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Special Issue: Essays on Inequality, Structural Change and Optimal Taxation

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Modern Macroeconomics and Heterogeneity

Macroeconomia Moderna e a Heterogeneidade

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ABSTRACT
Modern macroeconomics has evolved from focusing just on the dynamics of aggregates, such as income, consumption and savings, to the dynamics of the distributions that add up to those aggregates. This is a consequence of theoretical contributions and increasing data availability and computational power. Though contributions regarding heterogeneity in macroeconomics can be traced back to the first half of the 20th century, it is only by the 2010s that we evolved towards a framework where there is a rich interaction between macroeconomic aggregates and their distributions that goes both ways. This special edition focused on contributions that build on such framework to study open questions regarding the impact of fiscal shocks on output, the impact of investment-specific technological change on inequality, optimal tax structures, and the impact of the COVID-19 pandemic on the distribution of earnings.
Keywords: Macroeconomics; heterogeneity; fiscal policy; optimal taxation; inequality; COVID-19 pandemic.

JEL Classification: E62; E21; E13; E17.

RESUMO
A macroeconomia moderna evoluiu do foco apenas na dinâmica dos agregados, como rendimento, consumo e poupança, para a dinâmica das distribuições que constituem esses agregados. Isto é consequência de contribuições teóricas e do aumento da disponibilidade de dados e do poder computacional. Embora as contribuições relativas à heterogeneidade na macroeconomia possam ser encontradas desde a primeira metade do século XX, foi apenas na década de 2010 que se evoluiu para um quadro onde há uma rica interação entre agregados macroeconómicos e suas distribuições que se exprime nos dois sentidos. Esta edição especial é constituída por contribuições que se baseiam neste quadro conceptual e visam estudar questões em aberto sobre o impacto dos choques orçamentais sobre o produto, o impacto do progresso tecnológico dos bens de investimento na desigualdade, as estruturas fiscais ótimas e o impacto da pandemia COVID-19 na distribuição de rendimentos.

Palavras-chave: Macroeconomia; heterogeneidade; política orçamental; taxação ótima; desigualdade; pandemia da COVID-19.

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1. Introduction

Modern macroeconomics has expanded its focus from the study of aggregate variables such as income, consumption and wealth, to the dynamics of distributions of these variables (see Krueger et al. (2010)). Advances in computational methods and hardware and the greater availability of microdata has provided researchers not only the means to build, solve and simulate models that account in greater detail for characteristics that differ across agents (be it households, firms or other), but also the data do discipline them.

Rather than a revolution, seldom observed in the field of economics, the relevance of heterogeneous agent models has been growing in importance, in a slow but steady pace (see Cherrier (2018)). The most recent methodological contributions in macroeconomics have focused mainly on this, in particular on solution methods to heterogeneous agents new Keynesian (HANK) models.

The growth in importance of this class of models can only be partially justified by the greater availability of microdata and more powerful computational methods and hardware. This only tells the supply side of the story. There is also a demand side. First by the society at large. Macroeconomists have often been criticized by relying too much on the representative agent framework, (see Chancellor, 2017, for example), even if sometimes those critiques often depict the state of the art in macroeconomics research 20 or even 30 years before, as in the given example. Second, by the profession in itself. Following the words of Deaton (2016), *"While we often must focus on aggregates for macroeconomic policy, it is impossible to think coherently about national well-being while ignoring inequality and poverty, neither of which is visible in aggregate data"*, some questions cannot be properly addressed in representative agent frameworks. But Deaton (2016) goes beyond that and also claims that *"Indeed, and except in exceptional cases, macroeconomic aggregates themselves depend on distribution*".

This line of research has come a long way. Early work by Kaldor (1955) and Pasinetti (1962) focused on the distributional implications of economies with two types of agents, capitalists and workers. In this framework, agents are *ex-ante* different, and as such, heterogeneity is exogenous. In a similar fashion, models where agents feature life-cycle behavior started to be explored. Following Aliprantis, Brown, and Burkinshaw (1990), macroeconomic models where agents of different ages coexist, owes its intellectual origins to the works of Irvin Fischer (see Fisher (1930)). This inspired the work by Maurice Allais (see Malinvaud (1987)) and Samuelson (1958)), with the latter often considered the seminal paper given its rigorous formulation and characterization of an overlapping generations model. Later, Diamond (1965) introduced a neoclassical aggregate production function with two purposes, namely to examine the long-run competitive equilibrium in a growth model and then to explore the effects on this equilibrium, of government debt. It is also in this paper that Diamond shows that despite the absence of all the usual sources that can lead to inefficiency, the competitive solution can be inefficient.

