Optimal Linear Income Taxation and Education Subsidies under Skill-Biased Technical Change*

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Abstract

This paper studies how tax and education policy should optimally respond to skill-biased technical change (SBTC). To do so, it merges the canonical model of SBTC (Katz and Murphy, 1992) and the optimal linear tax model (Sheshinski, 1972), which is extended with a discrete education decision. For a given level of skill-bias, the optimal income tax and education subsidy equate marginal distributional benefits to the marginal distortions in labor supply and education. Optimal income taxes are lower and optimal education subsidies are higher if general-equilibrium effects cause stronger wage compression. Skill-biased technical change (SBTC) has theoretically ambiguous impacts on both optimal income taxes and education subsidies, since SBTC simultaneously changes i) distributional benefits, ii) distortions in education, and iii) wage compression effects of both policies. The model is calibrated to the US economy to quantify the impact of SBTC on optimal policy. SBTC is found to make the tax system more progressive, since the distributional benefits of higher income taxes rise more than the tax distortions on education and the wage-decompression effects of taxes. SBTC also lowers optimal education subsidies, since the distributional losses and the distortions of higher education subsidies increase more than the wage-compression effects of subsidies.

Keywords: Human capital; General equilibrium; Optimal taxation; Education subsidies, Technological Change.

JEL-Codes: H2; H5; I2; J2; O3.

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1 Introduction

Skill-biased technical change (SBTC) is an important driver of rising income inequality in many developed countries over the last decades (see, e.g., Van Reenen, 2011). Skill-biased technology raises the relative demand for skilled workers. If relative demand grows faster than relative supply, the skill-premium increases, and so does income inequality.[1] The idea that income inequality is the result of the "race between education and technology" dates back to Tinbergen (1975). He suggested that governments should increase enrollment into higher education in order to win the race with technology and to compress the earnings distribution. Goldin and Katz (2010, Ch.9, pp. 350-351) take up Tinbergen's metaphor and argue that in the US policy should respond to SBTC with a more progressive tax system and more financial aid for higher education.

Despite the obvious relevance of SBTC for explaining rising skill premia and wage inequality, very little analysis exists on the normative question whether it is a good idea to make tax systems more progressive or to stimulate investments in higher education in response to SBTC. Therefore, this paper studies how skill-biased technical change affects optimal linear taxes and education subsidies. We do so by extending the standard model of optimal linear income taxation of Sheshinski (1972) with endogenous skill formation and embed it in the 'canonical model' of SBTC, where high-skilled and low-skilled workers are imperfect substitutes in production (Katz and Murphy, 1992; Violante, 2008; Acemoglu and Autor, 2011).[2] In our model, individuals differ in their earning ability. They decide how much to work and whether to enroll in higher education. Only individuals with a sufficiently high ability become high-skilled, everyone else remains low-skilled. The wages of high-skilled and low-skilled workers are endogenously determined by relative demand, relative supply, and the level of skill-bias. An inequality-averse government maximizes social welfare by optimally setting linear income taxes and education subsidies as in Bovenberg and Jacobs (2005).[3] Our findings are the following.

First, we derive optimal tax and education policies for given skill bias. We show that the optimal linear income tax trades off the benefits of income redistribution against the distortions of labor supply and investment in education. The total distributional benefits of income taxes consist of direct redistributional benefits and indirect distributional losses. The indirect distributional losses arise from changes in the skill-premium in response to higher taxes. Intuitively, as the income tax discourages investment in education, the relative supply of skilled workers falls, so that the relative wage of skilled workers increases. Hence, the income tax generates a 'wage decompression' effect through general-equilibrium effects on wages.[4] The optimal education subsidy similarly faces an equity-efficiency trade off. Education should be taxed on a net basis for equity reasons, since high-skilled individuals have higher incomes than low-skilled individuals. However, this comes at an efficiency cost of distorting investment in education.

[1] For the canonical model of SBTC see Katz and Murphy (1992), Violante (2008) and Acemoglu and Autor (2011).

[2] Dixit and Sandmo (1977) and Hellwig (1986) elaborate further on the optimal linear tax model.

[3] Bovenberg and Jacobs (2005) analyze optimal linear taxes and education policy with human capital formation on the intensive margin, rather than on the extensive margin.

[4] Although relative wages may also respond to relative changes in hours worked, this mechanism does not play a role in our model, since we assume that high-skilled and low-skilled workers have equal labor-supply elasticities. Hence, relative labor supply does not change in response to changing the linear tax rate. See also Jacobs (2012).

Like in Bovenberg and Jacobs (2005), the education subsidy serves to alleviate tax distortions on human capital formation. Finally, the government wants to exploit indirect distributional gains by setting lower net taxes on education or even subsidize education on a net basis. Intuitively, subsidizing education generates a wage-compression effect via general-equilibrium effects on wages. By increasing the relative supply of skilled workers the skill premium declines and this reduces income inequality.

Second, we explore the comparative statics of optimal policy with regard to a change in skill-bias. The response of optimal taxes and subsidies to SBTC depends on the effect of SBTC on i) direct distributional benefits, ii) education distortions, and iii) wage-(de)compression effects of each policy instrument. In contrast, the efficiency costs of distorting labor supply are invariant to SBTC due to a constant elasticity of labor supply. Analytically, SBTC has ambiguous effects on each of the three effects. Therefore, we resort to numerical simulations to quantify the comparative statics of optimal taxes and subsidies with respect to SBTC.

We calibrate our model to the US economy using data from the US Current Population Survey and empirical evidence on labor market responses to tax and education policy. We then simulate the effects of a shock in skill bias such that the skill premium rises with 24 percent, in line with the observed increase in the skill premium between 1980-2016. We find that the optimal tax rate modestly increases with SBTC. Moreover, education is subsidized on a net basis so as to compress the wage distribution. Hence, enrollment in higher education is distorted upward. However, the optimal education subsidy declines with SBTC.

To understand better what drives the policy response to SBTC, we conduct a quantitative comparative statics exercise in which we study the impact of SBTC on the different determinants of tax and education policy. We find that the optimal tax rate increases because i) the distributional benefits of taxing income increase and ii) upward distortions of education become more severe, which overturns iii) the larger wage decompression effects of taxing income. The optimal education subsidy declines with SBTC, since both i) the distributional benefits of taxing education and ii) the (upward) distortions of subsidizing education increase more than iii) the larger wage compression effects of subsidizing education.

This paper is most closely related to Jacobs and Thuemmel (2018) and Ales et al. (2015). Both papers analyze the optimal response of tax or education policy to technical change. Using a nearly equivalent model of the labor market, Jacobs and Thuemmel (2018) study optimal non-linear taxes that can be conditioned on education.[5] They find that wage compression effects do not enter optimal policy rules.[6] Intuitively, any redistribution from high-skilled to low-skilled workers via a compression of the wage distribution can be achieved as well with the tax system, while the distortions in skill formation of compressing wages can be avoided. In simulations for the US economy, very similar to the ones in this paper, they document that marginal tax rates increase with SBTC around the marginally high-skilled, whereas they decrease elsewhere. Overall tax progressivity optimally rises. Furthermore, the optimal net tax on education falls with SBTC. Together with rising marginal tax rates, this implies that optimal subsidies increase with SBTC.

[5] Jacobs and Thuemmel (2018) do not allow for the costs of higher education to vary with ability.

[6] The allocations are generally affected by general-equilibrium effects on the wage structure.

This paper adds to Jacobs and Thuemmel (2018) by showing that the setting of optimal taxes and education subsidies and the optimal policy response to SBTC critically depend on the availability of skill-dependent income tax rates. In particular, if income taxes cannot be conditioned on education, the tax system can no longer achieve the same income redistribution as a compression of the wage distribution.[7] Therefore, by exploiting general-equilibrium effects on wages the government can redistribute more income over and above what can be achieved with the income tax system alone. This explains why optimal income taxes should be lowered and optimal education subsidies should be increased to generate wage compression. Indeed, for this reason education may even be subsidized on a net basis, which can never occur in Jacobs and Thuemmel (2018). Moreover, while the simulations of this paper also suggest that income taxes optimally increase with SBTC, the optimal subsidy rate decreases with SBTC.

Ales et al. (2015) analyze how the non-linear income tax should adjust to technical change in a task-based model of the labor market with exogenous human capital decisions.[8] They also derive that general-equilibrium effects are exploited to compress the wage redistribution. Based on a calibration to US data, Ales et al. find that wage polarization calls for higher marginal tax rates at the very bottom of the income distribution, lower tax rates on low- to middle-incomes, and higher tax rates at high-incomes (but not at the very top).[9] In contrast to Ales et al. (2015), we allow individuals to choose their education to analyze not only the optimal response of income taxes, but also the optimal response of education subsidies to SBTC. We do so in a neoclassical model of the labor market instead of a task-based model. We assume that the income tax system is linear and cannot be conditioned on education like Ales et al. (2015). We confirm their finding that the tax system becomes more progressive in response to SBTC. Moreover, we add that SBTC quantitatively matters more for education policy than for tax policy.

Our simulations demonstrate that SBTC calls for a more progressive tax system, but the subsidy rate on investment in higher education should optimally decline. Therefore, the suggestions of Tinbergen (1975) and Goldin and Katz (2010) to promote stronger investment in higher education to win the race against technology, may not be correct. This paper – joint with Jacobs and Thuemmel (2018) – demonstrates that (the absence of) skill-dependencies in tax schedules are crucial for how education policy should respond to SBTC. Since most real-world tax systems do not feature such skill dependencies, optimal education subsidies should decline if the task of redistributing income from high-skilled to low-skilled workers becomes more important due to SBTC. Naturally, it would be more desirable to introduce skill-dependent tax schedules – as in Jacobs and Thuemmel (2018) – to directly redistribute income from high-skilled to low-skilled workers. They show that education subsidies increase with SBTC, while their adverse distributional consequences on the wage distribution can be perfectly off-set via the tax system.

The remainder of this paper proceeds as follows. Section 2 reviews the literature. Section 3

[7] In this respect, our focus on linear policies is not a fundamental constraint, since also a linear tax system with education-dependent marginal tax rates can achieve the same redistribution as wage compression. The reason is that wage rates are linear prices so that linear tax rates are sufficient to achieve the same income redistribution.

[8] For task-based assignment models see, e.g., Acemoglu and Autor (2011).

[9] Wage polarization refers to the hollowing out of earnings in the middle of the income distribution. See for example Acemoglu and Autor (2011), Autor and Dorn (2013), and Goos et al. (2014).

sets up the model. Section 4 analyzes optimal policy. The simulations are discussed in Section 5. Finally, Section 6 concludes. Additional derivations and material are contained in an Appendix.

2 Related literature

This paper is related to five strands in the literature. First, we analyze optimal linear income taxes and education subsidies in an extension of the optimal linear tax model due to Sheshinski (1972).[10] In that model, like in Mirrlees (1971), individuals are heterogeneous in their exogenous earnings ability and they supply labor on the intensive margin. A welfarist government maximizes social welfare by optimally setting linear income tax rates and providing non-individualized income transfers. We extend this model with an endogenous education decision on the extensive margin and endogenous wage rates for high-skilled and low-skilled labor as in Roy (1951). This allows us to analyze optimal linear education subsidies and to explore the potential role of tax and education policies to compress the wage distribution. The standard optimal linear tax model is nested as a special case where education choices and wages are exogenous.

Second, we extend the canonical model of SBTC, which goes back to Katz and Murphy (1992), see also Violante (2008) and Acemoglu and Autor (2011). In the canonical model of SBTC, output is produced with high- and low-skilled labor, which are complementary but imperfectly substitutable inputs in production. Despite its simplicity, the model has been quite consistent with the data (Acemoglu and Autor, 2011, 2012).[11] The canonical model treats the supply of high-skilled and low-skilled labor as exogenous. By extending the linear tax model with endogenous labor supply and education on the extensive margin and merging it with the canonical model of SBTC, we are able to analyze the consequences of SBTC for optimal linear taxes and education subsidies.

Third, we add to the literature that analyzes optimal income taxes jointly with optimal education subsidies, see, for example, Bovenberg and Jacobs (2005), Maldonado (2008), Bohacek and Kapicka (2008), Anderberg (2009), Jacobs and Bovenberg (2011), and Stantcheva (2017). In contrast to these papers, we analyze optimal tax and education policies with education on the extensive margin rather than on the intensive margin. Moreover, we allow for endogenous wage rates. Nevertheless, we confirm a central result from this literature that education subsidies are employed to alleviate tax distortions on education. However, education subsidies generally do not fully eliminate all tax-induced distortions on education as in Bovenberg and Jacobs (2005). Since investment in education generates infra-marginal rents for all but the marginally skilled individuals, the government likes to tax education on a net basis to redistribute income from high-skilled to low-skilled workers – ceteris paribus. This finding is in line with Findeisen and Sachs (2016, 2017), who also analyze optimal education policies with discrete education choices. Also related is Gomes et al. (2018) who study optimal income taxation with multi-dimensional heterogeneity and occupational choice. They find that it is optimal to distort sectoral choice with sector-dependent non-linear income taxes so to alleviate labor-supply distortions on the

[10] See also Dixit and Sandmo (1977) and Hellwig (1986) for extensions and further analysis

[11] By construction, the model cannot capture the more recent trend of employment and wage polarization, as this would require at least three groups of individuals, see Acemoglu and Autor (2011, 2012).

intensive margin. We find no such role for education subsidies or taxes, since labor-supply distortions are identical for high-skilled and low-skilled workers, since income taxes are linear and labor-supply elasticities are constant.

Fourth, we contribute to the literature on optimal income taxation and education subsidies in the presence of general-equilibrium effects on the wage distribution. Feldstein (1972) and Allen (1982) study optimal linear income taxation with endogenous wage rates. They derive that the optimal linear income tax needs to be adjusted if general-equilibrium effects on wages are present. In particular, income taxes result in wage decompression, and thus need to be lowered, if the (uncompensated) elasticity of high-skilled labor supply is larger than the (uncompensated) elasticity low-skilled labor supply (and vice versa). In this case, high-skilled labor supply decreases more than low-skilled labor supply in response to a higher tax rate, and wage inequality increases accordingly. However, in our model, elasticities of high-skilled and low-skilled labor supply are the same, so this mechanism is absent. Instead, linear income taxes result in wage decompression, since taxes reduce investment in education. Intuitively, the skill premium rises as the supply of high-skilled labor falls relative to low-skilled labor. Therefore, wage decompression results in distributional losses and optimal income taxes are lowered – ceteris paribus.[12]

Other papers which – like us – find that optimal tax and education policy should exploit wage-compression effects for income redistribution are Dur and Teulings (2004) and Krueger and Ludwig (2015): Dur and Teulings (2004) analyze optimal log-linear tax and education policies in an assignment model of the labor market; Krueger and Ludwig (2015) study optimal income taxation and education subsidies using a calibrated OLG model for the US economy with endogenous labor supply, human capital investment, saving and financial frictions. Intuitively, subsidies and income taxes do not generate equivalent wage-compression effects. Hence, income taxes and education subsidies are both used to compress the wage distribution – ceteris paribus. Like in Dur and Teulings (2004), we find that education should be subsidized on a net basis in our baseline model. In contrast, Jacobs (2012) analyses optimal linear taxes and education subsides in a two-type version of the model of Bovenberg and Jacobs (2005) and shows that optimal education subsidies are *not* employed to compress the wage distribution. The reason is that the wage-compression effect of education subsidies is identical to the wage-compression effect of income taxes, hence education subsidies have no distributional value added over income taxes, but generate additional distortions in education. Our model does not have this property.

Fifth, our paper contributes to studies that analyze redistributive policies with skill-biased technical change. In particular, Heckman et al. (1998) estimate structural dynamic OLG-models with skill-specific human capital accumulation technologies and SBTC. They find the model to be consistent with data on rising wage inequality. Moreover, using the same model, Heckman et al. (1999) demonstrate that general-equilibrium effects on wages largely offset the initial impacts of tax and education policies. These papers do not analyze optimal tax and education

[12] Under optimal non-linear income taxation, Stiglitz (1982) and Stern (1982) show that marginal tax rates for high-skilled workers are lowered to encourage their labor supply, thereby compressing wages. Jacobs (2012) adds human capital formation on the intensive margin to these models and shows that education policies are used as well for wage compression. Rothschild and Scheuer (2013) and Sachs et al. (2017) generalize the two-type Stiglitz-Stern model to continuous types and explore the role of general-equilibrium effects in setting optimal non-linear income taxes.

policies like we do. Related is Heathcote et al. (2014), who study optimal tax progressivity, using a parametric tax function. In an extension, they also analyze a model that features endogenous human capital formation and imperfect substitutability of skills.[13] They calibrate their model to the US economy and analyze the impact of SBTC on the optimal degree of tax progressivity. In the absence of wage-compression effects, SBTC raises optimal tax progressivity. However, if wage-compression effects are present, optimal tax progressivity remains modest, but still higher than in the model without SBTC. These results are in line with our finding that optimal taxes should become more progressive in response to SBTC. In contrast to Heathcote et al. (2017), we also analyze optimal education policy and find that optimal education subsidies decline due to SBTC. Finally, as discussed in the introduction, this paper is complementary to Jacobs and Thuemmel (2018) who study the impact of SBTC on non-linear education-specific taxes and Ales et al. (2015) who study the impact of technical change on optimal non-linear taxes in a task-based model of the labor market.

3 Model

This section sets up the model consisting of individuals, firms and a government. Utility maximizing individuals supply labor on the intensive margin and optimally decide to become high-skilled or remain low-skilled. Profit maximizing firms demand high-skilled and low-skilled labor, while facing SBTC. The government optimally sets progressive income taxes and education subsidies by maximizing social welfare.

3.1 Individuals

There is a continuum of individuals of unit mass. Each worker is endowed with earnings ability $\theta \in [\underline{\theta}, \overline{\theta}]$, which is drawn from distribution $F(\theta)$ with corresponding density $f(\theta)$. Individuals have identical, quasi-linear preferences over consumption c and labor supply l:

$$U(c, l) \equiv c - \frac{l^{1+1/\varepsilon}}{1+1/\varepsilon}, \quad \varepsilon > 0, \tag{1}$$

where ε is the constant wage-elasticity of labor supply.[14] Consumption is the numraire commodity and its price is normalized to unity.

In addition to choosing consumption and labor supply, each individual makes a discrete choice to become high-skilled or to remain low-skilled. We indicate an individual's education type by $j \in \{L, H\}$ and define $\mathbb{I}$ as an indicator function for being high-skilled:

$$\mathbb{I} \equiv \begin{cases} 1, & \text{if } j = H, \\ 0, & \text{if } j = L. \end{cases} \tag{2}$$

[13]This extension is dropped in the published version of Heathcote et al. (2017).

[14]Since income effects are absent, compensated and uncompensated wage elasticities coincide. This utility function is employed in nearly the entire optimal-tax literature with endogenous wages, see, e.g., Rothschild and Scheuer (2013) and Sachs et al. (2017). The reason is that income effects in labor supply and heterogeneous labor-supply elasticities substantially complicate the analysis if general-equilibrium effects on wages are present, see also Feldstein (1972), Allen (1982), and Jacobs (2012).

