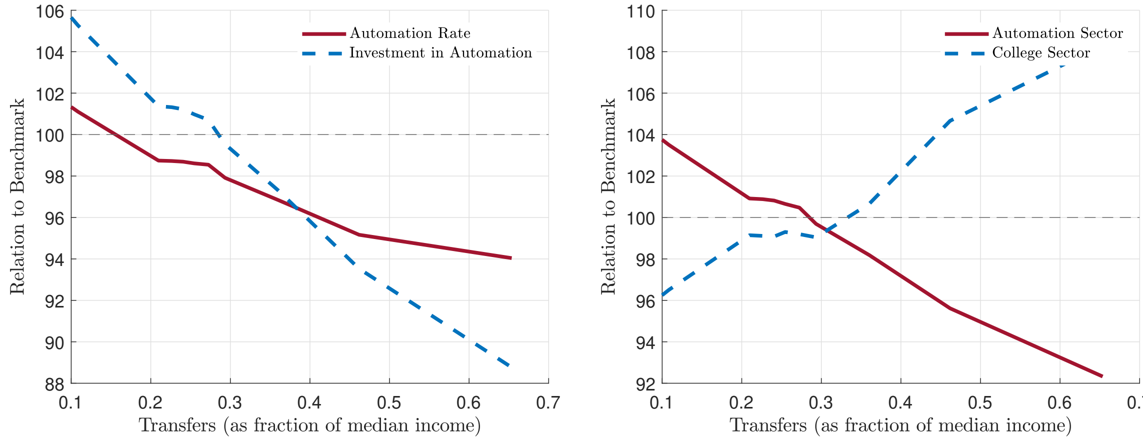
(d) Total Labor Supply

Figure 3: Effects of different NIT schemes on labor market outcomes. NIT schemes are ordered by the amount of guaranteed income as fraction of median income.

out rate of the transfers, is then chosen to keep the government budget fixed with regards to the exogenous parameters.[13] All other tax rates are held constant. Note that the break-even income at which households receive no transfers and pay no taxes is immediately determined by the transfer level and the tax rate, $\hat{y} = Tr/\tau$, so that it cannot be used as additional policy variable. All else equal this scheme results in a smaller tax burden for the households than the introduction of UBI, since transfers are not distributed in a lump-sum manner but face out for higher income earners.

Labor Market. First, Figure 3 shows how introducing an NIT would effect the labor market. Transfers from the NIT policy are measured as fractions of median income and

[13]This leads to a slight change in the computational solution method: The average labor income tax is now an equilibrium outcome and pinned down by the balanced budget condition. Also, the costs of creating a vacancy, κ_m^v, are now held constant and instead the market tightness will shift to adjust to the new equilibrium.



(a) Automation Rate (b) Intermediate goods prices

Figure 4: Effects of different NIT schemes on automation and intermediate goods prices.

the outcomes are given in relation to the benchmark equilibrium. In Figure 3b we can see how higher transfers discourage workers from obtaining a college degree. Higher transfers are financed by higher income taxes. At the same time, the insurance against automation induced job loss provided by a college degree is partially offset by the unconditional transfers provided by the NIT policy. This reduces the incentive to join the college sector and college attendance drops to nearly 60% of the benchmark level with higher transfers.

Concerning labor supply, we can see that the introduction of an NIT has mostly adverse effects on total labor supply in both sectors, while the effects on average working hours differ greatly. Average working hours in the college sector are positively affected. With an NIT the marginal tax rates of high income earners fall relative to the benchmark economy which incentivises them to supply more labor. However, the fall in the college rate leads to an overall fall in total labor supply in the college sector which subsequently reduces output in this sector. Workers in the automation sector, in contrast, drastically reduce their labor hours as transfers become more generous. A transfer level above 60% of median income leads to a reduction in average working hours of 25%. This reduction in average working hours also reduces total labor supply in the automation sector, even though the share of workers who join this sector increases relative to the benchmark economy.

Lastly, the unemployment rate in the economy increase with more generous transfer levels (cf. Figure 3a), but once again we can see sizable difference between sectors. Unemployment rates in the college sector are nearly unaffected and remain below the benchmark level for all transfer schemes. In the automation sector, in contrast, the unemployment rate rises by more than 25% with the highest transfer scheme, while dropping by nearly 50% when transfers are low. Overall, we can see a clear adverse relationship between the generosity of the transfer system and labor supply.

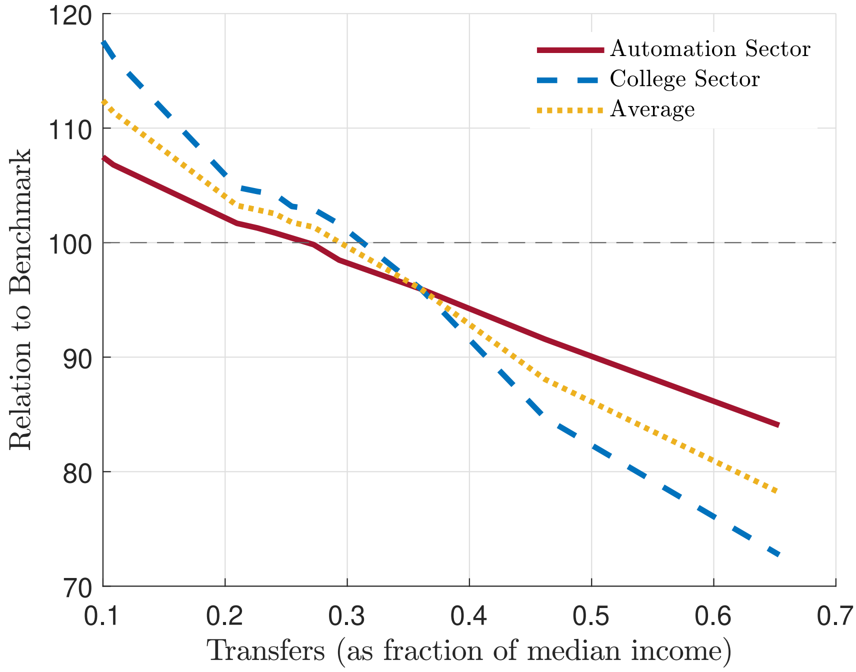


Figure 5: Effects of different NIT schemes on output.

Effects on Automation. Seeing how labor supply decreases with higher transfers poses the natural question whether firms will react by increasing their investment in automation. Figure 4a, however, reveals that automation is also negatively affected by more generous NIT schemes. When transfers are below 30% of median income, firms start to invest more in automation, while the investment is discouraged when transfers become higher. This effect is driven by the responses in the labor market which deeply impact the prices for the intermediate goods (cf. Figure 4b). With the fall in the college rate, production in the college sector decreases and consequently, the price for the intermediate good from sector 2 increases. Meanwhile, the price for the intermediate good from the automation sector falls which depresses expected profits from investing in robots and subsequently discourages investment in automation.