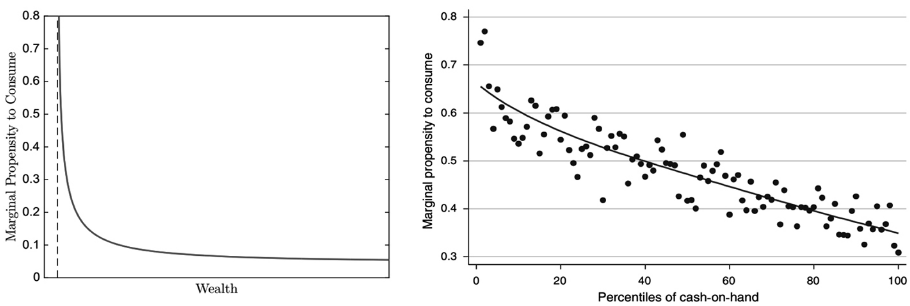
Despite the fact that age as a dimension of micro-heterogeneity preceded incomplete markets in being explored in macroeconomic models, contemporaneously the term heterogeneous agents model is typically used to refer to models of incomplete markets. These models feature uninsurable idiosyncratic risk and may include other sources of market incompleteness such as potentially binding credit constraints. The seminal reference in this class of models is Bewley (1980) who revisits the permanent income hypothesis in a stochastic endowment economy and no state-contingent bonds through which agents could insure against their idiosyncratic risk. Imrohoroğlu (1989) disputes the results in the classical paper on welfare costs of business cycles by Lucas (see Lucas (1987)) by studying an environment with indivisibilities and liquidity constraints. Huggett (1993) looks at precautionary behavior as an explanation of why the risk free interest rate in representative agent models was higher than what was observed in the data. Later Aiyagari (1994) showed that the aggregate implications of such channel are likely to be small. This paper was the first to provide a general equilibrium model with uninsurable idiosyncratic risk and borrowing constraints and remains the main reference for what is commonly referred to as the standard incomplete markets (SIM) model.

The next big methodological leap in the modeling of incomplete markets came with Krusell and Smith (1998) who provide an algorithm to solve models that feature both uninsurable idiosyncratic shocks and aggregate risk. In principle, the problem is infinitely dimensional, because the whole distribution of wealth in the economy becomes a state variable, and this is an infinite dimension object. In practice, however, Krusell and Smith (1998) show that using only one moment of the whole distribution – *average wealth* – sufficed to solve the model to a very high degree of accuracy. Of particular importance for some of the discussion ahead, Krusell and Smith (1998) use heterogeneity in discount factors to generate an empirically plausible wealth distribution. A few years later, Castaneda, Diaz--Gimenez, and Rios-Rull (2003) use the SIM model to also account for income and wealth inequality in the U.S. without resorting to heterogeneity in discount factors, but instead by estimating, within the model, income processes that generate moments of the observed distribution on wealth and income.

This first generation of incomplete market models provided macroeconomists with the methodological tools to study the distributional impacts of events at the macro level but the implications of micro-heterogeneity for the macro aggregates were just not quantitatively relevant. First, as mentioned above, despite the point that Huggett (1993) made regarding the role of precautionary behavior in response to uninsurable risk and its potential implications for the risk free rate, the macro impacts were found to be very small by Aiyagari (1994). Second, and most importantly, the results by Krusell and Smith (1998) – the fact that average capital, as opposed to the whole distribution of capital was enough to solve for the model – seemed to suggest that the micro-heterogeneity simply was not that relevant for aggregate dynamics. In fact, Lucas (2003) went as far as to say that *"For determining the behavior of aggregates, they* [Krusell and Smith (1998)] *discovered, realistically modeled household heterogeneity just does not matter very much"*.

One of the key reasons why this generation of models did not generate meaningful impacts from micro-heterogeneity into aggregate dynamics, had to deal with the fact that, though typically the models could account for the distribution of wealth and income and even other dimensions, it failed in accounting for the distribution of marginal propensities to consume (and to work), as Moll (2017) shows in the Figure 1 below, using data from Jappelli and Pistaferri (2014) on self- reported marginal propensities to consume.