To become high-skilled, workers need to invest a fixed amount of resources $p(\theta)$, such as tuition fees, books and the (money value of) effort. High-skilled individuals also forgo earnings as a low-skilled worker. We model the direct costs of education as a strictly decreasing function of the worker's ability θ:

$$p(\theta) \equiv \pi\theta^{-\psi}, \quad \pi \in (0,\infty), \quad \psi \in [0,\infty). \tag{3}$$

Hence, more able students need to spend less on education, e.g., because they have lower costs of effort, lower tuition fees, require less tutoring, or obtain grants. If $\psi = 0$, all individuals face the same direct costs of education. If $\psi > 0$, individuals with higher ability have lower direct costs. Moreover, the parameter ψ allows us to calibrate the enrollment elasticity of education at empirically plausible values in our simulations.

The government levies linear taxes t on labor income and provides a non-individualized lump-sum transfer b. The tax system is progressive if both t and b are positive. In addition, high-skilled individuals receive an education subsidy at rate s on resources $p(\theta)$ invested in education. We do not restrict the education subsidy to be positive, hence we allow for the possibility that high-skilled individuals may have to pay an education tax. The wage rate per efficiency unit of labor is denoted by w^j. Gross earnings are denoted by $z_\theta^j \equiv w^j\theta l_\theta^j$. Workers of type θ with education j thus face the following budget constraint:

$$c_\theta^j = (1-t)z_\theta^j + b - ((1-s)p(\theta))\mathbb{I}. \tag{4}$$

The informational assumptions of our model are that individual ability θ and labor effort l_θ^j are not verifiable, but aggregate labor earnings z_θ^j are. Hence, the government can levy linear taxes on income. Moreover, education expenditures $p(\theta)$ are assumed to be verifiable and can thus be subsidized. Importantly, the tax implementation does not exploit all information available to the government. In particular, we realistically assume that marginal tax rates are not conditioned on education choices. Consequently, income taxes can no longer achieve the same income redistribution as a compression of wage rates, hence exploiting wage-compression effects becomes socially desirable.

Workers maximize utility by choosing consumption, labor supply and education, taking wage rates and government policy as given. For a given education choice, optimal labor supply is obtained by maximizing utility in (1), subject to the budget constraint in (4), which leads to

$$l_\theta^j = [(1-t)w^j\theta]^\varepsilon. \tag{5}$$

Labor supply increases in net earnings per hour $(1-t)w^j\theta$, and more so if labor supply is more elastic (higher ε). Income taxation distorts labor supply downward as it drives a wedge between the social rewards of labor supply ($w^j\theta$) and the private rewards of labor supply ($(1-t)w^j\theta$).

By substituting the first-order condition (5) into the utility function (1), and using the budget constraint (4), the indirect utility function is obtained for all θ and j:

$$V_\theta^j \equiv \frac{[(1-t)w^j\theta]^{1+\varepsilon}}{1+\varepsilon} + b - ((1-s)p(\theta))\mathbb{I}. \tag{6}$$

A low-skilled individual chooses to invest in education if and only if she derives higher utility from being high-skilled than remaining low-skilled, i.e., if $V_\theta^H \geq V_\theta^L$. The critical level of ability Θ that separates the high-skilled from the low-skilled individuals is determined by $V_\Theta^H = V_\Theta^L$, and thus follows from

$$\frac{[(1-t)w^H\Theta]^{1+\varepsilon}}{1+\varepsilon} + b - (1-s)p(\Theta) = \frac{[(1-t)w^L\Theta]^{1+\varepsilon}}{1+\varepsilon} + b. \tag{7}$$

This implies that the cutoff ability Θ is

$$\Theta = \left[\frac{\pi(1-s)(1+\varepsilon)}{(1-t)^{1+\varepsilon}((w^H)^{1+\varepsilon} - (w^L)^{1+\varepsilon})}\right]^{\frac{1}{1+\varepsilon+\psi}}. \tag{8}$$

All individuals with ability $\theta < \Theta$ remain low-skilled, whereas all individuals with $\theta \geq \Theta$ become high-skilled. A decrease in Θ implies that more individuals become high-skilled. If w^H/w^L rises, more individuals invest in higher education. The same holds true for a decrease in the marginal net cost of education $(1-s)\pi$. The income tax potentially distorts the education decision, since the direct costs of education are not tax-deductible, while the returns to education are taxed. Investment in education is also distorted because income taxation reduces labor supply, and thereby lowers the 'utilization rate' of human capital. If labor supply would be exogenous ($\varepsilon = 0$), and education subsidies would make all education expenses effectively deductible (i.e., $s = t$), human capital investment would be at its first-best level: $\Theta = [\pi/(w^H - w^L)]^{\frac{1}{1+\varepsilon+\psi}}$ (see Jacobs, 2005; Bovenberg and Jacobs, 2005). Due to the Inada conditions on the production technology, there is a strictly positive mass of both high-skilled individuals and low-skilled individuals (i.e., $0 < \Theta < \infty$) if $\varepsilon > 0$, $0 \leq t < 1$, and $w^H > w^L$. Throughout this paper we assume that the primitives of our model are such that the high-skilled wage rate is above the low-skilled wage rate: $w^H > w^L$.

3.2 Firms

A representative firm produces a homogeneous consumption good, using aggregate low-skilled labor L and aggregate high-skilled labor H as inputs according to a constant-returns-to-scale CES production technology:

$$Y(L,H,A) = \tilde{A}\left(\omega L^{\frac{\sigma-1}{\sigma}} + (1-\omega)(AH)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}, \quad \omega \in (0,1), \sigma > 1, \tag{9}$$

where $\tilde{A}$ is a Hicks-neutral productivity shifter, ω governs the income shares of low- and high-skilled workers, σ is the elasticity of substitution between low- and high-skilled labor, and skill-bias is parameterized by A. We model technology like in the canonical model of SBTC (Katz and Murphy, 1992; Violante, 2008; Acemoglu and Autor, 2011). All theoretical results generalize to a general constant-returns-to-scale production technology that satisfies the Inada conditions and has an elasticity of substitution σ that is larger than unity, i.e., $\sigma \equiv \frac{Y_H Y_L}{Y_{HL} Y} > 1$, see the Appendix.

The competitive representative firm maximizes profits taking wage rates as given. The first-order conditions are:

$$w^L = Y_L(L, H, A), \tag{10}$$

$$w^H = Y_H(L, H, A). \tag{11}$$

In equilibrium, the marginal product of each labor input thus equal its marginal cost. Moreover, in equilibrium, wage rates w^L and w^H depend on skill-bias A. With $\sigma > 1$, w^H/w^L increases in A, which is essential for the model to generate an increasing skill-premium. To improve readability, we suppress arguments L, H, and A in the derivatives of the production function in the remainder of the paper.

Since we have normalized the mass of individuals to one, average labor earnings $\bar{z}$ equals total income, which in turn equals output Y:

$$\bar{z} \equiv \int_{\underline{\theta}}^{\Theta} z_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} z_\theta^H \mathrm{d}F(\theta) = Y. \tag{12}$$

3.3 Government

The government maximizes social welfare, which is given by

$$\int_{\underline{\theta}}^{\Theta} \Psi(V_\theta^L)\mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \Psi(V_\theta^H)\mathrm{d}F(\theta), \quad \Psi' > 0, \quad \Psi'' < 0, \tag{13}$$

where $\Psi(\cdot)$ is a concave transformation of indirect utilities of low- and high-skilled workers. The government budget constraint states that total tax revenue equals spending on education subsidies $sp(\theta)$, non-individualized transfers b, and an exogenous government revenue requirement R

$$t\left[\int_{\underline{\theta}}^{\Theta} w^L\theta l_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} w^H\theta l_\theta^H \mathrm{d}F(\theta)\right] = s\int_{\Theta}^{\overline{\theta}} p(\theta)\mathrm{d}F(\theta) + b + R. \tag{14}$$

3.4 General equilibrium

In equilibrium, factor prices w^L and w^H are such that labor markets and the goods market clear. Labor-market clearing implies that aggregate effective labor supplies for each skill type equal aggregate demands:

$$L = \int_{\underline{\theta}}^{\Theta} \theta l_\theta^L \mathrm{d}F(\theta), \tag{15}$$

$$H = \int_{\Theta}^{\overline{\theta}} \theta l_\theta^H \mathrm{d}F(\theta). \tag{16}$$

Goods-market clearing implies that total output Y equals aggregate demand for private consumption and education expenditures and exogenous government spending:

$$Y = \int_{\underline{\theta}}^{\Theta} c_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} (c_\theta^H + p(\theta))\mathrm{d}F(\theta) + R. \tag{17}$$

3.5 Behavioral elasticities

Before deriving the optimal tax formulas, it is instructive to derive the behavioral elasticities with respect to the income tax and education subsidy. Table 1 provides these elasticities. The derivations are given in Appendix A.

Table 1: Elasticities with respect to tax rate t and subsidy rate s

$$\varepsilon_{w^H,t} \equiv -\frac{\partial w^H}{\partial t}\frac{1-t}{w^H} = -\varsigma\left(\frac{(1-\alpha)\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right) < 0, \qquad \varepsilon_{w^H,s} \equiv \frac{\partial w^H}{\partial s}\frac{s}{w^H} = -\varsigma\left(\frac{(1-\alpha)\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\rho < 0,$$

$$\varepsilon_{w^L,t} \equiv -\frac{\partial w^L}{\partial t}\frac{1-t}{w^L} = \varsigma\left(\frac{\alpha\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right) > 0, \qquad \varepsilon_{w^L,s} \equiv \frac{\partial w^L}{\partial s}\frac{s}{w^L} = \varsigma\left(\frac{\alpha\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\rho > 0,$$

$$\varepsilon_{l^H,t} \equiv -\frac{\partial l^H_\theta}{\partial t}\frac{1-t}{l^H_\theta} = \varsigma\left(\frac{\sigma+\varepsilon+\delta(\beta-1)}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\varepsilon > 0, \qquad \varepsilon_{l^H,s} \equiv \frac{\partial l^H_\theta}{\partial s}\frac{s}{l^H_\theta} = -\varsigma\left(\frac{(1-\alpha)\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\varepsilon\rho < 0,$$

$$\varepsilon_{l^L,t} \equiv -\frac{\partial l^L_\theta}{\partial t}\frac{1-t}{l^L_\theta} = \varsigma\left(\frac{\sigma+\varepsilon+\delta\beta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\varepsilon > 0, \qquad \varepsilon_{l^L,s} \equiv \frac{\partial l^L_\theta}{\partial s}\frac{s}{l^L_\theta} = \varsigma\left(\frac{\alpha\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\varepsilon\rho > 0,$$

$$\varepsilon_{\Theta,t} \equiv \frac{\partial \Theta}{\partial t}\frac{1-t}{\Theta} = \varsigma\left(\frac{\sigma+\varepsilon}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right) > 0, \qquad \varepsilon_{\Theta,s} \equiv -\frac{\partial \Theta}{\partial s}\frac{s}{\Theta} = \varsigma\left(\frac{\sigma+\varepsilon}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\rho > 0.$$

Note: The term $\beta \equiv \frac{(w^H)^{1+\varepsilon}}{(w^H)^{1+\varepsilon}-(w^L)^{1+\varepsilon}} = \frac{1}{1-(w^L/w^H)^{1+\varepsilon}}$ is a measure of the inverse skill-premium, $\delta \equiv \left(\frac{\Theta l^L_\Theta f(\Theta)}{L} + \frac{\Theta l^H_\Theta f(\Theta)}{H}\right)\Theta$ measures the importance of the marginal individual with ability Θ in aggregate effective labor supply, and $\rho \equiv \frac{s}{(1-s)(1+\varepsilon)} > 0$ captures the importance of education subsidies in the total direct costs of education. Finally, $\varsigma \equiv \frac{1+\varepsilon}{1+\varepsilon+\psi}$ is a measure of the total education elasticity, which takes into account the feedback with labor supply.

In order to understand all the behavioral elasticities with respect to tax and education policy, it is instructive to first consider the case in which general-equilibrium effects on wages are completely absent, i.e., $\sigma \to \infty$. In this case, the production function becomes linear, and high- and low-skilled labor are perfect substitutes production. Consequently, all the terms in brackets in the expressions for the elasticities are either zero or one. The first two rows in Table 1 indicate that the wage rates of high-skilled and low-skilled workers are then invariant to taxes and education subsidies ($\varepsilon_{w^j t} = \varepsilon_{w^j s} = 0$). The other elasticities become very simple. Labor supplies only respond to income taxes, but not to education subsidies ($\varepsilon_{j,t} = \varsigma\varepsilon$, $\varepsilon_{j,s} = 0$). An increase in the income tax rate depresses labor supply of both high-skilled and low-skilled workers and more so if the wage elasticity of labor supply ε is larger. Labor supply is also more elastic with respect to taxation if the education elasticity $\varsigma \equiv \frac{1+\varepsilon}{1+\varepsilon+\psi}$ increases, because education and labor supply are complementary in generating earnings. Intuitively, if labor supply increases, the returns to the investment in education increase. And, if education increases, aggregate labor supply increases since the high-skilled work more than the low-skilled (see Jacobs, 2005; Bovenberg and Jacobs, 2005). The education subsidy does not affect labor supply of high-skilled and low-skilled workers. With quasi-linear preferences, labor supply only depends on the net after-tax wage, which is unaffected by the education subsidy. Education responds to both taxes and education subsidies ($\varepsilon_{\Theta,t} = \varepsilon_{\Theta,s}/\rho = \varsigma$). A higher income tax rate discourages education, because not all costs of education are deductible. The education response is stronger if the education elasticity $\varsigma \equiv \frac{1+\varepsilon}{1+\varepsilon+\psi}$ is larger. Complementarity of education with labor supply makes the education response more elastic also here. Moreover, the education subsidy boosts education more if the share of direct costs in education ρ is larger.

The behavioral elasticities change in the presence of general-equilibrium effects on the wage structure (i.e., $0 < \sigma < \infty$), so that in Table 1 the terms in brackets are no longer equal to 0 or 1. Now, the elasticities of wages with respect to the policy instruments, i.e., $\varepsilon_{w^j,t}$ and $\varepsilon_{w^j,s}$, are non-zero. If a policy increases the supply of high-skilled workers relative to the supply of low-skilled workers, the high-skilled wage rate falls relative to the low-skilled wage rate. These general-equilibrium effects change labor supply and education decisions, to which we return below. How strong these general-equilibrium effects on wages are depends on the education elasticity ς, the elasticity of substitution in production σ, and the wage elasticity of labor supply ε. Policy can change relative supplies only via a change in investment in education, and not via changing labor supply, see also the discussion below. The smaller is ς, the smaller is the education response. The lower is σ, the more difficult it is to substitute high- and low-skilled workers in production. The lower is ε, the less elastic labor supply responds to a change in the wage. Hence, if ς, σ and ε are lower, general-equilibrium effects are stronger, i.e., $\varepsilon_{w^j,t}$ and $\varepsilon_{w^j,s}$ are larger in absolute value.

From the expressions for $\varepsilon_{l^j,t}$ follows that both high-skilled and low-skilled labor supply decline if the tax rate increases for two reasons. First, a higher income tax directly distorts individual labor supply downward. Second, an increase in the tax reduces investment in education, which in turn reduces relative supply of skilled labor, and wages of high-skilled labor increase relative to low-skilled labor as a result. Hence, the direct effect of a tax increase on high-skilled labor supply l_θ^H is dampened by the relative increase in w^H, whereas the drop in low-skilled labor supply l_θ^L is exacerbated by the relative decline in w^L. As a result, the labor-supply elasticity of low-skilled labor is higher than that of high-skilled labor ($\varepsilon_{l^L,t} > \varepsilon_{l^H,t}$).[15] Similarly, by boosting enrollment in education, the subsidy on higher education increases the supply of high-skilled workers relative to the supply of low-skilled workers. This generates general-equilibrium effects on the wage structure: high-skilled wages fall and low-skilled wages rise. Consequently, the education response to education subsidies is muted by general-equilibrium effects on high-skilled and low-skilled wages. Finally, high-skilled labor supply falls and low-skilled labor supply increases if the education subsidy rises due to the changes in wage rates.

4 Optimal taxation

The government maximizes social welfare (13) by choosing the marginal tax rate t on labor income, the lump-sum transfer b, and the education subsidy s, subject to the government budget constraint (14). In order to interpret the expressions for the optimal tax rate t and the subsidy s, we introduce some additional notation.

First, we define the net tax wedge on skill formation Δ as:

$$\Delta \equiv tw^H \Theta l_\Theta^H - tw^L \Theta l_\Theta^L - sp(\Theta). \tag{18}$$

[15] Relative wage rates w^H/w^L change only due to the effect of taxes on the education margin, not due to direct changes in labor supply. This is because the direct effect of a tax increase on individual labor supplies does not lead to a change in relative supply H/L, since all individual labor supplies fall by the same relative amount.

Δ gives the increase in government revenue if the marginal individual with ability Θ decides to become high-skilled instead of staying low-skilled. If $\Delta > 0$, education is taxed on a net basis. $tw^H\Theta l^H_\Theta$ gives the additional tax revenue when the marginal individual becomes high-skilled. $tw^L\Theta l^L_\Theta$ gives the loss in tax revenue as this individual no longer pay taxes as a low-skilled worker. The government also looses $sp(\Theta)$ in revenue due subsidizing education of individual Θ.

Let the social welfare weight of an individual of type θ be defined as $g_\theta \equiv \Psi'(V_\theta)/\eta$, where η is the Lagrange multiplier on the government budget constraint. Following Feldstein (1972), we define the distributional characteristic ξ of the income tax as:

$$\xi \equiv \frac{\int_{\underline{\theta}}^{\Theta}(1-g_\theta)z^L_\theta \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}}(1-g_\theta)z^H_\theta \mathrm{d}F(\theta)}{\overline{z}\overline{g}} > 0. \tag{19}$$

ξ equals minus the normalized covariance between social welfare weights g_θ and labor earnings z^j_θ. ξ measures the social marginal value of income redistribution via the income tax, expressed in monetary equivalents, as a fraction of taxed earnings. Marginal distributional benefits of income taxation are positive, since the welfare weights g_θ decline with ability θ. We have $0 \leq \xi \leq 1$, where ξ is larger if the government has more redistributive social preferences. For a Rawlsian/maxi-min social welfare function, which features $\Psi'_{\underline{\theta}} = 1/f(\underline{\theta}) \gg 1$ and $\Psi'_\theta = 0$ for all $\theta > \underline{\theta}$, we obtain $\xi = 1$ if the lowest ability is zero ($\underline{\theta} = 0$). In contrast, for a utilitarian social welfare function with constant weights $\Psi' = 1$, we obtain $\xi = 0$.[16] We also derive that $\xi = 0$ if z^j_θ is equal for everyone so that the government is not interested in income redistribution. An alternative intuition for the distributional characteristic ξ is that it measures the social value of raising an additional unit of revenue with the income tax. It gives the income-weighted average of the additional unit of revenue (the '1') minus the utility losses (g_θ) that raising this unit of revenue inflicts on tax payers.