The reduction in automation together with the fall in labor supply also leads to a reduction in overall output for higher transfer levels (cf. Figure 5). An NIT policy which provides more than 60% of median income as unconditional transfers leads to a fall in overall output by more than 20% relative to the benchmark level. With lower transfers, however, the supply of labor increases in both sectors together with investment in automation which leads to higher output.

Welfare Implications. To understand the welfare effects of a basic income policy, I compute the consumption equivalence value (CEV), which is the factor by which the consumption of an individual has to be increased in order to make the household indifferent between the benchmark economy and the economy with an NIT policy. Specifically, for

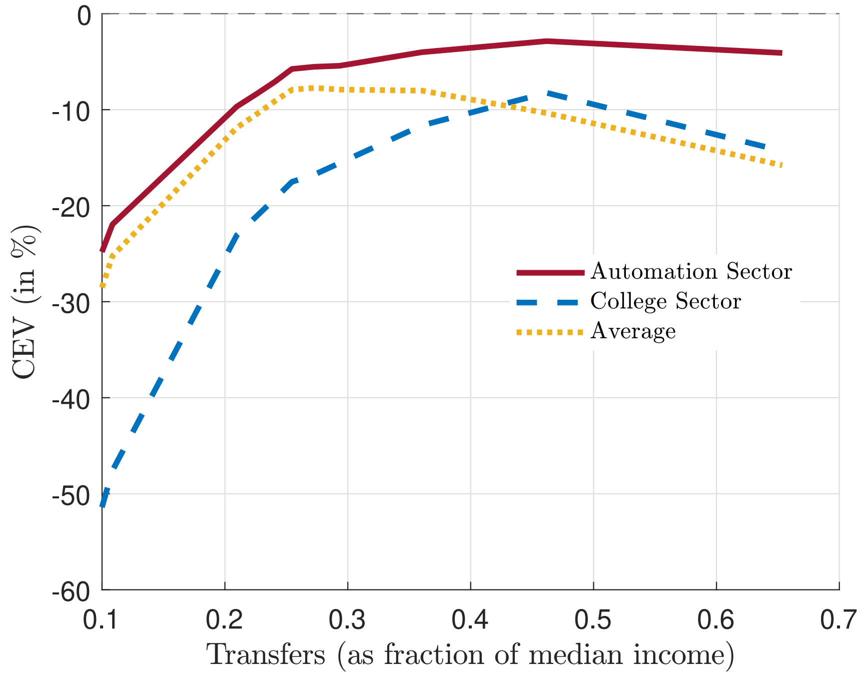


Figure 6: Welfare effects of different NIT schemes in terms of consumption equivalence

an individual in state s, the CEV is calculated by

$$V^B((1 + CEV)c(s), h(s)) = \tilde{V}(c(s), h(s)) \quad (14)$$

where V^B and $\tilde{V}$ indicate the value functions in the benchmark economy and the counterfactual economy, respectively. Hence, if $CEV > 0$ households prefer the economy with an NIT given their state s.

Figure 6 shows the expected welfare gains or losses of a newborn under the veil of ignorance for all transfer levels and both sectors. Looking first at average welfare, the graph reveals a slight u-shape, showing that very high transfers are nearly as bad for the workers as exceedingly restrictive ones. However, even with the transfer levels which lead to the lowest welfare loss workers still experience a loss in consumption equivalence of about 9%. The reason for the strong negative effects of an NIT scheme with low transfers seems clear: Relative to the benchmark economy unemployed workers receive far less benefits (especially high productive workers who in the benchmark economy can enjoy a fraction of their past income). This leads to a reduction in expected life-time consumption, even if working hours remain the same. With a more generous NIT scheme, the reason for the negative effects is different. Unemployed workers can now enjoy a fixed amount of high transfers, which especially favors low productive workers who also reduce their average working hours. High productive workers, in contrast, stem most of the tax burden, as their higher income finances the transfers to the rest. Overall, this again leads to lower disposable income, lower consumption, and consequently, lower welfare in the

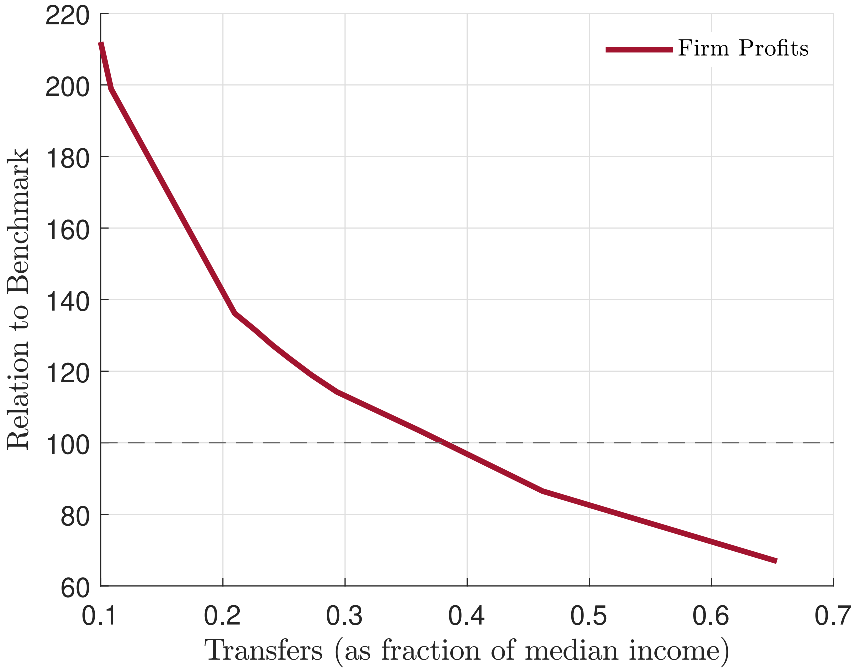


Figure 7: Effects of different NIT schemes on firm profits.

economy.

Looking at the effects on the different sectors reveals similar patterns for all workers. However, workers in the college sector experience higher losses than workers in the automation sector. This is mostly due to the income premium in the college sector. Workers with a college degree earn higher wages than workers in the automation sector on average and therefore finance the unconditional transfers through higher tax payments. At the same time, high income earners often prefer the benchmark economy even when being unemployed, since their benefits are independent of their productivity under the NIT policy, while in the benchmark economy they can enjoy a fraction of their past income. Overall, we can conclude that higher productive workers experience large welfare losses which are not counteracted by welfare gains in the automation sector and workers would always prefer being born into the benchmark economy, irrespective of the generosity of the unconditional transfers.