Figure 1: Marginal Propensities to consume in a standard Aiyagari (1994) model and data



So far, the use of these models had been mostly to study the dynamics of real variables and their respective distributions. One would have to wait until Oh and Reis (2012) for the first general equilibrium incomplete markets model with nominal rigidities. The paper focused on the fiscal response to the Great Recession that, the authors show, was predominantly through the increase in government transfers. With this environment, the authors show that targeted lump-sum transfers are expansionary both because of a neoclassical wealth effect and because of a Keynesian aggregate demand effect. The first model with nominal rigidities and both aggregate and idiosyncratic risk was featured in McKay and Reis (2016), who use it to study the role of automatic stabilizers in the U.S. business cycle. This was, in effect, the first HANK model, despite the term being popularized only later by Kaplan, Moll, and Violante (2018). This new generation of models was praised by policy makers (see Yellen (2016) and Constâncio (2017) for example) as they provided a much greater role for micro-heterogeneity to have an impact on aggregate variables than the previous one. A key feature for this was precisely an addition of a number of extensions (such as illiquid assets as in Kaplan and Violante (2014)) that improved the empirical plausibility of marginal propensities to consume in this class of models and thus gave a much larger role to the micro-heterogeneity.

2. **Model Features**

In the series of essays that make this special issue, the baseline model is the one I have used with my co-authors in a series of papers, starting with Brinca et al. (2016), with some changes depending on the research question being asked. The main differences in the subsequent papers can be found in alternative wage processes, as well as alterning production technologies. In this section, I will start outlying the general model features, commenting on the rationale behind each part, and introduce the different specifications the following papers use. The mechanism that served as motivation for Brinca et al. (2016) is not an original contribution in itself. The point we wanted to make was that, using an unrealistic though stylized fiscal policy experiment in the literature a balanced-budget increase in government expenditures financed by a lumpsum tax, observable cross-country differences in the wealth distribution can lead to economically meaningful differences in fiscal multipliers. Following Heathcote (2005), the Ricardian insight, revisited by Barro (1974), is that if capital markets are perfect, taxes are lump-sum and households dynastic, the timing of taxes does not matter for households' consumption decisions. Hence, in a dynastic representative agent framework, differences in wealth distributions would not, by assumption, produce any difference in terms of fiscal multipliers, since Ricardian Equivalence would hold. However, we do know (as did Ricardo), that not only capital markets are not perfect, people also do live finite lives. So, if out to study the role of the wealth distribution in the response of the economy to fiscal policy shocks, one needs to take these features into account, both methodologically and for the sake of empirical relevance, as the literature seems to agree that budget deficits have non-negligible effects on both consumption and interest rates. This is a key motivation behind Brinca et al. (2016). Not the mechanism in itself the breaking of Ricardian Equivalence due to market incompleteness, something we know for a long time but its quantitative relevance, in particular in face of other relevant dimensions along which different economies also differ, be it social security systems, tax structures, etc.

Demographics

The economy is populated by overlapping generations of finitely lived households. The choice of an overlapping generations (OLG) structure is twofold. Recent work by Peterman and Sager (2016) makes the case for having a life-cycle dimension when studying the impacts of government debt. All households start life at age 20 and enter retirement at age 65. Let j denote the household's age. Retired households face an age-dependent probability of dying, $\pi(j)$ and die for certain at age 100.[1] A model period is 1 year, so there are a total of 45 model periods of active work life. We assume that the size of the population is fixed (there is no population growth). We normalize the size of each new cohort to 1. Using $\omega(j)=1-\pi(j)$ to denote the age-dependent survival probability, by the law of large numbers the mass of retired agents of age $j \geq 65$ still alive at any given period is equal to $\Omega = \prod_{q=65}^{q=j-1} \omega(q)$. There are no annuity markets, so that a fraction of households leave unintended bequests, which are redistributed in a lump-sum manner between the households that are currently alive. We use to denote the per-household bequest. Retired households' utility is increasing in the bequest they leave when they die. This helps us calibrate the asset holdings of old households.

Preferences

The momentary utility function of a household, $U(c,n)$, depends on consumption and work hours, $n \in (0,1)$, and takes the following form:

$$U(c,n) = \frac{c^{1-\sigma}}{1-\sigma} - \chi \frac{n^{1+\eta}}{1+\eta}$$

[1] This means that $J = 81$.

where σ and η pin down the coefficient of relative risk aversion and the Frisch elasticity, and χ scales the disutility of hours worked which helps us to match the average hours worked in the economy. In order to make the age profile of wealth empirically plausible, in Brinca, H. Ferreira, et al. (2019) we made it such households gain utility from the bequest they leave when they die, again scaled by φ:

$$D(k) = \varphi \log(k)$$

Note also that we allow for agents to have different time preference parameters β. As it will be clear in the calibration section of each of the applications, the number of different time preference parameters will be chosen by the number of moments in the wealth distribution that targeted.