Similarly, we define the distributional characteristic of the education tax ζ:

$$\zeta \equiv \int_{\Theta}^{\overline{\theta}} \theta^{-\psi}(1-g_\theta)\mathrm{d}F(\theta) \geq 0. \tag{20}$$

ζ captures the marginal benefits of income redistribution from the high-skilled to the low-skilled via a higher tax on education (lower education subsidy). In contrast to the expression for ξ, the distributional benefits in ζ are not weighted with income, since the education choice is discrete. Moreover, there is a correction term $\theta^{-\psi}$ for the fact that the costs of education decline with θ and the more so if ψ is larger. If costs of education are larger for individuals with a lower ability θ, and every individual receives a linear subsidy on total costs, the low-ability individuals receive higher education subsidies in absolute amounts. Hence, the distributional benefits of taxing education decline if the low-ability individuals need to invest more to obtain a higher education. If the costs of education are the same for each individual, $\psi = 0$, and the distributional characteristic ζ only depends on the social welfare weights g_θ.

[16]Note that the absence of a redistributional preference in this case relies on a constant marginal utility of income at the individual level. In general, with non-constant private marginal utilities of income, also a utilitarian government has a preference for income redistribution, i.e. $\xi > 0$.

Finally, we define the income-weighted social welfare weights of each education group as

$$\tilde{g}^L \equiv \frac{\int_{\underline{\theta}}^{\Theta} g_\theta z_\theta^L \mathrm{d}F(\theta)}{\int_{\underline{\theta}}^{\Theta} z_\theta^L \mathrm{d}F(\theta)} > \tilde{g}^H \equiv \frac{\int_{\Theta}^{\overline{\theta}} g_\theta z_\theta^H \mathrm{d}F(\theta)}{\int_{\Theta}^{\overline{\theta}} z_\theta^H \mathrm{d}F(\theta)}. \tag{21}$$

The social welfare weights for the low-skilled are on average higher than the social welfare weighs for the high-skilled, since the social welfare weights continuously decline in income. Armed with the additional notation, we are now prepared to state the conditions for optimal policy in the next proposition.

Proposition 1. *The optimal lump-sum transfer, income tax and net tax on education are determined by*

$$\bar{g} \equiv \int_{\underline{\theta}}^{\overline{\theta}} g_\theta \mathrm{d}F(\theta) = 1, \tag{22}$$

$$\frac{t}{1-t}\varepsilon + \frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,t} = \xi - (\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}, \tag{23}$$

$$\frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,s} = \frac{s\pi}{(1-t)\bar{z}}\zeta - \rho(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}, \tag{24}$$

where $\varepsilon_{GE} \equiv (1-\alpha)\varepsilon_{w^L,t} = -\alpha\varepsilon_{w^H,t} = \frac{\alpha(1-\alpha)\varsigma\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}$ *is the general-equilibrium elasticity.*

Proof. See Appendix B. □

The optimality condition for the lump-sum transfer b in (22) equates the average social marginal benefit of giving all individuals one euro more in transfers (left-hand-side) to the marginal costs of doing so (right-hand-side), see also Sheshinski (1972), Dixit and Sandmo (1977) and Hellwig (1986).[17]

The optimal income tax in (23) equates the total marginal distortions of income taxation on the left-hand side with its distributional benefits on the right-hand side. On the left-hand side, $\frac{t}{1-t}\varepsilon$ captures the marginal deadweight loss of distorting labor supply. The larger the wage elasticity of labor supply ε, the more distortionary are income taxes for labor supply. $\frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,t}$ denotes the marginal distortion of the education decision due to the income tax. A higher marginal tax rate discourages individuals from becoming high-skilled. The larger is elasticity $\varepsilon_{\Theta,t}$, the larger are distortions of income taxation on education. The higher the net tax wedge on human capital (in terms of net income) $\Delta/(1-t)\bar{z}$, the more income taxation distorts education, and the lower should the optimal tax rate be. $\Theta f(\Theta)$ measures the relative importance of tax distortions on the marginal graduate Θ. The higher is the mass of individuals $f(\Theta)$ and the larger is their ability Θ, the more important are tax distortions on education.

The right-hand side of (23) gives the distributional benefits of income taxation. The larger are the marginal distributional benefits of income taxes – as captured by ξ – the higher should be the optimal tax rate. This is the standard term in optimal linear tax models, see also Sheshinski (1972), Dixit and Sandmo (1977) and Hellwig (1986). In addition, $(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE} > 0$

[17] The inverse of $\bar{g}$ is the marginal cost of public funds. At the tax optimum, the marginal cost of public funds equals one, since the government always has a non-distortionary marginal source of public finance. See also Jacobs (2018).

captures distributional losses of general-equilibrium effects on the wage structure. We refer to this term as the 'wage decompression effect' of income taxes. Income taxation reduces skill formation. Hence, the supply of high-skilled labor falls relative to low-skilled labor. This raises high-skilled wages and depresses low-skilled wages. Consequently, social welfare declines, since the income-weighted welfare weights of the low-skilled workers are larger than the income-weighted welfare weights of the high-skilled workers ($\tilde{g}^L > \tilde{g}^H$). The direct gains of income redistribution (ξ) are therefore reduced by decompressing the wage distribution ($(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$). The general-equilibrium elasticity ε_{GE} captures the strength of the wage decompression effect of income taxes. A lower elasticity of substitution σ, and a lower labor-supply elasticity ε provoke stronger general-equilibrium responses that erode the distributional powers of income taxation. If the effective labor supply around the skill margin is relatively low compared to aggregate labor supply, i.e. $\delta \equiv \left(\frac{\Theta l^L_\Theta f(\Theta)}{L} + \frac{\Theta l^H_\Theta f(\Theta)}{H}\right)\Theta$ is small, general-equilibrium effects will not be important for setting optimal tax rates. In the absence of general-equilibrium effects ($\sigma = \infty$), the general-equilibrium elasticity is zero ($\varepsilon_{GE} = 0$) and the wage decompression effect is no longer present.

Like Feldstein (1972), Allen (1982) and Jacobs (2012), we find that optimal linear income taxes are modified in the presence of general-equilibrium effects on wages. However, our economic mechanism is different. In all these papers, general-equilibrium effects depend on differences in (uncompensated) wage elasticities of labor supply between high-skilled and low-skilled workers. In particular, if high-skilled workers have the largest uncompensated wage elasticity of labor supply, then linear income taxes depress labor supply of high-skilled workers more than that of low-skilled workers, and this decompresses the wage distribution. Optimal income taxes are lowered accordingly. However, the reverse is also true: if low-skilled individuals have the highest uncompensated wage elasticity of labor supply, then income taxes generate wage compression, and are optimally increased for that reason. High- and low-skilled individuals can have different uncompensated labor-supply elasticities due to differences in income elasticities or compensated elasticities. This mechanism is not relevant here, since we assume no income effects and compensated wage elasticities of labor supply are equal for both skill types. Hence, the relative supply of skilled labor does not change due to changes in relative hours worked. Income taxes unambiguously generate wage decompression in our model, since education is endogenous, in contrast to these papers that abstract from an endogenous education decision.

The optimality condition for education subsidies is given in (24). The left-hand side gives the marginal distortions of taxing education on a net basis. The right-hand side gives the distributional benefits of doing so. If $\Delta > 0$, human capital formation is taxed on a net basis. Education distortions are larger if the optimal net tax on education $\frac{\Delta}{(1-t)\bar{z}}$ is larger. $\Theta f(\Theta)$ is the same as in (23). It captures the economic importance of distorting the decision of the marginal graduate. $\varepsilon_{\Theta,s}$ is the elasticity of education with respect to the subsidy on education. The larger is this elasticity, the more skill formation responds to net taxes, and the lower should be the optimal net tax on education.

For given distributional benefits of net taxes on education on the right-hand side of (24), and for a given elasticity of education on the left-hand side of (24), the optimal subsidy s on education rises if the income tax rate t increases, so as to keep the net tax Δ constant.

Therefore, we partially confirm Bovenberg and Jacobs (2005) that education subsidies should increase if income taxes are higher so as to alleviate the distortions of the income tax on skill formation – ceteris paribus.[18]

Note that there is no impact of education subsidies on labor-supply distortions. Intuitively, a marginally higher education subsidy does not directly affect labor supply on the intensive margin. However, the subsidy does affect labor supply indirectly via changes in the wage distribution.

The distributional gains of net taxes on education are given on the right-hand side of (24). Since $\zeta > 0$, taxing human capital yields net distributional benefits. The higher is the distributional gain of taxing education ζ, the more the government wishes to tax education on a net basis. In contrast to Bovenberg and Jacobs (2005), it is generally not optimal to set the education subsidy equal to the tax rate (i.e., $s = t$) to obtain a zero net tax on education (i.e., $\Delta = 0$). Since investment in education generates infra-marginal rents for all but the marginally skilled individuals, the government likes to tax education on a net basis to redistribute income from high-skilled to low-skilled workers. This finding is in line with Findeisen and Sachs (2016, 2017), who also analyze optimal education policies with discrete education choices.[19]

Furthermore, education subsidies (rather than taxes) generate what we call wage compression effects. $\rho(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$ captures the wage compression effects of subsidies on education. Wage compression gives distributional gains, since the income-weighted welfare weights of the low-skilled are higher than that of the high-skilled ($\tilde{g}^L > \tilde{g}^H$). The general-equilibrium elasticity ε_{GE} captures the strength of wage-compression effects. If wage-compression effects are sufficiently strong, education may even be subsidized on a net basis rather than taxed on a net basis (i.e., $\Delta < 0$), which is in fact the case in our baseline simulation below. This finding confirms Dur and Teulings (2004) who analyze optimal log-linear tax and education policies in an assignment model of the labor market.

The finding that education may be subsidized on a net basis contrasts with Jacobs (2012), who also analyzes optimal linear taxes and education subsidies with wage compression effects. However, he models education on the intensive rather than the extensive margin, as in Bovenberg and Jacobs (2005). He shows that education subsidies should not be employed to generate wage compression, because the wage-compression effect of linear education subsidies is identical to the wage-compression effect of linear income taxes. Hence, education subsidies have no distributional value added over income taxes, but only generate additional distortions in education.

Our findings also differ from Jacobs and Thuemmel (2018). They analyze optimal non-linear income taxes that can be conditioned on skill type in an otherwise very similar model as we study. Importantly, they find that wage compression effects do *not* enter optimal policy rules for both income taxes and education subsidies. Hence, they find that education is always taxed on a net basis, in contrast to this paper. The reason is that any redistribution from high-skilled to low-skilled workers via a compression of the wage distribution can be achieved as well with

[18]See also Maldonado (2008), Bohacek and Kapicka (2008), Anderberg (2009), Jacobs and Bovenberg (2011), and Stantcheva (2017).

[19]Related is Gomes et al. (2018) who show that it is optimal to distort occupational choice in two-sector model if optimal income taxes cannot be conditioned on occupation as in our model.

the income tax system, while the distortions of compressing wages in education can be avoided. Our analysis shows that tax and education policies should be geared towards wage compression in the realistic case that tax rates cannot be conditioned on education. By exploiting general-equilibrium effects on wages the government can redistribute more income beyond what can be achieved with the income tax system alone.

Furthermore, we should note that it is not the linearity of the tax schedule that drives our results. If we would allow for skill-dependent linear tax rates, wage compression effects will also not be exploited for income redistribution, because skill-dependent linear taxes can achieve exactly the same income redistribution as wage compression. The reason is that wage rates are linear prices so that linear tax rates are sufficient to achieve the same income redistribution as wage compression.

The logical next step would be to derive the impact of SBTC on optimal tax and education policy analytically. However, as it turns out, SBTC has theoretically ambiguous impacts on all terms of the optimal tax formulae in Proposition 1. Therefore, we choose a different approach to study the impact of SBTC on optimal policy. First, we simulate the impact of SBTC on optimal policy. Second, we conduct a numerical comparative statics exercise to better understand how SBTC affects the different terms in the optimal tax formulae.

5 Simulation

In this section, we simulate the consequences of SBTC for optimal tax and education policy. To do so, we first calibrate the model to the US economy. Then, we compute optimal policy for different levels of skill-bias. Finally, to better understand what drives the results, we isolate the impact of SBTC on three components of the optimal tax formulae, in particular: the impact of SBTC on i) distributional benefits, ii) education distortions, and iii) wage-compression effects.

5.1 Calibration

Our model aims to capture the essence of SBTC: a rising skill-premium, which is accompanied by an increase in the share of high-skilled workers. The calibration follows Jacobs and Thuemmel (2018). If possible, we directly set the parameters of the utility function, the ability distribution, and the production function to match the labor-supply elasticity, pre-tax earnings inequality, and the substitution elasticity between high-skilled and low-skilled workers. Other model parameters, especially of the cost function of education and the aggregate production function, are calibrated to match levels and changes in the skill premium and the share of high-skilled, based on data from the US Current Population Survey. We choose 1980 as the base year for the calibration, since evidence for SBTC emerges around that time. 2016 is chosen as the final year.

Parameters and calibration of functions. We set the wage elasticity of labor supply in (1) to $\varepsilon = 0.3$, based on empirical evidence extensively discussed in Blundell and Macurdy (1999) and Meghir and Phillips (2010).

We calibrate ψ in the cost function for education to match an enrollment elasticity of 0.17 based on estimates in Dynarski (2000). Many studies have estimated the effect of changes in tuition subsidies on college enrollment and find that an increase in student aid of $1000 increases college enrollment by 3 to 5 percentage points, see Nielsen et al. (2010) for an overview. Typically, the empirical literature reports quasi-elasticities that measure the change in enrollment in percentage points with respect to a percentage change in prices. We transformed the estimated quasi-elasticity to obtain a standard elasticity. See Appendix C for the details.[20]

We follow Tuomala (2010) and assume a log-normal distribution for $F(\theta)$ with mean $\mu^\theta = 0.4$ and standard deviation $\sigma^\theta = 0.39$. We append a Pareto tail to the log-normal distribution with with parameter $\alpha = 2$, which corresponds to empirical estimates provided in Atkinson et al. (2011).[21]

Technology is modeled according to (9). We set the elasticity of substitution between skilled and unskilled workers at $\sigma = 2.9$, following Acemoglu and Autor (2012).[22] We normalize the level of skill-bias in 1980 to $A_{1980} = 1$. SBTC between 1980 and 2016 then corresponds to an increase from A_{1980} to A_{2016}, while we keep all other parameters at their calibrated values.

To compute optimal policy, we assume a social welfare function with a constant elasticity of inequality aversion $\phi > 0$:

$$\Psi(V_\theta) = \begin{cases} \frac{V_\theta^{1-\phi}}{1-\phi}, & \phi \neq 1 \\ \ln(V_\theta), & \phi = 1 \end{cases}. \tag{25}$$

ϕ captures the government's desire for redistribution. $\phi = 0$ corresponds to a utilitarian welfare function, whereas for $\phi \to \infty$ the welfare function converges to a Rawlsian social welfare function.[23] In the simulations, we assume $\phi = 0.3$, which generates optimal tax and subsidy rates close to those the ones observed in the data.

Tax system. We calibrate the model for a given tax rate, transfer and education subsidy. The marginal tax rate in 1980 was on average $t = 35\%$.[24] The transfer b is pinned down by the average tax rate, which was 18% in 1980. The subsidy rate is set at $s = 47\%$ in 1980 (Gumport et al., 1997). It corresponds to the share of government spending in total spending on higher education in 1981.[25,26] At the calibrated equilibrium, the tax system also pins down the level of government expenditure R. When computing optimal policy, we maintain the same revenue requirement R.

[20]There is less empirical evidence on the enrollment elasticity with respect to the tax rate. In our model, the enrollment elasticities with respect to the tax and subsidy rate are mechanically related, hence we only target one of them.

[21]We append the Pareto tail such that the slopes of the log-normal and Pareto distributions are identical at the cut-off. We proportionately rescale the densities of the resulting distribution to ensure they sum to one.

[22]Katz and Murphy (1992) have estimated that $\sigma = 1.41$ for the period 1963 to 1987. Acemoglu and Autor (2012) argue that for the period up until 2008, a value of $\sigma = 2.9$ fits the data better.

[23]The utilitarian social welfare function is non-redistributive, since the marginal utility of income is constant due to the quasi-linear utility function.

[24]See http://users.nber.org/˜taxsim/allyup/ally.html.

[25]$p(\theta)$ corresponds to all direct costs of higher education, which includes grants and subsidies in-kind via government contributions for universities. In contrast, out model abstracts from effort costs of attending higher education.

[26]The OECD (2018) also provides data on subsidies and spending on higher education. However, the data only go back to 1995. According to the OECD, the share of public spending in total spending on tertiary education was 39% in 1995 in the US.

Other targets. To compute levels and changes in the skill premium and the share of high-skilled workers, we classify individuals with at least a college degree as high-skilled, and all other individuals as low-skilled, based on data from the US Current Population Survey.[27] The share of high-skilled workers in the working population was 24% in 1980 and 47% in 2016. We define the skill premium as average hourly earnings of high-skilled workers relative average hourly earnings of to low-skilled workers:

$$\text{skill premium} \equiv \frac{w^H}{w^L} \frac{\frac{1}{1-F(\Theta)} \int_{\Theta}^{\overline{\theta}} \theta \mathrm{d}F(\theta)}{\frac{1}{F(\Theta)} \int_{\underline{\theta}}^{\Theta} \theta \mathrm{d}F(\theta)}. \tag{26}$$

In the data, the skill premium changed from 1.47 in 1980 to 1.77 in 2016: an increase of 21%.

Moment matching. It remains to calibrate the production function parameters $\tilde{A}$, ω, and A_{2016}, as well as the parameters of the education cost function π and ψ. To do so, we compute the equilibrium of our model and set parameters such as to minimize a weighted distance between the moments generated by our model and the empirical moments. The parameters of the education cost function are calibrated to match the share of college graduates in 1980 and the enrollment elasticity, whereas $\tilde{A}$, ω and A_{2016} are calibrated to match levels and changes in the skill premium. We choose the distance weights such that we match the share of college graduates exactly. Moreover, we put higher weight on matching the relative change in the skill premium than on matching its level, since we are primarily interested in the response of optimal policy to a change in wage inequality, rather than in the level of wage inequality. Moreover, our stylized model generates a skill premium that is generally too high, because the wage distributions do not overlap: the least-earning high-skilled worker still earns a higher wage than the best-earning low-skilled worker. We summarize all calibrated parameters in Table 2. The implied moments are reported in Table 3. As expected, the levels of skill premia are too high. In contrast, the relative change in the skill premium is matched well. Our model thus generates a realistic change in wage inequality. Employment shares are matched perfectly. The enrollment elasticity in the model is also close to our target elasticity of 0.17.

The effect of SBTC on the share of high-skilled and the skill-premium. To gain some understanding of our model, in Figure 1 we simulate the impact of SBTC on the share of skilled workers and the skill-premium, while keeping taxes, subsidies and transfers at calibration values. For sake of comparison, we also plot the impact of SBTC if taxes and education subsidies are set to zero. Transfers b adjust to maintain government balance. We refer to this as 'laissez-faire'.[28] We plot the share of high-skilled workers and the skill-premium against skill-bias A, ranging from $A_{1980} = 1$ to $A_{2016} = 2.89$, as given in Table 2. As expected, SBTC substantially raises the share of high-skilled workers and the skill-premium. It does not matter much quantitatively whether taxes and subsidies are set at calibration levels or at zero, as in laissez-faire.