Effects on Capitalists. Seeing how the introduction of a basic income has mostly adverse effects on workers, the question remains whether this welfare loss is counteracted by higher profits of firms. However, Figure 7 reveals that profits are also falling with more generous NIT schemes. An NIT policy which provides unconditional transfers of about 60% of median income leads to a fall in profits by more than 20%. Seemingly, introducing a basic income leads to a deadweight loss with a reduction in output, welfare and profits.

5 The case for a specific NIT policy

While the discussion in section 4 already show that the introduction of an NIT policy which is solely financed by income taxation does not seem desirable, it is still worthwhile to disentangle the equilibrium effects by analyzing the transitional dynamics and to compare the new equilibrium to the benchmark economy in more detail. This section therefore analyzes the introduction of a specific transfer level. A natural starting point is an NIT scheme which at least provides an income of the level of the at-risk-of-poverty threshold which is commonly set around 60% of median disposable income.[14] Hence, in this exercise I introduce an NIT which provides exactly 60% of median income as unconditional transfers and present a deeper analyze of the effects such a policy would have on the economy.

First, Table 4 provides a detailed overview of the effects of a basic income of 60% of median income by comparing the benchmark equilibrium and the equilibrium after the introduction of the NIT. We can see how output in the new economy drops to only 84.5% of the benchmark level. Looking at the values for automation and labor supply, this drop in output seems to mostly stem from a reduction in investment in robots and reduced working hours. This also results in lower firm profits.

Next, the college rate drops to 22.6%. As discusses above, this is because the incentive to join the college sector is mostly driven by higher job security. However, for lower skilled workers the disutility of obtaining a college degree now outweighs the potential gains due to the additional insurance provided by the NIT. The drop in the college sector and higher labor force participation in the automation sector also lead to a change in factor prizes. The price for the intermediate goods in sector 1 drops by nearly 10%, whereas the price for intermediate goods in sector 2 rises by roughly 8%.. Consequently, gross wages in the college sector increase, while the wage rates in the automation sector drop. However, average disposable income still falls in both sectors. This also leads to a significant drop in average consumption, which decreases by more than 25% in both sectors.

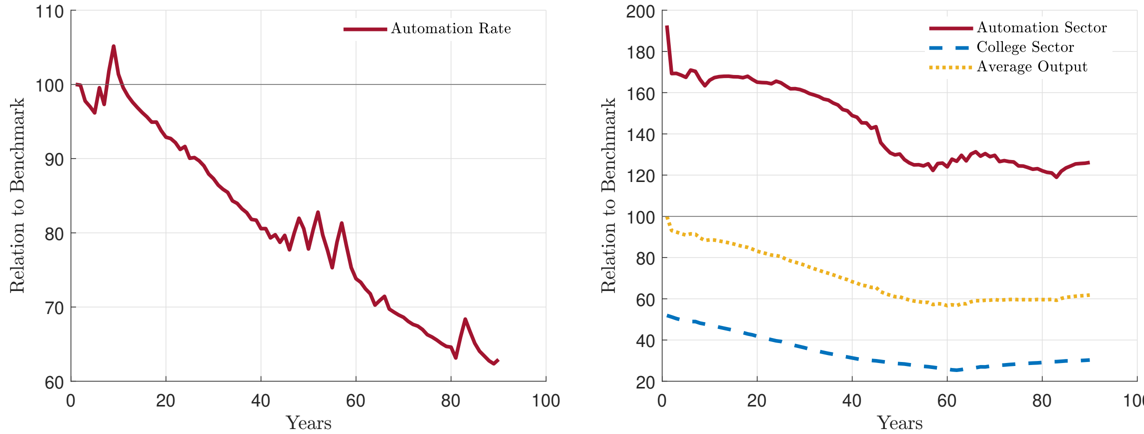
Lastly, the introduction of an NIT policy has significant consequences on the income distribution. The percent of overall income earned by top income earners falls drastically and the Gini coefficient drops from 0.37 in the benchmark economy to 0.3 in the economy with an NIT. Details on the income distribution can be found in Table B1 in appendix B.

Overall, combining the insights from the change in the income distribution with Table 4 we seemingly can conclude that the introduction of a basic income via a Negative Income Tax would mostly lead to a redistribution from high income earners to low income earners. However, this redistribution does not lead to welfare gains in the economy and the average expected welfare of a newborn under the veil of ignorance drops by 14% in terms of consumption equivalence.

[14] Compare, for example, Eurostat.

Table 4: Effects of NIT on macroeconomic outcomes

Variable		Benchmark	NIT
Output		100	84.5
Profits		100	72.5
College Rate		31%	22.6%
Automation		35%	34.4%
Avg. taxation		23%	10%
	Face-out rate		65%
Intermediate Goods Prices			
	autom. sector	100	92.2
	college sector	100	107.7
Avg Working Hours		100	80.9
	autom. sector	100	76.4
	college sector	100	105.4
Avg. Consumption		100	68.8
	autom. sector	100	77.3
	college sector	100	79.9
Unemployment Rate		7%	8.1%
	autom. sector	7.9%	9.1%
	college sector	5.1%	4.4%
Disposable Income		100	70.4
	autom. sector	100	78.6
	college sector	100	79.9
Gini		0.37	0.3
Welfare change (CEV)			−14%



(a) Investment in Automation

(b) Evolution of Output

Figure 8: Transitional Dynamics of Investment in Automation and Output.

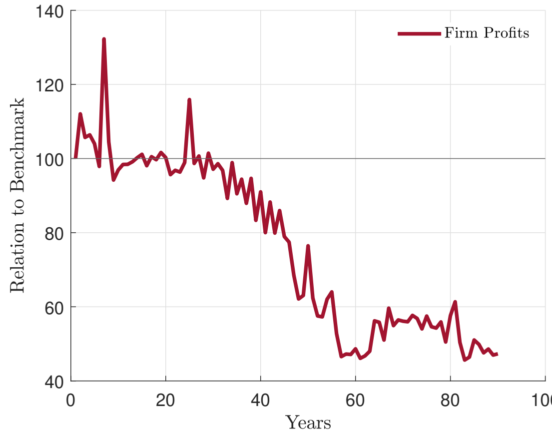
5.1 Transitional Dynamics

This section describes the dynamics which occur during the transition to the new equilibrium.[15] First, Figure 8 shows how the investment in automation and total output are effected during the transitional periods. Looking at Figure 8a we can see how initially firms react by increasing the stock of robots until it lies roughly 8% above the benchmark level. Then, investment slows down until the stock of robots falls to nearly 60% of the benchmark level.