Government

The government runs a balanced social security system where it taxes employees and the employer (the representative firm) at rates τ_{ss} and $\tilde{\tau}_{ss}$ and pays benefits, Ψ_t, to retirees. The government also taxes consumption and labor and capital income to finance the expenditures on pure public consumption goods, G_t, which enter separably in the utility function, interest payments on the national debt, rB_t, and a lump-sum redistribution, g_t. We assume that there is some outstanding government debt and that government debt-to-output ratio, $B_y = B_t / Y_t$, does not change over time in the stochastic steady state. Consumption and capital income are taxed at flat rates the τ_c and τ_k. To model the non-linear labor income tax, we use the functional form proposed in Benabou (2002) and recently used in Heathcote, Storesletten, and Violante (2017) and Holter, Krueger, and Stepanchuk (2017):

$$\tau_l(y) = 1 - \theta_0 y^{-\theta_1}$$

where y denotes pre-tax (labor) income and $\tau_l(y)$ the average tax rate given a pre-tax income of y. The parameters θ_0 and θ_1 govern the level and the progressivity of the tax code, respectively. Heathcote, Storesletten, and Violante (2017) argue that this function fits the U.S. data well.

In a steady state, the ratio of government revenues to output will remain constant. G_t, g_t, and Ψ_t must also remain proportional to output. Denoting the government's revenues from labor, capital, and consumption taxes by R_t and the government's revenues from social security taxes by R_t^{ss}, the government budget constraint in steady state takes the following form:

$$g\left(45 + \sum_{j \geq 65} \Omega_j\right) = R - G - rB$$
$$\Psi\left(\sum_{j \geq 65} \Omega_j\right) = R^{ss}$$

Labor Income

The wage of an individual depends on his/her own characteristics: age, j, permanent ability, $a \sim N(0, \sigma_a^2)$, and idiosyncratic productivity shock, u, which follows an AR(1) process:

$$u_{t+1} = \rho u_t + \epsilon_{t+1}, \qquad \epsilon \sim N(0, \sigma_\varepsilon^2)$$

These characteristics will dictate the number of efficient units of labor the household is endowed with. Individual wages will also depend on the wage per efficiency unit of labor w. Thus, individual 's wage is given by:

$$w_i(j,a,u) = we^{y_1 j + y_2 j^2 + y_3 j^3 + a + u}$$

y_1, y_2 and y_3 capture the age profile of wages. The wage w is determined by the first order condition specified in the technology section below.

Technology

The following papers use two distinct production functions. On the following we will illustrate the two distinct environments and call them model 1 and model 2 respectively. The last paper in this collection uses a variation of model 2, which will be explained in the respective paper, in detail.

Model 1

There is a representative firm, producing output with a Cobb-Douglas production function:

$$Y_t(K_t,L_t) = K_t^\alpha L_t^{1-\alpha}$$

where is the capital input and the labor input in efficiency units. The evolution of capital is given by:

$$K_{t+1} = (1 - \delta) K_t + I_t$$

where is gross investment and the capital depreciation rate. Each period, the firm hires labor and capital to maximize its profits:

$$\Pi_t = Y_t - w_t L_t - (r_t + \delta) K_t.$$

In a competitive equilibrium, the factor prices will be equal to their marginal products given by:

$$w_t = \partial Y_t / \partial L_t = (1 - \alpha)\left(\frac{K_t}{L_t}\right)^\alpha$$

$$r_t = \partial Y_t / \partial K_t - \delta = \alpha \left(\frac{L_t}{K_t} \right)^{1-\alpha} - \delta$$

Consequently, the wage rate in (7) will be determined by the first order condition (11).

Model 2

The second model differs from the one presented above in the production function employed. The economy still behaves in perfect competition, however a constant elasticity of substitution (CES) production function gathers the input capital (K), skilled (L_t^S) and unskilled labor (L_t^{NS}) to produce the final output Y_t. The factor Z_t describes an intermediate good which can be produced using either capital and skilled labor. The final output then combines the composite Z_t with unskilled labor to the final output as follows:

$$Y_t = F(A_t, N_t^{NS}, N_t^S) A_t (\phi_1 Z_t^{\frac{\sigma-1}{\sigma}} + (1-\phi_1) N_t^{NS, \frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}}$$

$$Z_t = (\phi_2 A_{k,t} K_t^{\frac{\rho-1}{\rho}} + (1-\phi_2) N_t^{S, \frac{\rho-1}{\rho}})^{\frac{\rho}{\rho-1}}$$