[27] Details of the data and our sample are discussed in Appendix C.

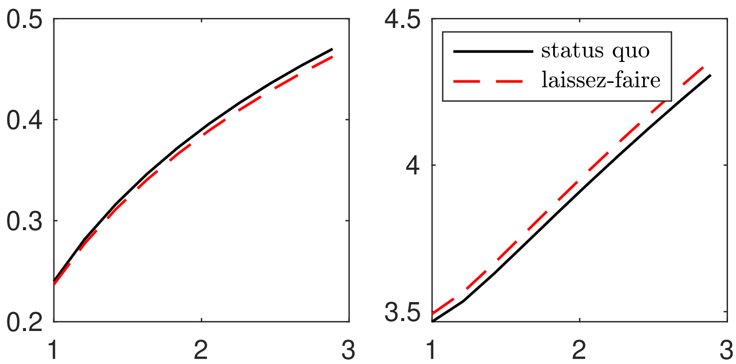
[28] Adjusting b to maintain government balance neither affects education nor labor-supply decisions and has thus no impact on the share of high-skilled or the skill-premium. Alternatively, we could set $b = R = 0$.

Table 2: Calibration

Parameter	Description	Value	Source
μ^{θ}	Ability distribution: mean	0.40	Tuomala (2010)
σ^{θ}	Ability distribution: standard deviation	0.39	Tuomala (2010)
α	Ability distribution: Pareto parameter	2.00	Atkinson et al. (2011)
ε	Labor supply elasticity	0.30	Blundell and Macurdy (1999); Meghir and Phillips (2010)
A_{1980}	Skill-bias 1980	1.00	normalized
σ	Elasticity of substitution	2.9	Acemoglu and Autor (2012)
t	Tax rate	0.35	NBER Taxsim
s	Subsidy rate	0.47	Gumport et al. (1997)
b	Tax intercept	1785.56	calibrated
R	Government revenue	1947.94	implied
π	Cost of education: avg. cost parameter	163487.78	calibrated
ψ	Cost of education: elasticity	5.32	calibrated
$\tilde{A}$	Productivity parameter	1189.27	calibrated
ω	Share parameter	0.43	calibrated
A_{2016}	Skill-bias 2016	2.89	calibrated
ϕ	Inequality aversion	0.3	calibrated

Table 3: Calibration: Model vs. Data

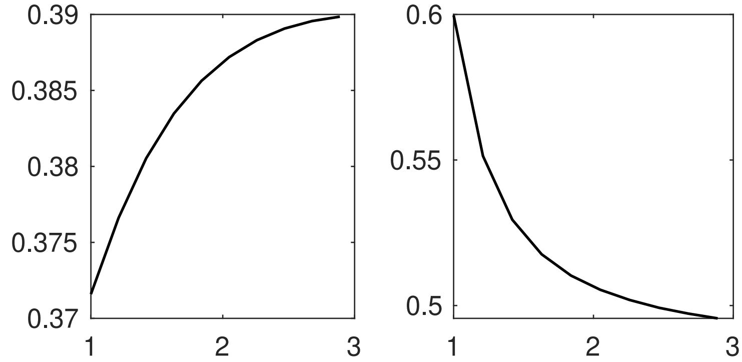
Moment	Model	Data
Skill premium in 1980	3.47	1.47
Skill premium in 2016	4.31	1.77
Skill premium: relative change	0.24	0.21
Share of high-skilled in 1980	0.24	0.24
Share of high-skilled in 2016	0.47	0.47
Subsidy elasticity of enrollment	0.16	0.17



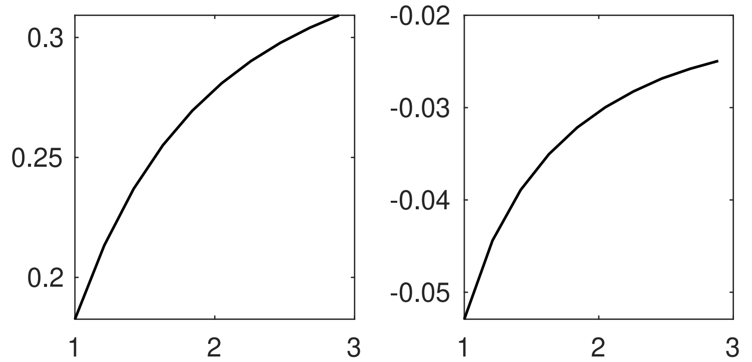
(a) Share of high-skilled (b) Skill-premium

Figure 1: Effect of SBTC under status quo tax system, and under laissez-faire

Note: The horizontal axis corresponds to skill-bias A. Status quo refers to the tax system used in the calibration, and summarized in Table 2. Laissez-faire corresponds to $t = 0$ and $s = 0$.



(a) Optimal tax rate t (b) Optimal subsidy rate s



(c) Optimal transfer b rel. to output (d) Optimal net tax Δ rel. to output

Figure 2: Optimal policy under SBTC, skill-bias A on the horizontal axis

5.2 Optimal policy and SBTC

We compute optimal policy for different levels of the skill bias parameter in 2016. Optimal policies are plotted in Figure 2. Panel 2a shows that the optimal tax rate increases monotonically with skill-bias from about 36% to 39%. In Panel 2b demonstrates that the optimal subsidy rate falls monotonically from about 60% to 50%. Panel 2c plots the optimal transfer relative to output. It increases monotonically from about 20% to 30%. Finally, Panel 2d shows the optimal net tax on skill formation as fraction of output. The optimal net tax on education relative to output, $\Delta/\overline{z}$, is negative, hence education is subsidized on a net basis. This implies that the general wage compression effects of education subsidies are stronger than the direct distributional benefits of education. The net tax (in terms of output) increases monotonically from -5% to -2%. Hence, the net subsidy on education becomes smaller with SBTC. The level of the net tax decreases, hence total expenditures on the marginal graduate go up with SBTC.

What is driving the driving optimal policy response to SBTC? To answer this question, we analyze the comparative statics of optimal policies with respect to skill-bias. First, we theoretically sign the comparative statics of all elements in the optimal tax formulae for income taxes and education subsidies. It turns out that the impact of SBTC on *all* these elements is ambiguous. Second, we therefore numerically quantify the comparative statics to sign the impact of SBTC on the various parts of the optimal tax formulae.

To obtain the analytical comparative statics for the optimal tax rate, we totally differentiate

Table 4: Effect of SBTC on determinants of optimal tax and subsidy rate

	Distributional benefits	Education distortions	Wage-compression effects
	ξ	$\frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,t}$	$(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$
Analytical	$\pm$	$\pm$	$\pm$
Simulation	$+$	$-$	$+$
	$\frac{s\pi}{(1-t)\bar{z}}\zeta$	$\frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,s}$	$\rho(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$
Analytical	$\pm$	$\pm$	$\pm$
Simulation	$+$	$-$	$+$

Note: Derivations for the analytical comparative statics are provided in Appendix E. The details of the numerical comparative statics are given in Table 5.

the first-order condition (23), while keeping the subsidy rate s fixed, and by allowing the transfer b to adjust in response to changing A and t via the government budget constraint (14).[29] Similarly, we obtain the analytical comparative statics for the optimal subsidy rate, by totally differentiating the first-order condition (24) with respect to A and s, while keeping the income tax rate t fixed, and by allowing the transfer b to adjust in response to changes in A and s via the government budget constraint (14).

We note that in our model, optimal policy is jointly optimized. In contrast, we obtain the comparative statics for t by holding s fixed, and vice versa. This approach simplifies the comparative statics. To ensure that fixing either the subsidy rate or the tax rate does not qualitatively change how optimal policy responds to SBTC, we plot in Figure 3 in Appendix E the optimal tax rate while fixing the subsidy rate, and the optimal subsidy rate while fixing the tax rate. Comparing this with Figure 2 reveals that the direction in which SBTC impacts the optimal tax or subsidy rate is the same, irrespective of whether we optimize over both policies or keep one fixed. However, the magnitude by which policy changes with SBTC is affected.

To obtain the numerical comparative statics, we start out from the optimum at $A = 1$ and then increase the level of skill-bias, while holding s and t fixed. We then compute how each of the terms in the first-order conditions (23) and (24) is affected by the increase in skill-bias. The results are given in Table 5. We do not report the effect of SBTC on labor-supply distortions. The marginal excess burden of income taxes ($\frac{t}{1-t}\varepsilon$) is not affected by SBTC, since the labor-supply elasticity ε is the same for all individuals. Hence, we show how SBTC affects i) distributional benefits, ii) education distortions, and iii) wage-compression effects. We summarize the sign of the impact of SBTC in Table 4. Appendix E contains the formal derivations and more detailed explanations for the analytical comparative statics.

Table 4 indicates that the impact of SBTC on all terms in the optimal tax and subsidy expressions (except the labor supply-distortions) is theoretically ambiguous. Numerically, SBTC increases distributional benefits of the income tax and a tax on education, makes education distortions more negative , and raises the importance of wage-compression effects. We now discuss the theoretical and numerical impact in more detail, and begin with the terms that determine the response of the optimal tax rate to SBTC.

[29] Once s and t are set, b is residually determined.

Table 5: Ceteris paribus impact of changing A

	Initial	Change
Policy Variables		
b	1959.07	678.84
s	0.60	0.00
t	0.37	0.00
SBTC Variables		
A	1.00	0.21
Θ	2.30	-0.18
w^L	563.72	51.95
w^H	634.45	99.07
$\alpha^\dagger$	63.16	5.68
$(1-F(\Theta))^\dagger$	25.00	4.51
Distributional benefits of the income tax and education tax		
$\xi^\dagger$	17.85	0.40
$\zeta^\ddagger$	0.89	0.36
$\zeta/\overline{z}^*$	0.08	0.02
Tax-distortions of skill-formation and decomposition		
$\frac{\Delta}{(1-t)\overline{z}} f(\Theta)\, \Theta \varepsilon_{\Theta,t}{}^\dagger$	-0.46	-0.35
Δ	-567.78	-312.71
$\overline{z}$	10729.99	2005.74
$\Delta/\overline{z}^\dagger$	-5.29	-1.62
$f(\Theta)^\dagger$	21.85	6.14
Θ	2.30	-0.18
$f(\Theta)\Theta^\dagger$	50.30	9.03
$\varepsilon_{\Theta,t}{}^\dagger$	10.84	1.49
β	7.02	-2.11
δ	2.07	0.22
$\delta(\beta-\alpha)$	13.24	-3.57
Subsidy-distortions of skill-formation and decomposition		
$\frac{\Delta}{(1-t)\overline{z}} f(\Theta)\, \Theta \varepsilon_{\Theta,s}{}^\dagger$	-0.53	-0.40
$\varepsilon_{\Theta,s}{}^\dagger$	12.49	1.72
ρ	1.15	0.00
Wage (de)compression effects and decomposition		
$(\tilde{g}^L-\tilde{g}^H)\varepsilon_{GE}{}^\ddagger$	57.08	8.32
$\rho(\tilde{g}^L-\tilde{g}^H)\varepsilon_{GE}{}^\ddagger$	65.78	9.59
$\tilde{g}^{L\dagger}$	104.22	1.32
$\tilde{g}^{H\dagger}$	69.27	1.71
$(\tilde{g}^L-\tilde{g}^H)^\dagger$	34.95	-0.39
$\varepsilon_{GE}{}^\dagger$	1.63	0.26
g_Θ	0.94	0.03

Note: † Table entries have been multiplied by 100. ‡ Table entries have been multiplied by 1e+04. * Table entries have been multiplied by 1e+07.

5.2.1 Comparative statics of the optimal tax rate

Distributional benefits of income taxes ξ. By raising the ratio of wage rates w^H/w^L, SBTC changes the income distribution: directly, by increasing before-tax wage differentials, and indirectly, by affecting labor-supply and education decisions of individuals. Income inequality between and within skill-groups increases, since the increase in labor supply is larger the higher is the wage rate or the higher is the worker's ability. Moreover, investment in education rises with SBTC, which also increases income inequality. General-equilibrium effects dampen the labor-supply and education responses by compressing wage differentials, but do not off-set the direct increase in inequality between and within education groups.

The effect of SBTC on welfare weights g_θ is theoretically ambiguous. Consumption, and thus utility, of all workers rises due to SBTC, since high-skilled and low-skilled workers are complements in production. SBTC increases the distributional benefits of taxing income (ξ) for a given set of declining social welfare weights, since utility increases more for workers with higher ability or higher education. However, since SBTC is not a marginal change, the social welfare weights change as well. Social welfare weights for the high-ability workers fall more than that of low-ability workers as they experience the largest infra-marginal utility gain due to SBTC. The reason is that social marginal welfare weights decline with utility, since the government is inequality averse. Therefore, the impact of SBTC on ξ is theoretically ambiguous: it raises both the utility of the high-ability individuals relatively more and lowers their welfare weights more. In the numerical comparative statics, we find that SBTC raises the distributional benefits of taxing income (Table 5). The immediate effects on social welfare thus dominate changes in welfare weights. Ceteris paribus, higher distributional benefits of income taxes ξ call for an increase in the optimal tax rate.

Education distortions of income taxes $\frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,t}$. The net tax on education $\Delta \equiv tw^H\Theta l^H_\Theta - tw^L\Theta l^L_\Theta - sp(\Theta)$ is a function of the optimal tax and subsidy rates. On the one hand Δ increases because SBTC raises the wage differential between the marginally high-skilled and the marginally low-skilled worker – ceteris paribus. On the other hand, if education is subsidized ($s > 0$), the net tax Δ falls, because subsidies increase as SBTC lowers the marginal graduate Θ, who has higher costs of education – ceteris paribus.[30] SBTC also raises average income $\bar{z}$.

Second, it is theoretically ambiguous whether the 'size of the tax base' at the marginal graduate $\Theta f(\Theta)$ increases or not with SBTC. SBTC lowers Θ, but whether $\Theta f(\Theta)$ increases or not depends in which part of the skill distribution Θ is located. We find numerically that the tax base $\Theta f(\Theta)$ increases with SBTC, hence distortions on education become larger for that reason (Table 5). SBTC changes the elasticity of education with respect to the tax rate $\varepsilon_{\Theta,t} = \varsigma\frac{\sigma+\varepsilon}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)} > 0$. SBTC raises the income share of the high-skilled workers α and reduces the measure for the inverse skill premium β. However, the impact of SBTC on δ is ambiguous, rendering the impact of SBTC on $\varepsilon_{\Theta,t}$ ambiguous as well. In the numerical comparative statics $\varepsilon_{\Theta,t}$ slightly increases.

Numerically, we find that education is distorted upward: the net tax on education is negative ($\Delta < 0$) and education is subsidized on a net basis. Moreover, SBTC exacerbates these upward

[30] If in contrast, $s < 0$, the net tax Δ unambiguously increases with SBTC.

distortions (Table 5). As education distortions become even more negative with SBTC, the tax rate should increase, ceteris paribus.

Wage decompression effects income taxes $(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$. How does SBTC affect the wage decompression effects of income taxes? Like with the distributional benefits of taxing income ξ, the impact of SBTC on the difference in welfare weights $\tilde{g}^L - \tilde{g}^H$ is ambiguous. SBTC raises the wage rates w^j for both low- and high-skilled workers, while the high-skilled workers benefit more. Moreover, individuals with a higher ability θ benefit relatively more from an increase in their wage rate than individuals with a lower ability. As a result, SBTC raises income inequality between and within education groups. Moreover, SBTC affects the composition of education groups as more individuals become high-skilled. Since the highest low-skilled worker and the lowest high-skilled worker now have a lower ability both $\tilde{g}^L$ and $\tilde{g}^H$ increase, while the net impact on $\tilde{g}^L - \tilde{g}^H$ is not clear. Moreover, as before, SBTC affects social welfare weights: the social welfare weights for individuals with higher ability or education decrease relative to the social welfare weights of the individuals with lower ability or education, so that $\tilde{g}^L - \tilde{g}^H$ increases. Numerically, the impact of SBTC on $\tilde{g}^L - \tilde{g}^H$ is negative (Table 5). Although the average social welfare weight of the low-skilled workers and the high-skilled workers both increase, this increase is found to be smaller for the low-skilled than for the high-skilled workers. Hence, the impact of larger inequality on social welfare weights is offset by the change in the composition of high- and low-skilled workers and the impact of declining social welfare weights due to larger inequality.

SBTC has an ambiguous effect on the general-equilibrium elasticity $\varepsilon_{GE} = \frac{\alpha(1-\alpha)\varsigma\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}$. SBTC raises the income share of the high-skilled workers α and reduces the measure for the inverse skill premium β. Moreover, the impact of SBTC on δ is ambiguous. Numerically, SBTC increases ε_{GE}, see also Table 5. Hence, if SBTC becomes more important, the skill-premium responds more elastically to changes in policy. Since ε_{GE} increases relatively more than $\tilde{g}^L - \tilde{g}^H$ decreases, we find that wage-decompression effects of income taxes become more important with SBTC. Ceteris paribus, this calls for lower income taxes.

All effects combined. Whether the income tax rate rises or falls with SBTC depends on which effects dominate. The increase in distributional benefits and larger upward education distortions call for an increase in the income tax, whereas stronger wage-decompression effects are a force for lower income taxes. Numerically, we find that the first two effects dominate (Table 5). As a consequence, SBTC leads to a higher optimal income tax rate.

5.2.2 Comparative statics of the optimal subsidy rate

Distributional losses of education subsidies $\frac{s\pi}{(1-t)\bar{z}}\zeta$. SBTC affects the distributional characteristic of education ζ by changing the social welfare weights g_θ, and by lowering the threshold Θ as more individuals become high-skilled. As before, the impact of SBTC on social welfare weights is ambiguous. The lowering of Θ increases ζ. Intuitively, as more individuals with lower social welfare weights become high-skilled, the average social welfare weight of high-skilled workers declines and it becomes more desirable to tax education on a net basis.

General-equilibrium effects dampen the labor-supply and education responses by compressing wage differentials. Numerically, we find that SBTC raises the distributional benefits of taxing education ζ (Table 5). Since the distributional losses of education subsidies increase (in other words, the distributional benefits of taxing education increase), the subsidy rate should decrease with SBTC, ceteris paribus.

Education distortions of education subsidies $\frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,s}$. The tax-distortions and subsidy-distortions of education only differ by a factor $\rho \equiv \frac{s}{(1-s)(1+\varepsilon)} > 0$, which captures the importance of education subsidies in the total direct costs of education, see also Table 1. Since ρ is not affected by SBTC, the effect of SBTC on the subsidy distortions on education is equal to ρ times the impact of SBTC on the income tax distortions on education, which – as we have argued above – is theoretically ambiguous. Numerically, the optimal net tax on education is negative, i.e., there is optimally a net subsidy on education so that there is overinvestment in education compared to the efficient level. Moreover, we find that SBTC exacerbates the distortions due to overinvestment in education (Table 5). Hence, the optimal subsidy rate should decrease with SBTC, ceteris paribus.