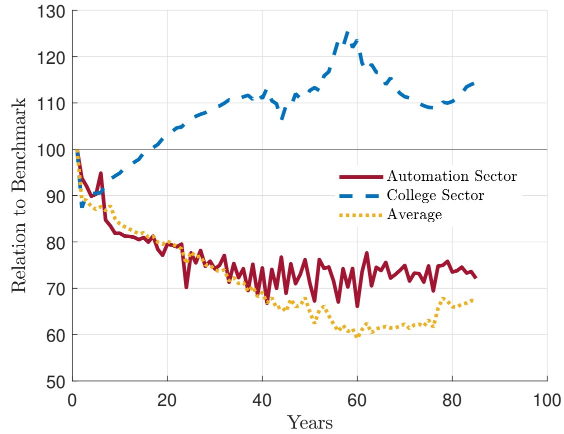
Turning to Figure 8b reveals that this change in automation does not immediately translate into a change in output. While output of the intermediate good in the automation sector is also falling during the transition to the new equilibrium, production lies above the benchmark for more than one generation (60 years). In contrast, output in the college sector falls drastically and remains at roughly 40% of the benchmark level. This considerable drop in production in sector 2 stems from the reduced labor supply in sector 2 as the amount of workers with a college degree drops (cf. Figure 9c). How firms are affected by these transitions is shown in Figure 9a. We can see how despite the increase in output in the automation sector, the profit of firms decreases. This is due falling prices of the intermediate good.

Next, Figure 9 also shows transitional paths for several statistics regarding the labor market. In Figure 9c we can see how the introduction of an NIT leads to a strong reduction in the college Rate, which only starts to rise again after 60 years. Regarding labor force participation, Figure 9d reveals that unemployment rates rise throughout all sectors. At the same, the average amount of working hours falls drastically in the automation sector, while increasing in the college sector. Overall, less people are finding a job during the

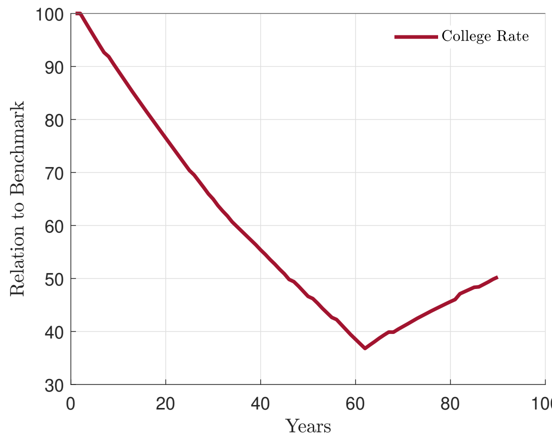
[15] For details on the computational method see appendix D.



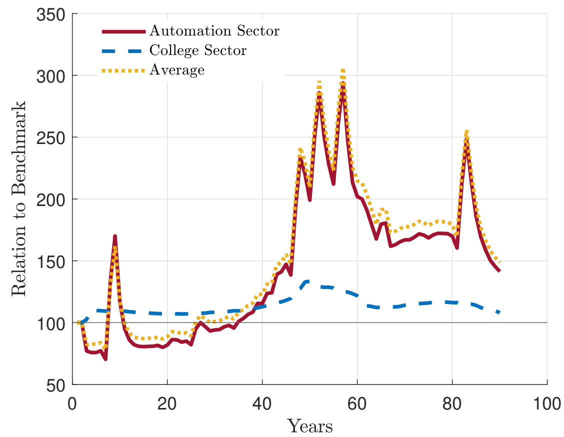
(a) Change in Profits



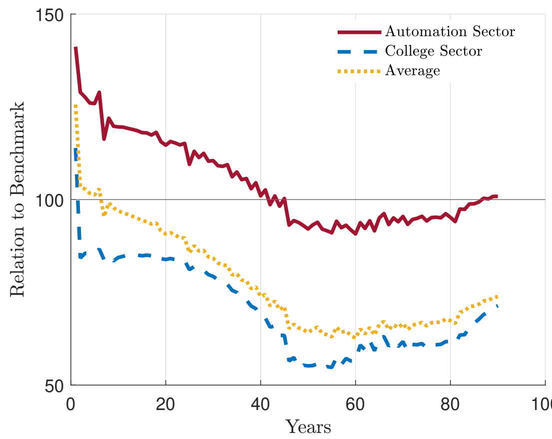
(b) Average Wage Rate



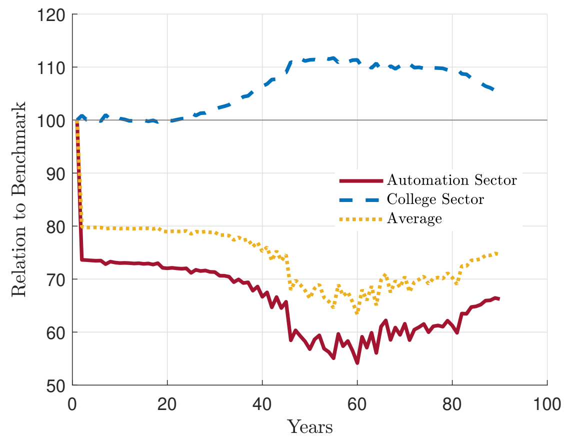
(c) Change in College Attendance



(d) Change in Unemployment Rates

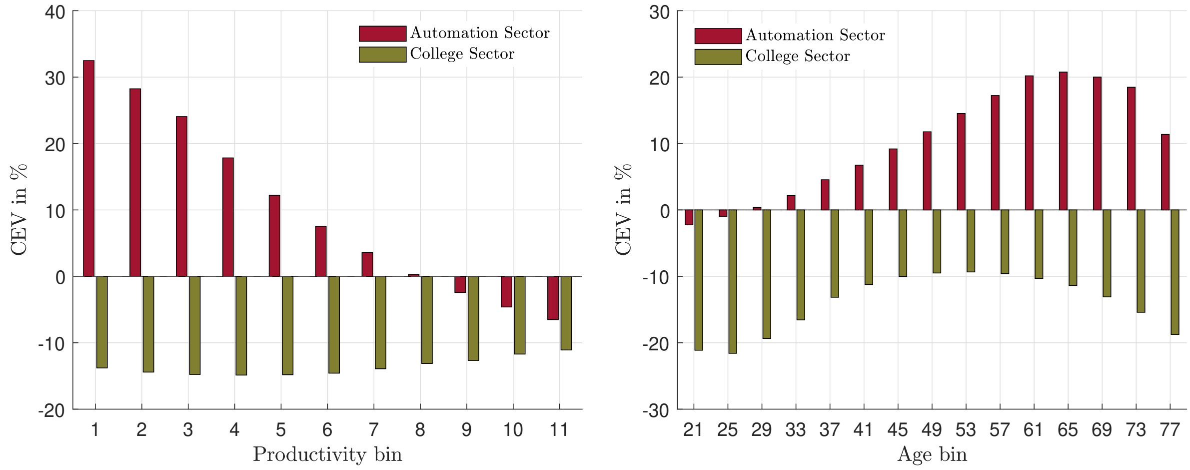


(e) Mean Disposable Income



(f) Average Working Hours

Figure 9: Transitional Dynamics in the labor market.



(a) Welfare Effects per Skill Group

(b) Welfare Effects per Age Group

Figure 10: Change in expected life-time utility of current generation when introducing the NIT policy next period.

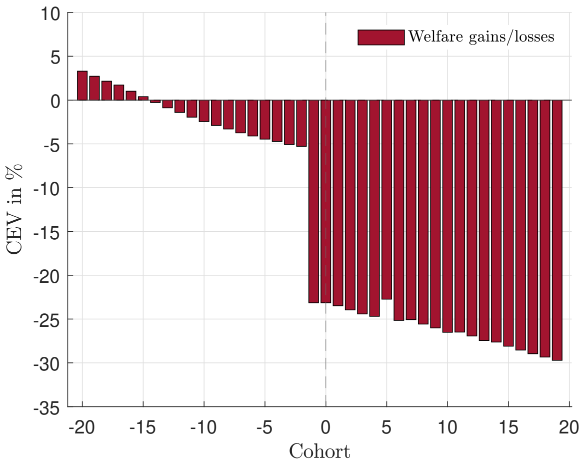
transitional periods and are spending less time at work.

Welfare Comparison. Lastly, the transitional dynamics are also important for the welfare implications of the new policy, since current cohorts experience different welfare effects than future generations who are immediately born into the new stationary equilibrium. Hence, Figure 10 reports the welfare gains and losses of cohorts who are born before the introduction of the NIT. The reported values for the consumption equivalence are calculated by comparing the life-time utility of remaining in the benchmark equilibrium to experiencing the transitional periods towards the new equilibrium[16].

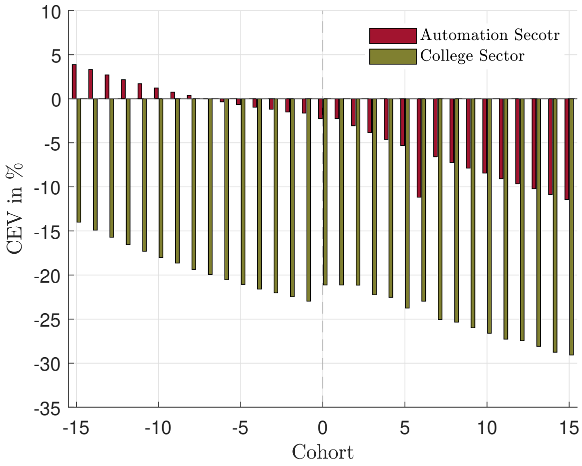
Turning to Figure 10a reveals the different effect the introduction of an NIT has on workers of different productivity levels and between sectors. A considerable fraction of workers in the automation sector experience large welfare gains (up to 33% for the least productive workers) and only the workers with the highest productivity are adversely affected (with welfare losses up to -8%). Workers in the college sector, in contrast, experience welfare losses throughout all skill groups.

Next, Figure 10b again shows the change in welfare for current cohorts, but this time reported for different age groups in both sectors. Again, the reform is clearly worse for workers who enter the college sector. Although there seems to be an upward trend with older workers being less adversely affected, they still experience welfare losses throughout all age groups. Even the oldest people, who are already at the end of their working life, would prefer staying in the benchmark economy. In the automation sector, in contrast, nearly all workers from the current generation can expect welfare gains when averaged

[16] This means that this comparison is not simply between expected welfare in the old economy and the new economy. The transitional dynamics which current cohorts would experience upon the introduction of the new policy are taken into account



(a) Average welfare effects



(b) Welfare effects per sector

Figure 11: Welfare Effects of NIT on different cohorts. Period 0 refers to introduction of NIT.

by age group. Similarly to the college sector, older workers are better off than younger workers. The highest welfare gains are expected by workers who enter the later phase of their working life around the age of 65. At this age, their age-efficiency profile starts to fall in order to mimicking retirement and the additional insurance provided by the NIT leads to an expected welfare gain of up to 21% in terms of CEV. These accentuated positive welfare effects are mainly driven by the fact that firms can invest in robots. Since aging workers become less productive, firms might be inclined to automate their tasks. Hence, older people face poorer contracts. The introduction of the NIT can now provide additional insurance against this rationalization.

Together these figures suggest that the introduction of the NIT would mainly yield redistributional effects from the college sector towards the automation sector and an overall assessment of welfare is mainly driven by the weights given to both groups. However, when looking purely at a potential voting outcome where every worker is assigned one vote in favor or against the reform based on whether they can expect welfare gains or welfare losses, the higher number of workers in the automation sector would be able to overrule the objections from workers in the college sector. Overall, in this experiment a majority of 56% of workers would vote in favor of the reform.

Effects on different cohorts. Lastly, the transitional dynamics also reveal huge differences in the effects the NIT would have on cohorts who are born before and after the introduction of the new policy. Figure 11a plots the average expected life-time welfare of a newborn under the veil of ignorance for several periods before and after the introduction of the NIT. First, for cohorts who are born before the introduction of the NIT, older people can expect welfare gains, while younger households suffer welfare losses.

Turning to Figure 11b again reveals that the welfare effects differ greatly between

Table 5: Optimal Tax and Transfer System

	Parameter	Value
Consumption Tax	τ_c	30%
Capital Income Tax	τ_a	-10%
Labor Income Tax[1]	τ	10%
Unconditional Transfers[2]	Tr	15%
Welfare gains[3]	CEV	+19%

[1] Note: The income tax rate is also the face-out rate of transfers.
[2] Transfers are measured as percent of median income.
[3] Welfare is measured in relation to the benchmark economy.

sectors. Again, workers in the automation sector are better off when being born more than 8 years before the introduction of the NIT policy, while workers entering the college sector experience substantial welfare losses throughout all cohorts. As we converge to the new equilibrium the average welfare of future generations who are born into the new equilibrium drops by 13.5% in terms of CEV. Hence, while current generations would vote in favor of the NIT, since the welfare gains in the automation sector outweigh the losses in the college sector, future generations are worse off and would prefer being born in the benchmark equilibrium.

6 Optimal Tax and Transfer System

So far, all the experiments have assumed the tax system to stay the same and only the tax on income was shifted upwards to finance the additional transfers. However, a more comprehensive policy analysis should consider possible changes in other tax rates as well. Hence, in this section I also vary the tax on consumption, τ_c, and the tax on profits, τ_a, to try and find the optimal tax and transfer system with regards to the expected welfare of a newborn under the veil of ignorance. Again, welfare is calculated in terms of consumption equivalence.