Wage compression effects education subsidies $\rho(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$. Apart from multiplication with $\rho \equiv \frac{s}{(1-s)(1+\varepsilon)} > 0$, which captures the importance of education subsidies in the total direct costs of education, this effect is the same as the wage-compression effect of the income tax, since ρ is not affected by SBTC. Theoretically its sign is ambiguous and it increases in our simulations (see the explanation above and Table 5). As the wage-compression effect of education subsidies becomes more important with SBTC, the optimal subsidy rate should increase, ceteris paribus.

Combined effect. While increased distributional losses and larger distortions due to overinvestment in education call for a lower subsidy rate, the increased importance of wage compression effects is a force for a higher subsidy rate. Numerically, we find the that first two effects dominate (Table 5). As a consequence, the optimal subsidy rate falls with SBTC.

5.3 Relation to the literature

Our finding that optimal tax progressivity should increase with technical change is in line with the results in Heathcote et al. (2014) and Ales et al. (2015), as well as with Jacobs and Thuemmel (2018). Like these papers, we thus add support to the call for more progressive taxes by Goldin and Katz (2010).

Moreover, our result that tax and education policy should optimally exploit general-equilibrium effects on the wage distribution for income redistribution is in line with Tinbergen (1975) and Dur and Teulings (2004). In contrast to this paper, Jacobs and Thuemmel (2018) find that education is optimally taxed, rather than subsidized on a net basis. This difference can be explained by the role of wage-compression effects in setting optimal policy. In Jacobs and Thuemmel (2018), income taxes can be conditioned on education, and as a result, wage-compression effects are not exploited for income redistribution. Intuitively, the tax system can redistribute the same amount of income without generating (additional) distortions in education decisions. With linear tax rates that are not conditioned on education, income redistribution by compressing the wage distribution cannot be achieved by the tax system.

Tinbergen (1975) and Goldin and Katz (2010) recommend raising education subsidies to win the race against technology. We find no support for this recommendation. The optimal subsidy rate, as well as expenditures on the marginal graduate as fraction of GDP, decline with SBTC.

5.4 Robustness

The baseline assumes an elasticity of inequality aversion of $\phi = 0.3$. Figure (4) in Appendix G presents robustness checks for two additional levels of inequality aversion. The tax and subsidy rate increase with ϕ. However, the qualitative pattern is the same as in our baseline in Figure (2): the tax rate increases with skill-bias, while the subsidy rate falls. We thus conclude that our results are robust to the degree of inequality aversion.

6 Conclusion

This paper studies how optimal linear income tax and education policy should respond to skill-biased technical change (SBTC). To do so, we introduce intensive-margin labor supply and a discrete education choice into the canonical model of SBTC based on Katz and Murphy (1992) (Violante, 2008; Acemoglu and Autor, 2011, see also). We derive expressions for the optimal income tax and education subsidy for a given level of skill-bias. The income tax and subsidy trade off distributional benefits against distortions of labor supply and education.

We show that wage-compression effects should be exploited for income redistribution. In contrast, Jacobs and Thuemmel (2018) find that general-equilibrium effects on wages should not be exploited for income redistribution if the government has education-dependent income tax rates. Our paper demonstrates that the absence of education-dependent tax rates has important implications for optimal tax and education policy. In particular, optimal income taxes are lower and optimal education subsidies are higher if general-equilibrium effects cause stronger wage compression.

Skill-biased technical change (SBTC) is shown to have theoretically ambiguous impacts on both optimal income taxes and education subsidies, since SBTC simultaneously changes i) distributional benefits, ii) distortions in education, and iii) wage compression effects of both policy instruments. To analyze the importance of each channel, the model is calibrated to the US economy to quantify the impact of SBTC on optimal policy. SBTC is found to make the tax system more progressive, since the distributional benefits of higher income taxes rise more than the tax distortions on education and the wage-decompression effects of taxes. Moreover, education is subsidized on a net basis, and thus above its efficient level. Hence, the subsidy indeed exploits general-equilibrium effects for redistribution. However, SBTC lowers optimal education subsidies, since the distributional losses and the distortions of higher education subsidies increase more than the wage-compression effects of subsidies.

In line with Tinbergen (1975) and Dur and Teulings (2004), we find that general equilibrium effects should matter for optimal tax and education policy. Moreover, our findings support the push for more progressive taxation in light of SBTC brought forward by Goldin and Katz (2010). However, Tinbergen and Goldin and Katz also advocate raising education subsidies to win the race against technology and to compress the wage distribution. Our findings do not lend support to this idea. The reason is that education subsidies not only compress wages, but also entail larger distributional losses and cause more over-investment in education as SBTC becomes more important. The latter are found to be quantitatively more important than the larger benefits of education subsidies in terms of wage compression.

In our model, education policy is only used for second-best reasons: the government cares about redistribution and does not have access to individualized lump-sum taxes. We abstract from other motives which might justify government involvement in education, such as positive externalities, information frictions, and credit constraints (Barr, 2004). For these factors to change our conclusion, they would have to interact with SBTC. The analysis of such interactions is an interesting avenue for future research.

Appendix

A Derivation of elasticities

We define $\tilde{x} \equiv \mathrm{d}x/x$ as the relative change in variable x, with the exception of $\tilde{t} \equiv \mathrm{d}t/(1-t)$. First, we log-linearize the labor-supply equations to obtain:

$$\tilde{l}_\theta^H = \varepsilon(\tilde{w}^H - \tilde{t}), \tag{27}$$

$$\tilde{l}_\theta^L = \varepsilon(\tilde{w}^L - \tilde{t}). \tag{28}$$

Next, we linearize the cutoff ability Θ to find:

$$\tilde{\Theta} = \frac{1}{1+\varepsilon+\psi}\left[(1+\varepsilon)\tilde{t} - \frac{s}{1-s}\tilde{s} - (1+\varepsilon)\beta\tilde{w}_H - (1+\varepsilon)(1-\beta)\tilde{w}_L\right], \tag{29}$$

where we define

$$\beta \equiv \frac{w_H^{1+\varepsilon}}{w_H^{1+\varepsilon} - w_L^{1+\varepsilon}}. \tag{30}$$

Collecting terms, we obtain

$$\tilde{\Theta} = \frac{1+\varepsilon}{1+\varepsilon+\psi}\left[\tilde{t} - \frac{s}{(1+\varepsilon)(1-s)}\tilde{s} - \beta\tilde{w}_H - (1-\beta)\tilde{w}_L\right]. \tag{31}$$

Define $\varsigma \equiv \frac{1+\varepsilon}{1+\varepsilon+\psi}$ and $\rho \equiv \frac{s}{(1+\varepsilon)(1-s)}$ to write

$$\tilde{\Theta} = \varsigma\tilde{t} - \varsigma\rho\tilde{s} - \varsigma\beta\tilde{w}_H - \varsigma(1-\beta)\tilde{w}_L. \tag{32}$$

Next, we log-linearize the labor-market clearing conditions:

$$\tilde{H} = \varepsilon\left(\tilde{w}^H - \tilde{t}\right) - \delta_H\tilde{\Theta}, \quad \delta_H \equiv \frac{\Theta^2 l_\Theta^H f(\Theta)}{H}, \tag{33}$$

$$\tilde{L} = \varepsilon\left(\tilde{w}^L - \tilde{t}\right) + \delta_L\tilde{\Theta}, \quad \delta_L \equiv \frac{\Theta^2 l_\theta^L f(\Theta)}{L}. \tag{34}$$

Finally, we log-linearize the wage equations using the homogeneity of degree zero of the marginal product equations (i.e., $Y_{LL}L = -Y_{LH}H$ and $Y_{HH}H = -Y_{HL}L$) to find

$$\tilde{w}^H = \frac{(1-\alpha)}{\sigma}(\tilde{L} - \tilde{H}), \tag{35}$$

$$\tilde{w}^L = \frac{\alpha}{\sigma}(\tilde{H} - \tilde{L}), \tag{36}$$

$$\alpha \equiv \frac{HY_H(\cdot)}{Y(\cdot)}, \quad \frac{1}{\sigma} \equiv \frac{Y_{LH}(\cdot)Y(\cdot)}{Y_L(\cdot)Y_H(\cdot)}, \tag{37}$$

where α denotes the income share of the skilled worker in total output, and σ is the elasticity of substitution between low-skilled and high-skilled labor in production. We now have a system of seven linear equations (27), (28), (32), (33), (34), (35), and (36) in seven unknowns

$\tilde{l}^H_\theta, \tilde{l}^L_\theta, \tilde{\Theta}, \tilde{H}, \tilde{L}, \tilde{w}^H, \tilde{w}^L$. First, rewrite (33) and (34) by subtracting them from each other

$$\tilde{H} - \tilde{L} = \varepsilon(\tilde{w}_H - \tilde{t}) - \delta_H \tilde{\Theta} - \varepsilon(\tilde{w}_L - \tilde{t}) + \delta_L \tilde{\Theta} = \varepsilon(\tilde{w}_H - \tilde{w}_L) - (\delta_H + \delta_L)\tilde{\Theta}. \tag{38}$$

Define $\delta \equiv \delta_H + \delta_L$ and substitute (32) to find

$$\begin{aligned} \tilde{H} - \tilde{L} =& \varepsilon(\tilde{w}_H - \tilde{w}_L) - \delta \left(\varsigma \tilde{t} - \varsigma \rho \tilde{s} - \varsigma \beta \tilde{w}_H - \varsigma (1-\beta) \tilde{w}_L \right) \\ =& (\varepsilon + \varsigma \beta \delta) \tilde{w}_H + (-\varepsilon + \varsigma (1-\beta) \delta) \tilde{w}_L - \delta \varsigma \tilde{t} + \delta \varsigma \rho \tilde{s}. \end{aligned} \tag{39}$$

Next, substitute $\tilde{w}_H$ and $\tilde{w}_L$ from (35) and (36) to obtain:

$$\begin{aligned} \tilde{H} - \tilde{L} =& -\left(\frac{\delta \varsigma \sigma}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)} \right) \tilde{t} + \rho \left(\frac{\varsigma \delta \sigma}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)} \right) \tilde{s} \\ =& \frac{\delta \varsigma \sigma}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)} (-\tilde{t} + \rho \tilde{s}). \end{aligned} \tag{40}$$

Since, $\beta > 1$ and $\alpha < 1$ and all other terms in $\frac{\delta \varsigma \sigma}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)}$ are positive, an increase in the tax rate reduces high-skilled labor input relative to low-skilled labor input, whereas an increase in the subsidy rate has the opposite effect. Substituting for $\tilde{H} - \tilde{L}$ in (35) and (36) yields:

$$\tilde{w}_H = \frac{(1-\alpha)\delta\varsigma}{\sigma + \varepsilon + \varsigma\delta(\beta - \alpha)} (\tilde{t} - \rho \tilde{s}), \tag{41}$$

and

$$\tilde{w}_L = \frac{\alpha\delta\varsigma}{\sigma + \varepsilon + \varsigma\delta(\beta - \alpha)} (-\tilde{t} + \rho \tilde{s}). \tag{42}$$

Substituting these results into (32), (27) and (28) and rearranging yields:

$$\tilde{\Theta} = \varsigma \left(\frac{\sigma + \varepsilon}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)} \right) \tilde{t} - \varsigma \left(\frac{\sigma + \varepsilon}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)} \right) \rho \tilde{s}, \tag{43}$$

$$\tilde{l}^H_\theta = \varepsilon \left(\frac{\delta \varsigma (1-\beta) - (\sigma + \varepsilon)}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)} \tilde{t} - \frac{(1-\alpha) \delta \varsigma}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)} \rho \tilde{s} \right), \tag{44}$$

$$\tilde{l}^L_\theta = \varepsilon \left(- \frac{\sigma + \varepsilon + \varsigma \delta \beta}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)} \tilde{t} + \frac{\alpha \delta \varsigma}{\sigma + \varepsilon + \varsigma \delta (\beta - \alpha)} \rho \tilde{s} \right). \tag{45}$$

We can now find explicit expressions for the tax elasticities by setting $\tilde{s} = 0$ and defining

$$\varepsilon_{\Theta,t} \equiv \frac{\partial \Theta}{\partial t} \frac{1-t}{\Theta} = \frac{\tilde{\Theta}}{\tilde{t}} = \varsigma \left(\frac{\sigma + \varepsilon}{\sigma + \varepsilon + \varsigma\delta(\beta - \alpha)} \right) > 0, \tag{46}$$

$$\varepsilon_{w^L,t} \equiv -\frac{\partial w^L}{\partial t} \frac{1-t}{w^L} = -\frac{\tilde{w}^L}{\tilde{t}} = \varsigma \left(\frac{\alpha\delta}{\sigma + \varepsilon + \varsigma\delta(\beta - \alpha)} \right) > 0, \tag{47}$$

$$\varepsilon_{w^H,t} \equiv -\frac{\partial w^H}{\partial t} \frac{1-t}{w^H} = -\frac{\tilde{w}^H}{\tilde{t}} = -\varsigma \left(\frac{(1-\alpha)\delta}{\sigma + \varepsilon + \varsigma\delta(\beta - \alpha)} \right) < 0. \tag{48}$$

$$\varepsilon_{l^L,t} \equiv -\frac{\partial l^L_\theta}{\partial t} \frac{1-t}{l^L_\theta} = -\frac{\tilde{l}}{\tilde{t}} = \varepsilon \left(1 + \varepsilon_{w^H,t} \right) = \varsigma \left(\frac{\sigma + \varepsilon + \delta\beta}{\sigma + \varepsilon + \varsigma\delta(\beta - \alpha)} \right) \varepsilon > 0, \tag{49}$$

$$\varepsilon_{l^H,t} \equiv -\frac{\partial l^H_\theta}{\partial t} \frac{1-t}{l^H_\theta} = -\frac{\tilde{h}}{\tilde{t}} = \varepsilon \left(1 + \varepsilon_{w^L,t} \right) = \varsigma \left(\frac{\sigma + \varepsilon + \delta(\beta - 1)}{\sigma + \varepsilon + \varsigma\delta(\beta - \alpha)} \right) \varepsilon > 0. \tag{50}$$

Similarly, we obtain the subsidy elasticities by setting $\tilde{t}=0$ and defining

$$\varepsilon_{\Theta,s} \equiv -\frac{\partial \Theta}{\partial s}\frac{s}{\Theta} = -\frac{\tilde{\Theta}}{\tilde{s}} = \varsigma\left(\frac{\sigma+\varepsilon}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\rho > 0, \tag{51}$$

$$\varepsilon_{w^L,s} \equiv \frac{\partial w^L}{\partial s}\frac{s}{w^L} = \frac{\tilde{w}^L}{\tilde{s}} = \varsigma\left(\frac{\alpha\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\rho > 0, \tag{52}$$

$$\varepsilon_{w^H,s} \equiv \frac{\partial w^H}{\partial s}\frac{s}{w^H} = \frac{\tilde{w}^H}{\tilde{s}} = -\varsigma\left(\frac{(1-\alpha)\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\rho < 0, \tag{53}$$

$$\varepsilon_{l,s} \equiv \frac{\partial l^L_\theta}{\partial s}\frac{s}{l^L_\theta} = \frac{\tilde{l}}{\tilde{s}} = \varepsilon\varepsilon_{w^L,s} = \varsigma\left(\frac{\alpha\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\varepsilon\rho > 0, \tag{54}$$

$$\varepsilon_{h,s} \equiv \frac{\partial l^H_\theta}{\partial s}\frac{s}{l^H_\theta} = \frac{\tilde{h}}{\tilde{s}} = \varepsilon\varepsilon_{w^H,s} = -\varsigma\left(\frac{(1-\alpha)\delta}{\sigma+\varepsilon+\varsigma\delta(\beta-\alpha)}\right)\varepsilon\rho < 0. \tag{55}$$

A.1 Elasticities with fixed Θ

Suppose Θ is fixed, and thus $\tilde{\Theta}=0$. Then (33) and (34) simplify to

$$\tilde{H} = \varepsilon\left(\tilde{w}^H - \tilde{t}\right), \tag{56}$$

$$\tilde{L} = \varepsilon\left(\tilde{w}^L - \tilde{t}\right). \tag{57}$$

Substituting these results in (35) and (36) gives:

$$\tilde{w}^H - \tilde{w}^L = \frac{(1-\alpha)}{\sigma}(\tilde{L}-\tilde{H}) + \frac{\alpha}{\sigma}(\tilde{L}-\tilde{H}) = (\tilde{L}-\tilde{H})\frac{1}{\sigma} = \varepsilon(\tilde{w}^L - \tilde{w}^H), \tag{58}$$

which holds only if $\tilde{w}^L - \tilde{w}^H = 0$. This implies $\tilde{w}^L = \tilde{w}^H$, and thus from (56) and (57), $\tilde{L} = \tilde{H}$, and thus $\tilde{w}^H = \tilde{w}^L = 0$. Hence if Θ is fixed, policy does not affect wages. A change $\tilde{t}$ still affects labor supplies, but it does so symmetrically across skill groups. Hence, both s and t affect wages only via changing Θ.

B Optimal policy

Introducing η as the Lagrange multiplier on the government budget constraint, we can formulate the Lagrangian for maximizing social welfare as:

$$\begin{aligned}\max_{b,t,s}\mathcal{L} \equiv & \int_{\underline{\theta}}^{\Theta}\Psi(V^L_\theta)\mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}}\Psi(V^H_\theta)\mathrm{d}F(\theta) \\ & +\eta\left[\int_{\underline{\theta}}^{\Theta} tw^L\theta l^L_\theta \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}}(tw^H\theta l^H_\theta - s\pi\theta^{-\psi})\mathrm{d}F(\theta) - b - R\right],\end{aligned} \tag{59}$$

Define marginal social utility as

$$\Psi'_\theta \equiv \begin{cases}\Psi'(V^L_\theta) & \text{if } \theta < \Theta, \\ \Psi'(V^H_\theta) & \text{if } \theta \geq \Theta.\end{cases} \tag{60}$$

Necessary, first-order conditions for an optimum are given by:

$$\frac{\partial \mathcal{L}}{\partial b} = \int_{\underline{\theta}}^{\Theta} \Psi'_\theta \frac{\partial V_\theta^L}{\partial b} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \Psi'_\theta \frac{\partial V_\theta^H}{\partial b} \mathrm{d}F(\theta) - \eta = 0, \tag{61}$$

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial t} &= \int_{\underline{\theta}}^{\Theta} \Psi' \frac{\partial V_\theta^L}{\partial t} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \Psi' \frac{\partial V_\theta^H}{\partial t} \mathrm{d}F(\theta) + \eta \left[\int_{\underline{\theta}}^{\Theta} w^L \theta l_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} w^H \theta h \mathrm{d}F(\theta) \right] \\ &+ \eta \left[\int_{\underline{\theta}}^{\Theta} t w^L \theta \frac{\partial l_\theta^L}{\partial t} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} t w^H \theta \frac{\partial l_\theta^H}{\partial t} \mathrm{d}F(\theta) \right] \\ &+ \eta \left[\int_{\underline{\theta}}^{\Theta} t \frac{\partial w^L}{\partial t} \theta l_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} t \frac{\partial w^H}{\partial t} \theta l_\theta^H \mathrm{d}F(\theta) \right] \\ &+ \underbrace{\left[\gamma_\Theta^L V_\Theta^L - \gamma_\Theta^H V_\Theta^H \right]}_{=0} f(\Theta) \frac{\partial \Theta}{\partial t} - \eta \left[t w^H \Theta l_\Theta^H - t w^L \Theta l_\Theta^L - s\pi\Theta^{-\psi} \right] f(\theta) \frac{\partial \Theta}{\partial t} = 0, \end{aligned} \tag{62}$$

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial s} &= \int_{\underline{\theta}}^{\Theta} \Psi' \frac{\partial V_\theta^L}{\partial s} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \Psi' \frac{\partial V_\theta^H}{\partial s} \mathrm{d}F(\theta) - \eta\pi \left[\int_{\Theta}^{\overline{\theta}} \theta^{-\psi} \mathrm{d}F(\theta) \right] \\ &+ \eta \left[\int_{\underline{\theta}}^{\Theta} t w^L \theta \frac{\partial l_\theta^L}{\partial s} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} t w^H \theta \frac{\partial l_\theta^H}{\partial s} \mathrm{d}F(\theta) \right] \\ &+ \eta \left[\int_{\underline{\theta}}^{\Theta} t \frac{\partial w^L}{\partial s} \theta l_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} t \frac{\partial w^H}{\partial s} \theta l_\theta^H \mathrm{d}F(\theta) \right] \\ &+ \underbrace{\left[\gamma_\Theta^L V_\Theta^L - \gamma_\Theta^H V_\Theta^H \right]}_{=0} f(\Theta) \frac{\partial \Theta}{\partial s} - \eta \left[t w^H \Theta l_\Theta^H - t w^L \Theta l_\Theta^L - s\pi\Theta^{-\psi} \right] f(\theta) \frac{\partial \Theta}{\partial s} = 0. \end{aligned} \tag{63}$$

Note that $V_\Theta^L = V_\Theta^H$ because the marginal graduate Θ is indifferent between being high-skilled or low-skilled.