Considering the results discussed in appendix of subsection E, the introduction of an NIT seems to be preferable over the introduction of a UBI in terms of CEV for any given level of unconditional transfers. Thus, in this exercise I vary the tax on consumption and the tax on profits and introduce an NIT of varying generosity to find the optimal combination of $\{\tau_c, \tau_a, Tr\}$. Note that the flat income tax, which is also the face-out rate of the transfers (cf. Equation 13), is not a variable of choice, since it has to be adjusted

Table 6: Comparing model outcomes from optimal NIT to benchmark

	Benchmark	Optimal NIT
College Share	31%	52.8%
Automation Rate	35%	74.5%
Average Taxation	23%	−10%
Output	100	217
Unemployment Rate	7%	3.8%
autom. sector	9.1%	3.8%
college sector	5.1%	3.8%
Mean Net Income	100	173
autom. sector	100	115
college sector	100	144
Average Consumption	100	143
autom. sector	100	94
college sector	100	119

to keep the government budget balanced under the given tax and transfer regime. The result of this exercise is shown in Table 5.

First, we can see how changing the whole tax and transfer system can lead to an improvement of average expected welfare by nearly 20% in relation to the benchmark economy. Next, while the optimal tax on labor income is very low with only 10%, the tax on consumption vastly exceed the benchmark value with 30% against only 0.075%, respectively. Also, the unconditional transfer to unemployed only amounts to 15% of median income, while profits of firms are actually being subsidized by a negative tax on capital income. Overall, this tax and transfer system vastly reduces tax rates on production, while putting a higher burden on unemployed and consumption. Seemingly, the average worker prefers the additional income when employed by a firm over better insurance provided by higher taxes and higher transfers.

Table 6 compares the equilibrium outcome of some macroeconomic variables from the optimal tax and transfer system to the benchmark equilibrium. We can see how the subsidy on profits leads to a surge in automation, while more people are obtaining a college degree. Consequently, output in both sectors rises and the production of the final good increases by more than 100%. At the same time, lower taxes and the slow face-out rate of transfers leads to a considerable increase in average disposable income which rises by 73% compared to the benchmark economy. This also leads to an increase in average consumption by roughly 43%. However, this is mostly driven by the higher consumption in the college sector and the fact that more people are now obtaining a college degree. Workers in the automation sector, however, experience a slight decrease in average consumption of about 6%. Lastly, since an NIT introduces transfers for employed workers, the average taxation in the economy is negative, with the average employed worker receiving transfers in the amount of 10% of their income. Hence, with capital income also being subsidized the government budget is nearly exclusively financed by the tax on consumption.

Overall, looking at tables 5 and 6 reveals that in this model setup the optimal tax and transfer system is simply a subsidy to capital and labor income, which increases labor supply in both sectors - unemployment drops to 3.8% in both markets -, while also encouraging further investment in automation. Both effects drastically increase production and on average workers can expect welfare gains. However, note that this tax regime harshly punishes unemployed workers who only receive 15% of median income as subsistence level, which lies way below every common indicator for poverty.

7 Conclusion

This paper develops a quantitative framework to study the effects of different basic income policies when there exist segregated labor markets which differ in the possibility of automation induced job-loss. I use this framework to analyze the adoption of a basic income with varying degree of generosity which is financed solely by adjusting income taxation. The analysis reveals that the effects on automation are highly dependent on the transfer level and that including search frictions in the labor market matters greatly for the outcome. An NIT with very low transfer levels increases the costs of unemployment and therefore increases search effort and labor supply of workers. The increased production in the college sector also raises expected profits in the automation sector and thus automation. With higher transfer, in contrast, the opposite happens. With the fall in the college rate, production in the college sector decreases and consequently, the price for the intermediate good from sector 2 increases. Meanwhile, the price for the intermediate good from the automation sector falls which depresses expected profits from investing in robots and subsequently discourages investment in automation. At the same time, labor supply falls in both markets and due to higher taxation disposable income also decreases. Overall, the equilibrium effects on output are strongly negative and a welfare analysis suggests that under the veil of ignorance workers would prefer being born into the benchmark equilibrium without a basic income.

A subsequent analysis of one specific NIT program which provides unconditional transfers in the amount of 60% of median income to everyone reveals additional insights on the effects of basic income programs. The analysis shows that such a policy has mainly adverse affects on macroeconomic outcomes. Output, consumption and college attendance fall, while average taxation rises drastically. The effect of the NIT policy is mainly a redistribution from high income earners to low income earners. Wages in the college sector are higher than in the automation sector and hence, the introduction of the NIT mostly redistributes income from the college sector to the automation sector. Consequently, workers in the college sector experience large welfare losses, while the average worker in the automation sector can expect some welfare gains during the transitional period. However, after the new equilibrium has been reached the expected life-time utility of a newborn under veil of ignorance is lower than in the benchmark equilibrium and thus, future generation would prefer being born into an economy without the NIT. The majority of the current generation, in contrast, can expect to experience welfare gains during the transition and would vote in favor of a reform, thereby creating a conflict between current and future generations.

The results of this exercises seem to be robust with respect to the specific regime with which an unconditional transfer is provided. For example, introducing a UBI which provides the same subsistence level of 60% of median income to unemployed households leads to the same qualitative result as the introduction of the NIT. Quantitatively, however, the effects are far more pronounced. Since the transfers paid in a lump-sum fashion to everyone, the overall tax burden is much higher than under the NIT regime. Hence, while leading to similar results, an NIT requires a far smaller budget. The natural next step is therefore to analyze whether an NIT together with a completely new tax regime to lead to welfare gains in relation to the benchmark equilibrium. I find that within this model setup a subsidy to capital income together with a high tax on consumption and a low face-out rate of transfers which leads to a negative average tax burden on income can lead to higher expected welfare of workers in terms of CEV. However, the subsistence level of income provided for unemployed workers is way below common poverty thresholds.

Overall, the analysis in this paper suggests that unconditional transfers can have counterintuitive effects on automation decisions and while the introduction of a UBI and an NIT lead to comparable results, the latter requires only a fraction of the budget of a UBI and can actually lead to welfare gains together with a subsidy on profits and labor income.