Next, use Roy's identity to derive that

$$\frac{\partial V_\theta^i}{\partial b} = 1, \tag{64}$$
$$\frac{\partial V_\theta^H}{\partial t} = -\theta w^H l_\theta^H + (1-t)\theta l_\theta^H \frac{\partial w^H}{\partial t}, \tag{65}$$
$$\frac{\partial V_\theta^L}{\partial t} = -\theta w^L l_\theta^L + (1-t)\theta l_\theta^L \frac{\partial w^L}{\partial t}, \tag{66}$$
$$\frac{\partial V_\theta^H}{\partial s} = \pi\theta^{-\psi} + (1-t)\theta l_\theta^H \frac{\partial w^H}{\partial s}, \tag{67}$$
$$\frac{\partial V_\theta^L}{\partial s} = (1-t)\theta l_\theta^L \frac{\partial w^L}{\partial s}. \tag{68}$$

Recall that the net tax wedge on skill formation is defined as $\Delta \equiv t w^H \Theta l_\Theta^H - t w^L \Theta l_\Theta^L - s\pi\Theta^{-\psi}$. We define $g_\theta \equiv \Psi'/\eta$ as the social welfare weight of individual θ, where g_θ gives the monetized value of providing this individual with an additional euro. Therefore, we can simplify the first-order conditions as:

$$\frac{\partial \mathcal{L}}{\partial b} = 0 : \int_{\underline{\theta}}^{\Theta} \frac{\Psi'}{\eta} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \frac{\Psi'}{\eta} \mathrm{d}F(\theta) = \int_{\underline{\theta}}^{\Theta} g_\theta \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} g_\theta \mathrm{d}F(\theta) = 1. \tag{69}$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial t} &= \int_{\underline{\theta}}^{\Theta} \Psi' \left(-\theta w^L l_\theta^L + (1-t)\theta l_\theta^L \frac{\partial w^L}{\partial t} \right) \mathrm{d}F(\theta) \\
&+ \int_{\Theta}^{\overline{\theta}} \Psi' \left(-\theta w^H l_\theta^H + (1-t)\theta l_\theta^H \frac{\partial w^H}{\partial t} \right) \mathrm{d}F(\theta) \\
&+ \eta \left[\int_{\underline{\theta}}^{\Theta} w^L \theta l_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} w^H \theta l_\theta^H \mathrm{d}F(\theta) \right] \\
&+ \eta \left[\int_{\underline{\theta}}^{\Theta} t w^L \theta \frac{\partial l_\theta^L}{\partial t} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} t w^H \theta \frac{\partial l_\theta^H}{\partial t} \mathrm{d}F(\theta) \right] \\
&+ \eta \left[\int_{\underline{\theta}}^{\Theta} t \frac{\partial w^L}{\partial t} \theta l_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} t \frac{\partial w^H}{\partial t} \theta l_\theta^H \mathrm{d}F(\theta) \right] - \eta \frac{\Delta}{1-t} \Theta f(\Theta) \frac{\partial \Theta}{\partial t} \frac{1-t}{\Theta} = 0,
\end{aligned} \tag{70}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial s} &= \int_{\underline{\theta}}^{\Theta} \Psi' \left((1-t)\theta l_\theta^L \frac{\partial w^L}{\partial s} \right) \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \Psi' \left(\pi \theta^{-\psi} + (1-t)\theta l_\theta^H \frac{\partial w^H}{\partial s} \right) \mathrm{d}F(\theta) \\
&- \eta \left[\pi \int_{\Theta}^{\overline{\theta}} \theta^{-\psi} \mathrm{d}F(\theta) \right] + \eta \left[\int_{\underline{\theta}}^{\Theta} t w^L \theta \frac{\partial l_\theta^L}{\partial s} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} t w^H \theta \frac{\partial l_\theta^H}{\partial s} \mathrm{d}F(\theta) \right] \\
&+ \eta \left[\int_{\underline{\theta}}^{\Theta} t \frac{\partial w^L}{\partial s} \theta l_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} t \frac{\partial w^H}{\partial s} \theta l_\theta^H \mathrm{d}F(\theta) \right] - \eta \frac{\Delta}{s} \Theta f(\theta) \frac{\partial \Theta}{\partial s} \frac{s}{\Theta} = 0.
\end{aligned} \tag{71}
$$

We will simplify the first-order conditions for t and s in a number of steps.

B.1 Optimal income tax

Rewrite the first-order condition for t using the definitions for $z_\theta^L \equiv w^L \theta l_\theta^L$ and $z_\theta^H \equiv w^H \theta l_\theta^H$ to find:

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial t} &= - \left[\int_{\underline{\theta}}^{\Theta} \Psi' z_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \Psi' z_\theta^H \mathrm{d}F(\theta) \right] + \eta \left[\int_{\underline{\theta}}^{\Theta} z_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} z_\theta^H \mathrm{d}F(\theta) \right] \\
&+ \frac{t}{1-t} \eta \left[\int_{\underline{\theta}}^{\Theta} z_\theta^L \frac{\partial l_\theta^L}{\partial t} \frac{1-t}{l_\theta^L} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} z_\theta^H \frac{\partial l_\theta^H}{\partial t} \frac{1-t}{l_\theta^H} \mathrm{d}F(\theta) \right] \\
&+ \int_{\underline{\theta}}^{\Theta} \left[\Psi' + \eta \frac{t}{1-t} \right] z_\theta^L \frac{\partial w^L}{\partial t} \frac{1-t}{w^L} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \left[\Psi' + \eta \frac{t}{1-t} \right] z_\theta^H \frac{\partial w^H}{\partial t} \frac{1-t}{w^H} \mathrm{d}F(\theta) \\
&- \eta \frac{\Delta}{1-t} \Theta f(\Theta) \frac{\partial \Theta}{\partial t} \frac{1-t}{\Theta} = 0.
\end{aligned} \tag{72}
$$

And, simplify the first-order condition for t using the definitions of elasticities:

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial t} &= - \left[\int_{\underline{\theta}}^{\Theta} \Psi' z_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \Psi' z_\theta^H \mathrm{d}F(\theta) \right] + \eta \left[\int_{\underline{\theta}}^{\Theta} z_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} z_\theta^H \mathrm{d}F(\theta) \right] \\
&- \frac{t}{1-t} \eta \left[\int_{\underline{\theta}}^{\Theta} z_\theta^L \varepsilon_{l,t} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} z_\theta^H \varepsilon_{h,t} \mathrm{d}F(\theta) \right] - \int_{\underline{\theta}}^{\Theta} \left[\Psi' + \eta \frac{t}{1-t} \right] z_\theta^L \varepsilon_{w^L,t} \mathrm{d}F(\theta) \\
&- \int_{\Theta}^{\overline{\theta}} \left[\Psi' + \eta \frac{t}{1-t} \right] z_\theta^H \varepsilon_{w^H,t} \mathrm{d}F(\theta) - \eta \frac{\Delta}{1-t} \Theta f(\Theta) \varepsilon_{\Theta,t} = 0.
\end{aligned} \tag{73}
$$

Important to note here is that all elasticities are independent of θ (they do depend on Θ, however). Hence, they can all be taken out of the integral signs. Next, we define average incomes of the low- and high-skilled

$$\bar{z}^L \equiv \int_{\underline{\theta}}^{\Theta} z_\theta^L \mathrm{d}F(\theta), \quad \bar{z}^H \equiv \int_{\Theta}^{\overline{\theta}} z_\theta^H \mathrm{d}F(\theta). \tag{74}$$

By dividing (73) by η and substituting for the definitions, we obtain

$$\begin{aligned} &-\left[\int_{\underline{\theta}}^{\Theta} g_\theta z_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} g_\theta z_\theta^H \mathrm{d}F(\theta)\right] + \bar{z}^L + \bar{z}^H - \frac{t}{1-t}\left[\varepsilon_{l,t}\bar{z}^L + \varepsilon_{h,t}\bar{z}^H\right] \\ &-\varepsilon_{w^L,t}\int_{\underline{\theta}}^{\Theta}\left[g_\theta + \frac{t}{1-t}\right] z_\theta^L \mathrm{d}F(\theta) - \varepsilon_{w^H,t}\int_{\Theta}^{\overline{\theta}}\left[g_\theta + \frac{t}{1-t}\right] z_\theta^H \mathrm{d}F(\theta) \\ &-\frac{\Delta}{1-t}\Theta f(\Theta)\varepsilon_{\Theta,t} = 0. \end{aligned} \tag{75}$$

Next, define the distributional characteristic of labor income as:

$$\xi \equiv 1 - \frac{\int_{\underline{\theta}}^{\Theta} g_\theta z_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} g_\theta z_\theta^H \mathrm{d}F(\theta)}{\left[\bar{z}^L + \bar{z}^H\right]\int_{\underline{\theta}}^{\overline{\theta}} g_\theta \mathrm{d}F(\theta)}. \tag{76}$$

Note also that $\bar{z} = \bar{z}^L + \bar{z}^H$ and $w^L L = \bar{z}^L$ and $w^H H = \bar{z}^H$ so that we can write for the income shares:

$$\alpha = \frac{\bar{z}^H}{\bar{z}^L + \bar{z}^H}, \quad 1-\alpha = \frac{\bar{z}^L}{\bar{z}^L + \bar{z}^H}. \tag{77}$$

Hence, the optimal income tax expression can be written as

$$\begin{aligned} \xi = &\frac{t}{1-t}\left[(1-\alpha)(\varepsilon_{l,t} + \varepsilon_{w^L,t}) + \alpha(\varepsilon_{h,t} + \varepsilon_{w^H,t})\right] + \frac{\Delta}{1-t}\frac{\Theta f(\Theta)}{\bar{z}}\varepsilon_{\Theta,t} \\ &+ \varepsilon_{w^L,t}\frac{\int_{\underline{\theta}}^{\Theta} g_\theta z_\theta^L \mathrm{d}F(\theta)}{\left[\bar{z}^L + \bar{z}^H\right]} + \varepsilon_{w^H,t}\frac{\int_{\Theta}^{\overline{\theta}} g_\theta z_\theta^H \mathrm{d}F(\theta)}{\left[\bar{z}^L + \bar{z}^H\right]}. \end{aligned} \tag{78}$$

Substitute the income-weighted social welfare weights of each skill group: $\tilde{g}^L \equiv \int_{\underline{\theta}}^{\Theta} g_\theta z_\theta^L \mathrm{d}F(\theta)/\bar{z}^L$ and $\tilde{g}^H \equiv \int_{\Theta}^{\overline{\theta}} g_\theta z_\theta^H \mathrm{d}F(\theta)/\bar{z}^H$ to find the optimal tax in the proposition:

$$\begin{aligned} &\frac{t}{1-t}\left[(1-\alpha)(\varepsilon_{l,t} + \varepsilon_{w^L,t}) + \alpha(\varepsilon_{h,t} + \varepsilon_{w^H,t})\right] + \frac{\Delta}{(1-t)}\frac{\Theta f(\Theta)}{\bar{z}}\varepsilon_{\Theta,t} \\ &= \xi - \varepsilon_{w^H,t}\alpha\tilde{g}^H - \varepsilon_{w^L,t}(1-\alpha)\tilde{g}^L. \end{aligned} \tag{79}$$

Finally, substitute for the elasticities from Appendix A to find:

$$\frac{t}{(1-t)}\varepsilon + \frac{\Delta}{(1-t)}\frac{\Theta f(\Theta)}{\bar{z}}\left(\frac{\sigma+\varepsilon}{\sigma+\varepsilon+\delta(\beta-\alpha)}\right) = \xi - \frac{(1-\alpha)\alpha\delta}{(\sigma+\varepsilon+\delta(\beta-\alpha))}(\tilde{g}^L - \tilde{g}^H). \tag{80}$$

B.2 Optimal education subsidy

Using similar steps as a above we rewrite the optimal education subsidy using the definitions for $z_\theta^L \equiv w^L \theta l_\theta^L$ and $z_\theta^H \equiv w^H \theta l_\theta^H$ to find:

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial s} &= \int_{\underline{\theta}}^{\Theta} \Psi' \left(\frac{(1-t)}{s} z_\theta^L \frac{\partial w^L}{\partial s} \frac{s}{w^L} \right) \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \Psi' \left(\pi \theta^{-\psi} + \frac{(1-t)}{s} z_\theta^H \frac{\partial w^H}{\partial s} \frac{s}{w^H} \right) \mathrm{d}F(\theta) \\ &- \eta \left[\pi \int_{\Theta}^{\overline{\theta}} \theta^{-\psi} \mathrm{d}F(\theta) \right] + \eta \left[\int_{\underline{\theta}}^{\Theta} \frac{t}{s} z_\theta^L \frac{\partial l_\theta^L}{\partial s} \frac{s}{l_\theta^L} \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \frac{t}{s} z_\theta^H \frac{\partial l_\theta^H}{\partial s} \frac{s}{l_\theta^H} \mathrm{d}F(\theta) \right] \\ &+ \eta \left[\int_{\underline{\theta}}^{\Theta} \frac{t}{s} \frac{\partial w^L}{\partial s} \frac{s}{w^L} z_\theta^L \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \frac{t}{s} \frac{\partial w^H}{\partial s} \frac{s}{w^H} z_\theta^H \mathrm{d}F(\theta) \right] - \eta \frac{\Delta}{s} \Theta f(\theta) \frac{\partial \Theta}{\partial s} \frac{s}{\Theta} = 0.\end{aligned} \tag{81}$$

Simplify the first-order condition for s using the definitions of the subsidy elasticities:

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial s} &= \int_{\underline{\theta}}^{\Theta} \Psi' \left(\frac{(1-t)}{s} z_\theta^L \varepsilon_{w^L,s} \right) \mathrm{d}F(\theta) + \int_{\Theta}^{\overline{\theta}} \Psi' \left(\pi \theta^{-\psi} + \frac{(1-t)}{s} z_\theta^H \varepsilon_{w^H,s} \right) \mathrm{d}F(\theta) \\ &- \eta \pi \int_{\Theta}^{\overline{\theta}} \theta^{-\psi} \mathrm{d}F(\theta) + \eta \left[\frac{t}{s} (\varepsilon_{l,s} + \varepsilon_{w^L,s}) \bar{z}^L + \frac{t}{s} (\varepsilon_{h,s} + \varepsilon_{w^H,s}) \bar{z}^H \right] + \eta \frac{\Delta}{s} \Theta f(\theta) \varepsilon_{\Theta,s} = 0.\end{aligned} \tag{82}$$

All elasticities are independent from θ (they do depend on Θ). Hence, they can be taken out of the integral signs. After dividing by η and multiplication with $s/(1-t)$ we obtain:

$$\begin{aligned}&\varepsilon_{w^L,s} \int_{\underline{\theta}}^{\Theta} g_\theta z_\theta^L \mathrm{d}F(\theta) + \varepsilon_{w^H,s} \int_{\Theta}^{\overline{\theta}} g_\theta z_\theta^H \mathrm{d}F(\theta) - \frac{s}{1-t} \pi \int_{\Theta}^{\overline{\theta}} \theta^{-\psi} (1 - g_\theta) \mathrm{d}F(\theta) \\ &+ \frac{t}{1-t} \varepsilon_{l,s} \bar{z}^L + \frac{t}{1-t} \varepsilon_{h,s} \bar{z}^H + \frac{t}{1-t} \varepsilon_{w^L,s} \bar{z}^L + \frac{t}{1-t} \varepsilon_{w^H,s} \bar{z}^H + \frac{\Delta}{1-t} \Theta f(\theta) \varepsilon_{\Theta,s} = 0.\end{aligned} \tag{83}$$

Divide by $\bar{z}$, use $\tilde{g}^L \equiv \int_{\underline{\theta}}^{\Theta} g_\theta z_\theta^L \mathrm{d}F(\theta)/\bar{z}^L$ and $\tilde{g}^H \equiv \int_{\Theta}^{\overline{\theta}} g_\theta z_\theta^H \mathrm{d}F(\theta)/\bar{z}^H$ and the definition of α to write

$$\begin{aligned}&\varepsilon_{w^L,s} (1-\alpha) \tilde{g}^L + \varepsilon_{w^H,s} \alpha \tilde{g}^H - \frac{1}{\bar{z}} \frac{s}{1-t} \pi \int_{\Theta}^{\overline{\theta}} \theta^{-\psi} (1 - g_\theta) \mathrm{d}F(\theta) \\ &+ \frac{t}{1-t} \varepsilon_{l,s} (1-\alpha) + \frac{t}{1-t} \varepsilon_{h,s} \alpha + \frac{t}{1-t} \varepsilon_{w^L,s} (1-\alpha) \\ &+ \frac{t}{1-t} \varepsilon_{w^H,s} (\alpha) + \frac{1}{\bar{z}} \frac{\Delta}{1-t} \Theta f(\theta) \varepsilon_{\Theta,s} = 0.\end{aligned} \tag{84}$$

Collect terms and rewrite to arrive at:

$$\begin{aligned}&\varepsilon_{w^L,s} (1-\alpha) \tilde{g}^L + \varepsilon_{w^H,s} \alpha \tilde{g}^H - \frac{1}{\bar{z}} \frac{s}{1-t} \pi \int_{\Theta}^{\overline{\theta}} \theta^{-\psi} (1 - g_\theta) \mathrm{d}F(\theta) \\ &+ \frac{t}{1-t} (1-\alpha) \left(\varepsilon_{l,s} + \varepsilon_{w^L,s} \right) + \frac{t}{1-t} \alpha \left(\varepsilon_{h,s} + \varepsilon_{w^H,s} \right) + \frac{1}{\bar{z}} \frac{\Delta}{1-t} \Theta f(\theta) \varepsilon_{\Theta,s} = 0.\end{aligned} \tag{85}$$

Now, substitute the definitions of the elasticities from Appendix A to derive the following results:

$$\left(\frac{\alpha \delta}{\sigma + \varepsilon + \delta(\beta - \alpha)} \right) \rho (1-\alpha) \tilde{g}^L - \left(\frac{(1-\alpha)\delta}{\sigma + \varepsilon + \delta(\beta - \alpha)} \right) \rho \alpha \tilde{g}^H = \left(\frac{\alpha (1-\alpha) \delta}{\sigma + \varepsilon + \delta(\beta - \alpha)} \right) \rho \left(\tilde{g}^L - \tilde{g}^H \right), \tag{86}$$

$$(1-\alpha)\left(\varepsilon_{l,s}+\varepsilon_{w^L,s}\right)=(1-\alpha)\left(1+\varepsilon\right)\frac{\alpha\delta}{\sigma+\varepsilon+\delta(\beta-\alpha)}\rho, \tag{87}$$

$$\alpha\left(\varepsilon_{h,s}+\varepsilon_{w^H,s}\right)=-\alpha(1+\varepsilon)\frac{(1-\alpha)\delta}{\sigma+\varepsilon+\delta(\beta-\alpha)}\rho. \tag{88}$$

Thus, we find:

$$\frac{t}{1-t}\left(1-\alpha\right)\left(\varepsilon_{l,s}+\varepsilon_{w^L,s}\right)+\frac{t}{1-t}\alpha(\varepsilon_{h,s}+\varepsilon_{w^H,s})=0. \tag{89}$$

The condition for the optimal subsidy (85), then simplifies to

$$\left(\frac{\alpha\left(1-\alpha\right)\delta}{\sigma+\varepsilon+\delta(\beta-\alpha)}\right)\rho(\tilde{g}^L-\tilde{g}^H)-\frac{1}{\overline{z}}\frac{s}{1-t}\pi\int_{\Theta}^{\overline{\theta}}\theta^{-\psi}(1-g_\theta)\mathrm{d}F(\theta)+\frac{1}{\overline{z}}\frac{\Delta}{1-t}\Theta f(\theta)\varepsilon_{\Theta,s}=0. \tag{90}$$

Substituting for $\varepsilon_{\Theta,s}$ from Appendix A then yields:

$$\begin{aligned}&\left(\frac{\alpha\left(1-\alpha\right)\delta}{\sigma+\varepsilon+\delta(\beta-\alpha)}\right)\rho(\tilde{g}^L-\tilde{g}^H)-\frac{1}{\overline{z}}\frac{s}{1-t}\pi\int_{\Theta}^{\overline{\theta}}\theta^{-\psi}(1-g_\theta)\mathrm{d}F(\theta)\\&+\frac{\Delta}{1-t}\frac{\Theta f(\theta)}{\overline{z}}\frac{\sigma+\varepsilon}{\sigma+\varepsilon+\delta(\beta-\alpha)}\rho=0.\end{aligned} \tag{91}$$

Substitute $\varepsilon_{GE}\equiv(1-\alpha)\varepsilon_{w^L,t}=-\alpha\varepsilon_{wH,t}=\frac{\alpha(1-\alpha)\delta}{(\sigma+\varepsilon+\delta(\beta-\alpha)}$, and the distributional characteristic of the education subsidy ζ, to find the optimal subsidy in the proposition:

$$\frac{\Delta}{1-t}\frac{\Theta f(\theta)}{\overline{z}}\varepsilon_{\Theta,s}=\frac{1}{\overline{z}}\frac{s\pi}{1-t}\zeta-\rho(\tilde{g}^L-\tilde{g}^H)\varepsilon_{GE}. \tag{92}$$

C Data Appendix

Data on wages and educational attainment are taken from the Current Population Survey (CPS) Merged Outgoing Rotation Groups (MORG) as prepared by the National Bureau of Economic Research (NBER).[31] The data cover the years from 1979 to 2016, where we focus on the period 1980 to 2016.

We use the same sample selection criteria as Acemoglu and Autor (2011). In particular, individuals are of age 16 to 64 and their usual weekly hours worked exceed 35. We obtain hourly wages by dividing weakly earnings by usual hours worked. We convert all wages into 2016 dollar values using the personal consumption expenditures chain-type price index.[32] The highest earnings in the CPS are top-coded. Top-coded earnings are therefore windsorized by multiplying them by 1.5. Like Acemoglu and Autor (2011), we exclude individuals who earn less than 50% of the 1982 minimum wage ($3.35) converted to 2016-dollars. We also exclude self-employed individuals, as well as individuals whose occupation does not have an `occ1990dd` classification. We weight observations by CPS sample weights. We code education levels based on the highest grade attended (before 1992) and the highest grade completed (after 1992).

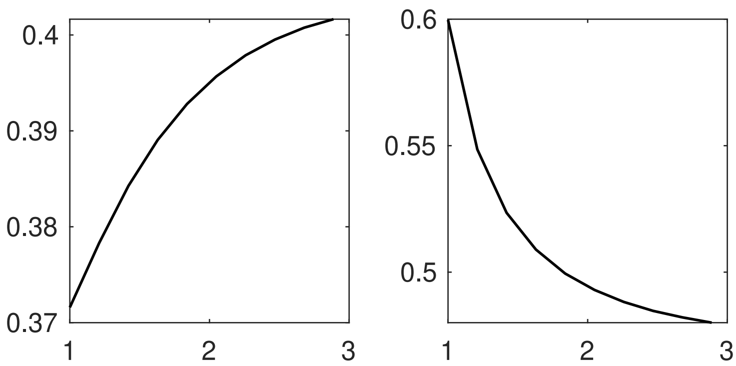
[31] See `http://www.nber.org/data/morg.html`.

[32] We obtain the price index from `https://fred.stlouisfed.org/series/DPCERG3A086NBEA`.

D Enrollment elasticity

Dynarski (2000) finds that \$ 1000 increase in financial aid raised college attendance rates in Georgia between 3.7 and 4.2 percentage points. Before the introduction of the scholarship, average tuition per student was \$1900. Based on data from the US Department of Education, Gumport et al. (1997) document that in 1992 government funding as a percentage of all funding for higher education in the US was around 40%, which we treat as the initial subsidy rate. We consider the tuition of \$1900 as the private cost of higher education, which equals 60% of the total cost of \$3167. A reduction of \$1000 corresponds to a change in the subsidy rate of 0.3 points. Using an initial college enrollment rate in Georgia of 0.32, and assuming an increase of 0.04 in the enrollment share due to the HOPE scholarship, we compute the relative change in enrollment as 0.04/0.32 and the relative change in the subsidy rate as 0.3/0.4. The resulting enrollment elasticity of the subsidy is then equal to 0.17.

E Comparative statics



(a) Optimal tax rate t (s fixed) (b) Optimal subsidy rate s (t fixed)

Figure 3: Optimal policy under SBTC with a constant subsidy rate or tax rate

Note: Skill-bias A on the horizontal axis. The respective values of s and t, are fixed at their optimum values at $A = 1$ as displayed in Figure 2.

E.1 Effect on optimal tax rate

Totally differentiating (23), while keeping the optimal subsidy s fixed, and rearranging leads to

$$\frac{\mathrm{d}t}{\mathrm{d}A} = \frac{\frac{\partial \xi}{\partial A} - \frac{\partial}{\partial A}\left(\frac{\Delta}{(1-t)\bar{z}} f(\Theta)\,\Theta\varepsilon_{\Theta,t}\right) - \frac{\partial}{\partial A}\left((\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}\right)}{\frac{1}{(1-t)^2}\varepsilon - \frac{\partial \xi}{\partial t} + \frac{\partial}{\partial t}\left(\frac{\Delta}{(1-t)\bar{z}} f(\Theta)\,\Theta\varepsilon_{\Theta,t}\right) + \frac{\partial}{\partial t}\left((\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}\right)}. \tag{93}$$

We argue in Appendix F below that the denominator in (93) is positive. To determine the sign of $\mathrm{d}t/\mathrm{d}A$ we can therefore focus on the numerator. The optimal tax rate increases with SBTC if the distributional benefits of income taxation increase more than tax-distortions and wage-compression effects taken together.

Distributional benefits of income taxes ξ. Recall that ξ is minus the normalized covariance between income and social welfare weights. By raising the ratio of wage rates w^H/w^L, SBTC directly affects gross incomes. However, incomes are affected indirectly via changes in labor supply. The direct effect increases the income gap between skill-groups. Moreover, since labor supply increases more strongly with the wage rate the higher an individual's ability, income inequality within skill-groups also increases. To see this, use (5) to write income as

$$z_\theta^j = l_\theta^j w^j \theta = \left[(1-t)w^j\theta\right]^\varepsilon w^j\theta = (w^j\theta)^{1+\varepsilon}(1-t)^\varepsilon. \tag{94}$$

An increase in w^j thus has a stronger effect on income z_θ^j, the higher is θ. Both the increase of between- and within-group inequality contribute to an increase in ξ.

At the same time, SBTC affects social welfare weights. Consumption, and thus utility, of the high-skilled increase more than for the low-skilled. Whether, as a result, social welfare weights decline more or less steeply with θ depends on the curvature of the social welfare function. Since a strictly concave social welfare function is steeper at low θ and flatter at high θ, the same increase in utility changes social marginal utility more at low θ and less at high θ. There are thus counteracting effects: at high θ, a larger change in utility goes along with social welfare weights being less responsive to such a change, while the opposite is true at low θ. The effect of SBTC on social welfare weights is therefore ambiguous. As a consequence, $\partial\xi/\partial A$ cannot be unambiguously signed.

Education distortions of income taxes $\frac{\Delta}{(1-t)\bar{z}} f(\Theta)\Theta\varepsilon_{\Theta,t}$. To analyze the partial impact of SBTC on the tax distortions of education, write

$$\frac{\partial}{\partial A}\left(\frac{\Delta}{(1-t)\bar{z}} f(\Theta)\Theta\varepsilon_{\Theta,t}\right) = \frac{1}{1-t}\left[\frac{\partial(\Delta/\bar{z})}{\partial A} f(\Theta)\Theta\varepsilon_{\Theta,t} + \frac{\partial f(\Theta)\Theta}{\partial A}\frac{\Delta}{\bar{z}}\varepsilon_{\Theta,t} + \frac{\partial\varepsilon_{\Theta,t}}{\partial A}\frac{\Delta}{\bar{z}} f(\Theta)\Theta\right]. \tag{95}$$

The sign of $\frac{\partial(\Delta/\bar{z})}{\partial A}$ is ambiguous. On the one hand, SBTC raises the income gap between the marginally high-skilled and the marginally low-skilled, which raises Δ – ceteris paribus. On the other hand, the costs of higher education for the marginal graduate $p(\Theta)$ increase, since Θ falls. If the subsidy rate is positive, an increase in $p(\Theta)$ education subsidies for the marginal graduate increase, which lowers Δ. If in contrast, $s < 0$, the net tax Δ unambiguously increases with SBTC. However, SBTC also raises $\bar{z}$. If aggregate income increases relatively more than Δ, $\Delta/\bar{z}$ falls nevertheless.

The sign of $\frac{\partial f(\Theta)\Theta}{\partial A}$ is again ambiguous. SBTC lowers Θ, but if $f'(\Theta) < 0$, the density increases as Θ falls, making the overall impact ambiguous. If in contrast, $f'(\Theta) > 0$, SBTC unambiguously decreases $f(\Theta)\Theta$.

Finally, consider $\partial\varepsilon_{\Theta,t}/\partial A$. We have that $\partial\alpha/\partial A > 0$, and $\partial\beta/\partial A < 0$.[33] Moreover, we cannot sign the impact of SBTC on δ. Hence, it is unclear whether SBTC raises or lowers $\varepsilon_{\Theta,t}$. Overall, we conclude that whether tax-distortions on education increase or decrease with SBTC is theoretically ambiguous.

[33] To verify this, write $\alpha = (\frac{H}{L}\frac{w^H}{w^L})/(\frac{H}{L}\frac{w^H}{w^L}+1)$. SBTC increases $\frac{H}{L}\frac{w^H}{w^L}$, and thus the numerator increases relatively more than the denominator. Write $\beta = (w^H/w^L)^{1+\varepsilon}/((w^H/w^L)^{1+\varepsilon}-1)$, where now the numerator increases relatively less with SBTC than the denominator.

Wage decompression effects of income taxes $(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$**.** How does SBTC affect wage decompression effects? First, we focus on the effect on the income-weighted social welfare weights $\tilde{g}^L$ and $\tilde{g}^H$ defined in (21). An increase in A changes these terms via three channels: by affecting incomes, by affecting social welfare weights, and by affecting Θ. We discuss them in turn.

SBTC increases incomes for both low- and high-skilled (though the high-skilled benefit more). Moreover, according to (94), an increase in the wage rate w^j raises income more, the higher is θ. As a result, in $\tilde{g}^L$ and $\tilde{g}^H$ the income weight z_θ^j increases for all g_θ, but more so the higher is θ. After normalizing by aggregate income per skill-group, within skill-groups, g_θ at low θ are weighted relatively less, whereas g_θ at high θ are weighted relatively more. Since social welfare weights are declining in θ, the impact on $\tilde{g}^L$ and $\tilde{g}^H$ is ambiguous. Add to this that the impact of SBTC on the social welfare weights themselves is ambiguous, as has already been discussed.

Finally, consider the effect of SBTC lowering Θ. As the marginal individual becomes high-skilled, both the numerator and the denominator of $\tilde{g}^L$ decrease. However, if $g_\Theta < \tilde{g}^L$, the numerator decreases relatively less than the denominator, and $\tilde{g}^L$ increases.[34] In contrast, the lowering of Θ increases both the numerator and denominator of $\tilde{g}^H$. If $g_\Theta > \tilde{g}^H$, the numerator increases relatively more, and $\tilde{g}^H$ rises with SBTC. Numerically, we find $\tilde{g}^L > g_\Theta > \tilde{g}^H$. Via lowering Θ, SBTC thus contributes to an increase in both $\tilde{g}^L$ and $\tilde{g}^H$. The overall effect on $\tilde{g}^L$ and $\tilde{g}^H$, and thus on $(\tilde{g}^L - \tilde{g}^H)$, is theoretically ambiguous.

Next, we turn to the impact of SBTC on ε_{GE}. Whether skill-bias increases or decreases ε_{GE} depends on its impact on α, β and δ. Moreover, we have $\partial\alpha/\partial A > 0$, and $\partial\beta/\partial A < 0$ and the sign of $\partial\delta/\partial A$ is ambiguous, prohibiting us to clearly sign the effect on ε_{GE} . We conclude that the theoretical impact of SBTC on wage decompression effects is ambiguous.

Combined effect. Since we cannot sign the effect of SBTC on the different determinants of the optimal tax rate, the theoretical effect of SBTC on the optimal tax rate is ambiguous.

E.2 Effect on optimal subsidy rate

Totally differentiating (24), while keeping t fixed, leads to

$$\frac{\mathrm{d}s}{\mathrm{d}A} = \frac{-\frac{\pi}{(1-t)}s\frac{\partial}{\partial A}\left(\frac{\zeta}{\bar{z}}\right) + \frac{\partial}{\partial A}\left(\frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,s}\right) + \rho\frac{\partial}{\partial A}\left(\left(\tilde{g}^L - \tilde{g}^H\right)\varepsilon_{GE}\right)}{\frac{\pi}{(1-t)}\left(\frac{\zeta}{\bar{z}} + \frac{\partial}{\partial s}\left(\frac{\zeta}{\bar{z}}\right)s\right) - \frac{\partial}{\partial s}\left(\frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,s}\right) - \frac{\partial}{\partial s}\left(\rho\left(\tilde{g}^L - \tilde{g}^H\right)\varepsilon_{GE}\right)}. \tag{96}$$

As we argue in Appendix F, the denominator of (96) is positive. To determine the sign of $\mathrm{d}s/\mathrm{d}A$ we can therefore focus on the numerator.

[34] To see this, note that sign of the impact of A on $\tilde{g}^L$ via Θ is given by $\mathrm{sgn}[\partial\Theta/\partial A g_\Theta z_\Theta^L f(\Theta)\bar{z}^L - \partial\Theta/\partial A z_\Theta^L f(\Theta)\int_{\underline{\theta}}^{\Theta} g_\theta z_\theta^L f(\Theta)\mathrm{d}\theta] = \mathrm{sgn}(\tilde{g}^L - g_\Theta)$, where we use $\partial\Theta/\partial A < 0$. The derivations for the effect on $\tilde{g}^H$ are analogue.

Distributional losses of education subsidies $\frac{s\pi}{(1-t)\bar{z}}\zeta$**.** For given s and t, only $\zeta/\bar{z}$ is affected by SBTC. To analyze the sign of $\partial\zeta/\partial A$, write

$$\frac{\partial\zeta}{\partial A} = -\int_{\Theta}^{\theta} \theta^{-\psi}\frac{\partial g_\theta}{\partial A}\mathrm{d}F(\Theta) - \frac{\partial\Theta}{\partial A}\Theta^{-\psi}(1-g_\Theta)f(\Theta). \tag{97}$$

SBTC thus affects ζ via two channels: by changing the social welfare weights g_θ, and by lowering the threshold Θ. As before, the impact of SBTC on social welfare weights is ambiguous. The drop in Θ corresponds to more individuals becoming high-skilled. If the social welfare weight attached to the newly high-skilled is lower than one, as one would expect, ζ increases. Intuitively, as more individuals with lower than average social welfare weights become high-skilled, it becomes more beneficial to raise revenue from the high-skilled by taxing education. In addition, SBTC unambiguously increases $\bar{z}$, and with $\partial\zeta/\partial A > 0$, the theoretical impact on $\zeta/\bar{z}$ is unclear.

Education distortions of education subsidies $\frac{\Delta}{(1-t)\bar{z}}\Theta f(\Theta)\varepsilon_{\Theta,s}$**.** Turning to the distortions of education, note that the tax-distortions and subsidy-distortions of education only differ by a factor ρ. Since ρ is not affected by A, the effect of SBTC on the subsidy-distortions of education is ρ times the impact of SBTC on the tax-distortions of education, which – as argued above – is theoretically ambiguous.

wage-compression effects education subsidies $\rho(\tilde{g}^L-\tilde{g}^H)\varepsilon_{GE}$**.** We have already discussed the effect of an increase in skill-bias on wage-compression effects when analyzing the response of the optimal tax rate given by (93) – all that differs, is that now the effect is multiplied by ρ, which is unaffected by A. As a consequence, the impact of SBTC on wage-compression effects is ambiguous.

Combined effect. Since we cannot sign the effect of SBTC on the different determinants of the optimal subsidy rate, the theoretical effect of SBTC on the optimal subsidy rate is ambiguous.

F Comparative statics: Denominators

In this Section, we discuss the impact of an increase in skill-bias on the denominators in (93) and (96). Combining analytical and numerical insights, we argue that in both cases, the denominator is positive.