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Appendices

A Experience Premium

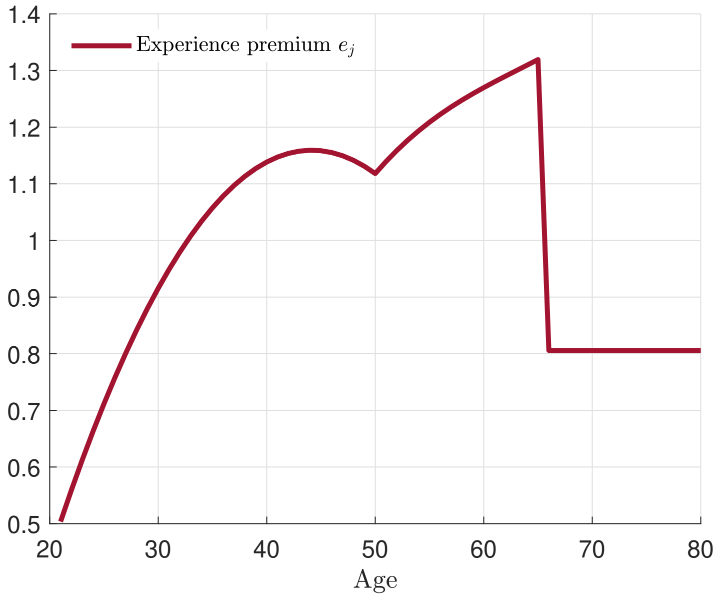


Figure A1: Experience premium to wages

B Effects of UBI on Income Distribution

Table B1: Earnings Distribution

Quintile	**Benchmark**	**NIT**[1]
Bottom 20%	6.1%	8.4%
20% to 40%	12.0%	15.1%
40% to 60%	14.6%	16.9%
60% to 80%	23.5%	18.7%
Top 20%	43.9%	40.9%
Gini	0.37	0.3

[1] NIT refers to the policy which pays exactly 60% of median income as described in section 5.

C Computational Solution Method

The model is solved numerically in MATLAB R2021b by using value function iteration on the discretized state space given by $S = Z \times Z \times m \times J \times u$. Where Z is the set of possible productivity levels, m the set of markets ($\{1, 2\}$), J the maximum life-span and u the possible employment status ($\{0, 1, 2\}$). The stochastic process for productivity level z is discretized into 11 states by using Rouwenhorst's method as described in Kopecky and Suen (2010).

Algorithm to compute competitive equilibrium:

I. Make guess on initial values for prices, p_1 and p_2, the costs of posting vacancies, κ_1^v and κ_2^v and the average wage rates, $\bar{w}_1$ and $\bar{w}_2$.

II. Solve model using the guess from I.

III. Given the solution for the value functions of employed and unemployed, W and U, and the optimal decision rules compute the invariant distribution over states $\Phi(z, z_{-1}, m, j, u)$.

IV. Update $(p_1, p_2, \kappa_1^v, \kappa_2^v, \bar{w}_1, \bar{w}_2)$

1. Calculate the implied parameters using the solution from II.
2. Compare implied values to initial guess. If difference is larger than 10^{-9}, update $(p_1, p_2, \kappa_1^v, \kappa_2^v, \bar{w}_1, \bar{w}_2)$ with appropriate root finding procedure (for this paper, Broyden's method has been used) and go to II.
   Else, end.

Model calibration: In order to fit the model to the data, the following objective function is minimized:

$$S(\mathcal{P}) = \left(\sum_i \omega_i (M_i(\mathcal{P}) - D_i)^2 \right)^{1/2} \tag{15}$$

where D_i are the data moments sought to be matched and $M_i(\mathcal{P})$ are the moments calculated from the model for a given set of structural parameters $\mathcal{P}$. The parameters to be jointly determined are $\mathcal{P} = \{\kappa_a, \phi, \delta_c, \lambda_0\}$ and deviations are weighted equally (i.e. $\forall i : \omega_i = 1$)

D Computing Transitional Dynamics

To compute the dynamics which during the convergence to the new equilibrium after the introduction of a new policy, I need the transition paths for the prices, p_1 and p_2, the costs of posting vacancies, κ_1^v and κ_2^v, and the average wage rates, $\bar{w}_1$ and $\bar{w}_2$, during all periods. That is, I need to solve for the values of $\{p_{1,t}, p_{2,t}, \kappa^v_{1,t}, \kappa^v_{2,t}, \bar{w}_{1,t}, \bar{w}_{2,t}\}_{t=1}^T$, which satisfy the conditions for the competitive equilibrium in every period t, given the optimal decision rules in this period. To solve for these parameters, the following algorithm has been used:

Algorithm to compute transitional Dynamics:

I. Compute decision rules and distribution over states for the old equilibrium and the new equilibrium and save the outcome.

II. Decide on a number of transitional periods T and make a guess on initial values for $\{p_{1,t}, p_{2,t}, \kappa^v_{1,t}, \kappa^v_{2,t}, \bar{w}_{1,t}, \bar{w}_{2,t}\}_{t=1}^T$, which is a matrix of dimension $7 \times T$.

III. Given the guess for $\{p_{1,t}, p_{2,t}, \kappa^v_{1,t}, \kappa^v_{2,t}, \bar{w}_{1,t}, \bar{w}_{2,t}\}_{t=1}^T$ recursively compute decision rules for all periods T given the next periods value functions (starting from the value function from the new equilibrium obtained in I).