F.1 Denominator of (93)

Distributional benefits of income taxes ξ**.** An increase in t affects gross incomes and social welfare weights. Gross incomes fall as higher taxes distort labor supply downwards. Since this distortion is larger for individuals with high ability, the income distribution becomes compressed, which contributes to a drop in ξ. Social welfare weights change for two reasons. First, a drop in gross income directly lowers consumption of each individual, thereby lowering utility. Second, the increased tax revenue is redistributed lump sum, increasing everyone's utility. Individuals of low ability on net gain utility relative to individuals of high ability. This leads to a decrease of social welfare weights at the bottom and an increase at the top. In other words, social welfare weights become flatter. With incomes that are more equal, and social welfare weights declining less steeply, the benefits of redistributing with the income tax decline, that is $\partial\xi/\partial t < 0$. This is also confirmed by our numerical results in Table 7.

Education distortions of income taxes $\frac{\Delta}{(1-t)\bar{z}} f(\Theta)\,\Theta\varepsilon_{\Theta,t}$. The term $\frac{\partial(\Delta/\bar{z})}{\partial t}$ is likely to be positive. For given incomes z_{Θ}^{H} and z_{Θ}^{L}, a higher tax rate leads to a larger increase in tax revenue if the marginal individual becomes high-skilled, contributing to an increase of Δ. Still, a change in the tax rate lowers incomes, as it distorts labor supply downwards, and more so for the high-skilled than the low-skilled workers, partly counteracting the increase in tax revenue.[35] Moreover, by increasing Θ, expenditures on education subsidies are affected. If education is subsidized ($s > 0$), expenditures on education subsidies fall, since $p(\Theta)$ decreases in Θ, thereby contributing to an increase in Δ. In contrast, if education is taxed ($s < 0$), revenue from the education tax falls, which lowers Δ – ceteris paribus. Still, we expect an increase in Δ unless the latter effect is very strong. In addition, $\bar{z}$ decreases with t due to labor-supply distortions, and we thus also expect $\Delta/\bar{z}$ to increase with t. Numerically, we confirm that both Δ and $\Delta/\bar{z}$ increase with t (Table 7). The impact of a higher tax on $\Theta f(\Theta)$ is less clear. While Θ increases, $f(\Theta)$ may increase or decrease, depending on the shape of the density and the location of Θ. In our simulations, we find a decrease in $f(\Theta)$. Numerically, $\Theta f(\Theta)$ falls with t whereas there is no impact on $\varepsilon_{\Theta,t} = \varsigma$. Overall, distortions on education rise as t becomes larger.

Wage decompression effects of income taxes $(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$. Finally, consider the effect of t on wage-decompression effects. First, focus on the terms $\tilde{g}^L$ and $\tilde{g}^H$. Due to distorting labor supply, incomes z_{θ}^{j} are depressed, and more so the higher is θ. After normalizing by aggregate incomes per skill-group, social welfare weights g_θ at low θ receive relatively more weight, whereas the income weighting for social welfare weights at high θ decreases. Since social welfare weights are decreasing in θ – and thus in income – $\tilde{g}^L$ and $\tilde{g}^H$ increase, ceteris paribus. However, so far, we have not taken into account the change in social welfare weights themselves and the increase in Θ. With higher taxes, and thus more redistribution, we expect g_θ to flatten, which ceteris paribus lowers $\tilde{g}^L$ and increases $\tilde{g}^H$. Finally, for given incomes and social welfare weights, the increase in Θ leads to lower $\tilde{g}^L$ if $g_\Theta < \tilde{g}^L$ and to lower $\tilde{g}^H$ if $g_\Theta < \tilde{g}^H$. Due to decreasing g_θ, we expect $\tilde{g}^H < g_\Theta < \tilde{g}^L$, and thus – ceteris paribus – an decrease in $\tilde{g}^L$ and an increase in $\tilde{g}^H$. Numerically, we indeed find that $\tilde{g}^L$ falls, while $\tilde{g}^H$ increases. As a consequence, $\tilde{g}^L - \tilde{g}^H$ declines. The impact of t on ε_{GE} works again via α, β, and δ. While higher taxes decrease α, they increase β via general-equilibrium effects. Still, the impact on δ remains ambiguous, making the theoretical impact on ε_{GE}, and on general-equilibrium effects overall, ambiguous as well. Numerically, we find an increase in ε_{GE}. However, the drop in $(\tilde{g}^L - \tilde{g}^H)$ dominates, such that general-equilibrium effects become less important as t increases.

[35] It is unlikely that, at the optimum, an increase in the tax rate leads to lower tax revenue from the marginal graduate. For that to be the case, the optimal tax rate would have to maximize revenue from the marginal graduate.

Combined effect. Quantitatively, the decline in wage decompression effects is small compared to the drop in ξ and the increase in education distortions. As a consequence, the denominator in (93) is positive.

F.2 Denominator of (96)

Distributional losses of education subsidies $\frac{s\pi}{(1-t)\overline{z}}\zeta$. An increase in s affects ζ via its impact on social welfare weights, as well as by lowering Θ:

$$\frac{\partial \zeta}{\partial s} = -\int_{\Theta}^{\theta} \theta^{-\psi} \frac{\partial g_\theta}{\partial s} \mathrm{d}F(\Theta) - \frac{\partial \Theta}{\partial s} \Theta^{-\psi}(1-g_\Theta) f(\Theta). \tag{98}$$

The first term is expected to be positive. The second term is positive if $g_\Theta < 1$, that is, if the social welfare weight attached to the marginally high-skilled is below one, as we would expect as well. In this case, raising the subsidy distributes income from low-skilled to high-skilled individuals – thereby increasing the benefits of taxing – rather than subsidizing – education. Numerically, we find $g_\Theta < 1$, and consequently $\partial\zeta/\partial s > 0$ (Table 6). The impact of s on $\overline{z}$ works via raising H/L due to lowering Θ, and depends on the specific production function. For example, if the high-skilled contribute more to output than the low-skilled, output can increase with the subsidy rate. Table 6 reports that $\overline{z}$ increases in s. However, the relative increase in ζ is larger, so that $\zeta/\overline{z}$ rises with the subsidy rate.

Education distortions of education subsidies $\frac{\Delta}{(1-t)\overline{z}}\Theta f(\Theta)\varepsilon_{\Theta,s}$. Next, we analyze the impact on the distortions of education:

$$\frac{\partial}{\partial s}\left(\frac{\Delta}{(1-t)\overline{z}} f\left(\Theta\right)\Theta\varepsilon_{\Theta,s}\right) = \frac{1}{1-t}\left[\frac{\partial(\Delta/\overline{z})}{\partial s} f\left(\Theta\right)\Theta\varepsilon_{\Theta,t} + \frac{\partial f\left(\Theta\right)\Theta}{\partial s}\frac{\Delta}{\overline{z}}\varepsilon_{\Theta,t} + \frac{\partial\varepsilon_{\Theta,t}}{\partial s}\frac{\Delta}{\overline{z}} f\left(\Theta\right)\Theta\right]. \tag{99}$$

First, consider the effect of s on Δ. Using $z_\theta^j = (w^j\theta)^{1+\varepsilon}(1-t)^\varepsilon$, we arrive at

$$\frac{\partial \Delta}{\partial s} = -p(\Theta) + (1+\varepsilon)\frac{\partial \Theta}{\partial s}\Theta^\varepsilon t(1-t)(w^H - w^L) - sp'(\Theta)\frac{\partial \Theta}{\partial s} < 0 \tag{100}$$

$-p(\Theta)$ is the direct effect of a lower Θ on subsidy expenditures, which lowers Δ. In addition, an increase in s has indirect effects on Δ. Due to the lower Θ, the income differential between the marginally high- and low-skilled decreases. Moreover, expenditures on education subsidies increase further, since $-p(\Theta)$ increases as Θ falls. This adds to the drop in Δ. Numerically, we confirm $\partial\Delta/\partial s < 0$ (Table 6). Moreover, since $\overline{z}$ increases, we see a drop in $\Delta/\overline{z}$.

As with the tax rate, the impact of the subsidy on $\Theta f(\Theta)$ is theoretically ambiguous. Θ decreases, whereas the impact on $f(\Theta)$ depends on the density. Numerically, we find that the increase in $f(\Theta)$ more than compensates the drop in Θ, so that $\Theta f(\Theta)$ increases. Finally, how does the elasticity $\varepsilon_{\Theta,s}$ respond to an increase in s? Note that with exogenous wages, $\varepsilon_{\Theta,s} = \varsigma\rho$, with $\rho = \frac{s}{(1-s)(1+\varepsilon)}$. Since ς is not affected by s, and $\partial\rho/\partial s > 0$, $\varepsilon_{\Theta,s}$ increases with s. Still the overall impact on education distortions is theoretically ambiguous. Numerically, we find that education distortions decrease with s.

Wage-compression effects education subsidies $\rho(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$. Finally, we turn to the impact of s on wage-compression effects. A higher subsidy affects the income-weighted social welfare weights $\tilde{g}^L$ and $\tilde{g}^H$ via three channels: by changing the social welfare weights, by changing incomes, and by lowering Θ. A higher subsidy redistributes from the low-skilled to the high-skilled. The direct consequence is that consumption rises most for the marginally high-skilled individual (who faces the highest cost of higher education). Larger utility leads to a decline of social welfare weights for the high-skilled around Θ , due to the concavity of the social welfare function. In addition, the subsidy also affects consumption – and thus utility and social welfare weights – by changing incomes: as Θ falls, H/L increases and the wage differential w^H/w^L is compressed. These general-equilibrium effects raise consumption of the low-skilled workers, while decrease consumption of the high-skilled workers. For the low-skilled workers, the increase in w^L runs against the direct loss in consumption due to the higher subsidy. As a consequence, welfare weights for the low-skilled increase less than if there were no general-equilibrium effects on wages. The decrease in w^H partly offsets the gains of the high-skilled workers due to the larger subsidy. Moreover, the high-skilled workers with the highest ability benefited less from the larger subsidy, since they have low direct costs of higher-education. The same individuals experience the largest drop in consumption due to the decreased wage w^H. As a result, we expect social welfare weights to increase at high θ. Hence, taking all effects together, we expect an increase in $\tilde{g}^L$, whereas the effect on $\tilde{g}^H$ is unclear. The income weighting of the welfare weights suggests that the lower social welfare weights at the top compensate for the decrease around Θ, hence $\tilde{g}^H$ might increase as well. However, the income weights are also affected. As w^H falls, the income distribution among the high-skilled is compressed, and more so at the top. This raises $\tilde{g}^H$, since social welfare weights decline, and social welfare weights for workers with lower ability θ now receive relatively more weight. In contrast, among the low-skilled income dispersion increases with w^L, which raises g_θ at higher θ. This contributes to a drop in $\tilde{g}^L$. Finally, the drop in Θ affects $\tilde{g}^L$ and $\tilde{g}^H$ in the same way as SBTC, i.e., $\tilde{g}^L$ and $\tilde{g}^H$ increase if $\tilde{g}^L > g_\Theta > \tilde{g}^H$, which we find to be satisfied numerically. Overall, we find that the higher subsidy raises both $\tilde{g}^L$ and $\tilde{g}^H$, and since the increase in $\tilde{g}^H$ is more pronounced, $\tilde{g}^L - \tilde{g}^H$ decreases. The impact on the general-equilibrium elasticity ε_{GE} is theoretically ambiguous, since we cannot sign $\partial\delta/\partial s$. Numerically, we find that ε_{GE} decreases with s. Finally, the general-equilibrium term also changes with ρ, which increases in s. Numerically, we find this effect to dominate, such that $\rho(\tilde{g}^L - \tilde{g}^H)\varepsilon_{GE}$ becomes larger as s increases.

Combined effect. If the positive impact on wage-compression effects is large, the denominator of (96) might become negative. However, we find quantitatively that distortions on education decrease by more than the increase in wage-compression effects, and hence, the denominator is positive (compare the respective terms in Table 6).

Table 6: Ceteris paribus impact of changing s

	Initial	Change
Policy Variables		
b	1959.07	-136.57
s	0.60	0.30
t	0.37	0.00
SBTC Variables		
A	1.00	0.00
Θ	2.30	-0.21
w^L	563.72	23.74
w^H	634.45	-14.21
$\alpha^\dagger$	63.16	2.78
$(1-F(\Theta))^\dagger$	25.00	5.16
Distributional benefits of the income tax and education tax		
$\xi^\dagger$	17.85	-0.86
$\zeta^\ddagger$	0.89	0.45
$\zeta/\bar{z}^*$	0.08	0.04
Tax-distortions of skill-formation and decomposition		
$\frac{\Delta}{(1-t)\bar{z}} f(\Theta)\Theta\varepsilon_{\Theta,t}{}^\dagger$	-0.46	-1.08
Δ	-567.78	-2059.23
$\bar{z}$	10729.99	57.44
$\Delta/\bar{z}^\dagger$	-5.29	-19.06
$f(\Theta)^\dagger$	21.85	7.06
Θ	2.30	-0.21
$f(\Theta)\Theta^\dagger$	50.30	10.32
$\varepsilon_{\Theta,t}{}^\dagger$	10.84	-4.29
β	7.02	7.65
δ	2.07	0.25
$\delta(\beta-\alpha)$	13.24	19.32
Subsidy-distortions of skill-formation and decomposition		
$\frac{\Delta}{(1-t)\bar{z}} f(\Theta)\Theta\varepsilon_{\Theta,s}{}^\dagger$	-0.53	-10.09
$\varepsilon_{\Theta,s}{}^\dagger$	12.49	32.71
ρ	1.15	5.75
Wage (de)compression effects and decomposition		
$(\tilde{g}^L-\tilde{g}^H)\varepsilon_{GE}{}^\ddagger$	57.08	-21.03
$\rho(\tilde{g}^L-\tilde{g}^H)\varepsilon_{GE}{}^\ddagger$	65.78	182.94
$\tilde{g}^{L\dagger}$	104.22	1.03
$\tilde{g}^{H\dagger}$	69.27	2.24
$(\tilde{g}^L-\tilde{g}^H)^\dagger$	34.95	-1.21
$\varepsilon_{GE}{}^\dagger$	1.63	-0.57
g_Θ	0.94	0.02

Note: † Table entries have been multiplied by 100. ‡ Table entries have been multiplied by 1e+04. * Table entries have been multiplied by 1e+07.

Table 7: Ceteris paribus impact of changing t

	Initial	Change
Policy Variables		
b	1959.07	427.44
s	0.60	0.00
t	0.37	0.05
SBTC Variables		
A	1.00	0.00
Θ	2.30	0.02
w^L	563.72	-2.08
w^H	634.45	1.38
$\alpha^\dagger$	63.16	-0.26
$(1-F(\Theta))^\dagger$	25.00	-0.45
Distributional benefits of the income tax and education tax		
$\xi^\dagger$	17.85	-0.96
$\zeta^\ddagger$	0.89	-0.14
$\zeta/\bar{z}^*$	0.08	-0.01
Tax-distortions of skill-formation and decomposition		
$\frac{\Delta}{(1-t)\bar{z}} f(\Theta)\Theta\varepsilon_{\Theta,t}{}^\dagger$	-0.46	0.09
Δ	-567.78	159.45
$\bar{z}$	10729.99	-270.94
$\Delta/\bar{z}^\dagger$	-5.29	1.39
$f(\Theta)^\dagger$	21.85	-0.59
Θ	2.30	0.02
$f(\Theta)\Theta^\dagger$	50.30	-0.91
$\varepsilon_{\Theta,t}{}^\dagger$	10.84	0.28
β	7.02	-0.31
δ	2.07	-0.02
$\delta(\beta-\alpha)$	13.24	-0.76
Subsidy-distortions of skill-formation and decomposition		
$\frac{\Delta}{(1-t)\bar{z}} f(\Theta)\Theta\varepsilon_{\Theta,s}{}^\dagger$	-0.53	0.10
$\varepsilon_{\Theta,s}{}^\dagger$	12.49	0.33
ρ	1.15	0.00
Wage (de)compression effects and decomposition		
$(\tilde{g}^L-\tilde{g}^H)\varepsilon_{GE}{}^\ddagger$	57.08	-1.93
$\rho(\tilde{g}^L-\tilde{g}^H)\varepsilon_{GE}{}^\ddagger$	65.78	-2.22
$\tilde{g}^{L\dagger}$	104.22	-0.27
$\tilde{g}^{H\dagger}$	69.27	1.55
$(\tilde{g}^L-\tilde{g}^H)^\dagger$	34.95	-1.81
$\varepsilon_{GE}{}^\dagger$	1.63	0.03
g_Θ	0.94	0.01

Note: † Table entries have been multiplied by 100. ‡ Table entries have been multiplied by 1e+04. * Table entries have been multiplied by 1e+07.

G Robustness

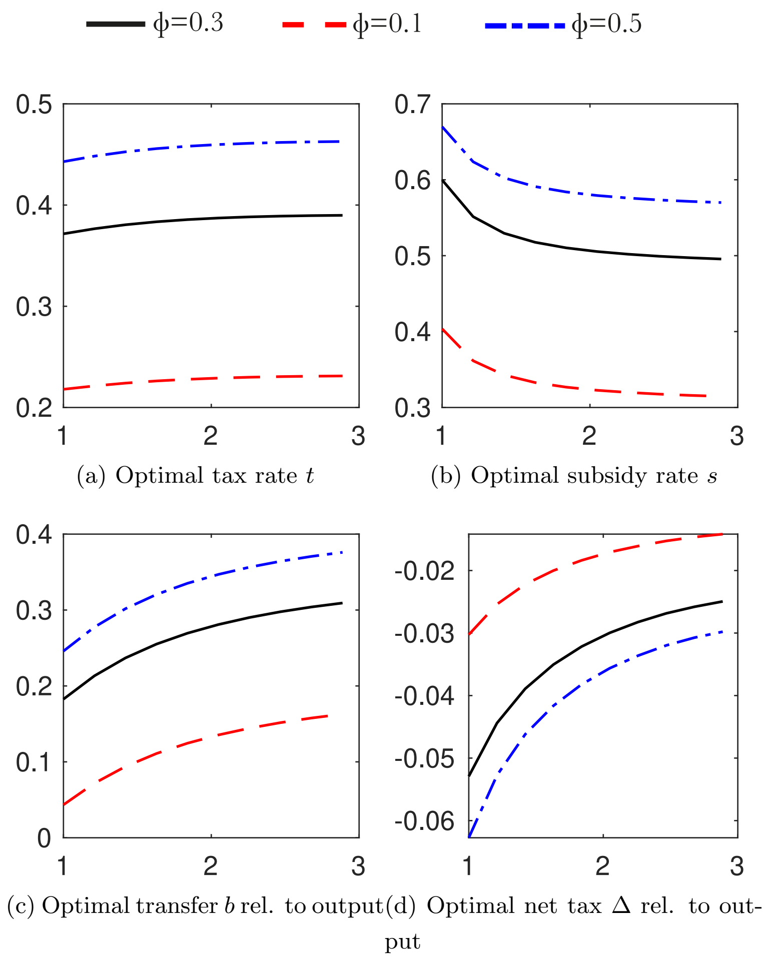


Figure 4: Optimal policy with SBTC - Robustness wrt. inequality aversion ϕ

Note: Skill-bias A on the horizontal axis.

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