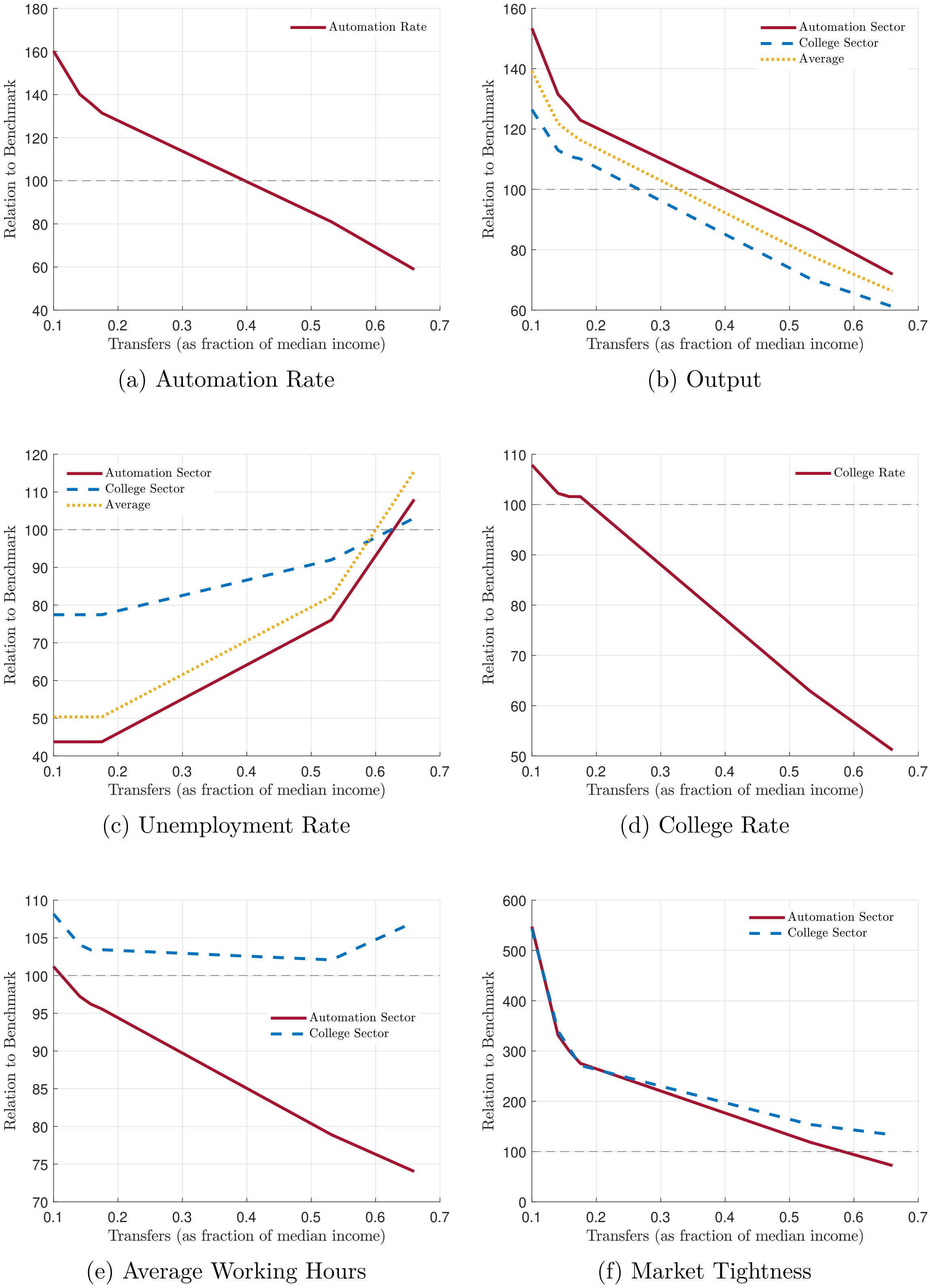
IV. Given the decision rules obtained in III, start from the distribution over states in the old equilibrium obtained in I to compute distributions over states during all the transitional periods

V. Update $\{p_{1,t}, p_{2,t}, \kappa^v_{1,t}, \kappa^v_{2,t}, \bar{w}_{1,t}, \bar{w}_{2,t}\}_{t=1}^T$

   1. Calculate the implied parameters during every transitional period using the solutions from III and IV.
   2. Compare implied values to initial guess. If difference is larger than 10^{-9}, update the parameters with appropriate root finding procedure (for this paper, Broyden's method has been used) and go to III.
      Else, end.

E Effects of UBI

This section presents the effects of introducing a UBI policy as described in Equation 12 and depicted in Figure 2a. As in section 4, I analyze the introduction of a UBI policy which keeps the government budget balanced. To do so, I introduce universal transfers of varying generosity which are paid to everyone and which replace all unemployment benefits. All other exogenous parameters are again held constant (including government consumption) and only the shift parameter of the labor income tax, λ_0, is adjusted to keep the government budget balance. The parameter for progressivity, however, remains the same as in the benchmark economy. This might lead to a higher tax burden, but at the same time everyone receives lump-sum transfers. Hence, it is not immediately clear who wins and who looses from such a policy.



(a) Automation Rate

(b) Output

(c) Unemployment Rate

(d) College Rate

(e) Average Working Hours

(f) Market Tightness

Figure E1: Effects of different levels of UBI transfers on labor market outcomes.

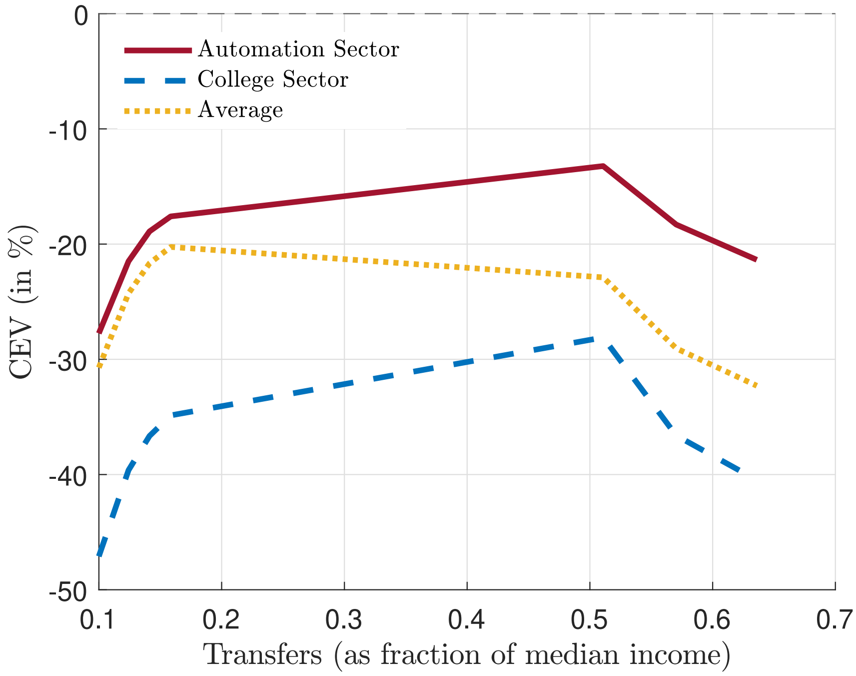


Figure E2: Welfare effects of UBI in terms of consumption equivalence

As shown in Figure E1, the effects of UBI are very similar to the effects of an NIT. However, responses are even stronger. Output, for example, falls by nearly 40% under a UBI scheme with high transfers, while a generous NIT only leads to a drop of roughly 20%. Also, looking at the welfare effects depicted in Figure E1[17] reveals that workers experience considerably higher welfare losses after the introduction of a UBI than after the introduction of an NIT. Average expected welfare never drops by less than 20% in terms of CEV with the introduction of UBI. In comparison, the expected welfare loss after the introduction of an NIT is always less than 20% for transfers above 15% of median income. At the same time, the introduction of a UBI requires much more additional revenue than an NIT, since transfers are paid to everyone and do not face out. For example, the introduction of a UBI which provides 60% of median income and keeps the government budget balanced requires an increase in the average income taxation by more then 100%, while average taxation actually falls under an NIT scheme.

Overall, this brief discussion already shows that UBI and NIT provide similar incentives to firms and workers while differing vastly in their quantitative effects. Introducing a UBI would be way more expensive than introducing an NIT while leading to even more adverse effects on the economy. Hence, NIT seems to be strictly preferably over UBI.

[17]Welfare is computed in terms of consumption equivalence as described in section 4