A_t refers to the technology level, $A_{k,t}$ refers to capital augmented technological level, ϕ_1 describes the share of the intermediate factor, ϕ_2 the share of capital within the intermediate factor, whereas ρ is the elasticity of substitution between capital and skilled labor and σ is the elasticity of substitution between composite factors and unskilled labor. This nested production function is similar to (Karabarbounis and Neiman 2013) and (Krusell et al. 2000) with capital and skilled labor acting as complements, whereas unskilled labor is a substitute with respect to the composite intermediate factor. As in the model 1, capital evolves according to the equation:

$$K_{t+1} = (1-\delta) K_t + I_t$$

Finally, perfect competition implies that in competitive equilibrium factor prices equal the marginal products:

$$r_t = \frac{\partial Y_t}{\partial K_t} - \delta = \left[A_t^{\sigma-1} Y_t \right]^{\frac{1}{\sigma}} \phi 1 Z_t^{\frac{\sigma-\rho}{\sigma\rho}} \phi_2 \left(\frac{1}{Kt} \right)^{\frac{1}{\rho}} - \delta$$

$$W_t^S = \frac{\partial Y_t}{\partial N_t^S} = \left[A^{\sigma-1} Y_t \right]^{\frac{1}{\sigma}} \phi_1 Z_t^{\frac{\sigma-\rho}{\sigma\rho}} (1-\phi_2) \left(\frac{1}{N_t^S} \right)^{\frac{1}{\rho}}$$

$$W_t^{NS} = \frac{\partial Y_t}{\partial N_t^{NS}} = (1-\phi_1) \left(\frac{A_t^{\sigma-1} Y_t}{N_t^{NS}} \right)^{\frac{1}{\sigma}}$$

In contrast to model 1, now there are two different wage rates. Depending on the individual providing skilled or unskilled labor the wage in equation (8) is substituted through the expression (17) and (18).

Recursive Formulation of the Household Problem

At any given time a household is characterized by (k, β, a, u, j), where k is the household's savings, β is the time discount factor that randomly takes up to four different lifetime values, a is permanent ability, u is the idiosyncratic productivity shock, and j is the age of the household. In the case of model 2, households furthermore are differentiated by their different skill level $s \in \{NS, S\}$ refering to non-skilled labor, and skilled labor. We can formulate the household's optimization problem over consumption, c, work hours, n, and future asset holdings, k', recursively as follows:

$$V(k, \beta, a, u, j) = \max_{c,k',n}[U(c, n) + \beta E_{u'} V(k', \beta, a, u, j + 1)]$$

s.t.

$$c(1 + \tau_c) + k' = (k + \Gamma)(1 + r(1 - \tau_k)) + g + Y^L$$

$$Y^L = \frac{nw(j, a, u)}{1 + \tilde{\tau}_{ss}}\left(1 - \tau_{ss} - \tau_l\left(\frac{nw(j, a, u)}{1 + \tilde{\tau}_{ss}}\right)\right)$$

$$n \in [0,1],\ k' \geq -b,\ c > 0$$

Here, Y^L is the household's labor income after social security taxes and labor income taxes. τ_{ss} and $\tilde{\tau}_{ss}$ are the social-security contributions paid by the employee and by the employer, respectively. The problem of a retired household, who has a probability $\pi(j)$ of dying and gains utility $D(k')$ from leaving a bequest, is:

$$V(k, \beta, j) = \max_{c,k'}[U(c, n) + \beta(1 - \pi(j))V(k', \beta, j + 1) + \pi(j))D(k')]$$

s.t.

$$c(1 + \tau_c) + k' = (k + \Gamma)(1 + r(1 - \tau_k)) + g + \Psi$$

$$k' \geq 0,\ c > 0$$

For model 2 we can formulate the recursive problem once for the skilled and the non--skilled individuals, both facing their respective factor prices. Besides this, the recursive formulation illustrated above remains unchanged.

Stationary Recursive Competitive Equilibrium

Let the measure of households with the corresponding characteristics be given by $\Phi(k, \beta, a, u, j)$. The stationary recursive competitive equilibrium is defined by:

Given the factor prices and the initial conditions the consumers' optimization problem is solved by the value function $V(k, \beta, a, u, j)$ and the policy functions, $c(k, \beta, a, u, j)$, $k'(k, \beta, a, u, j)$, and $n(k, \beta, a, u, j)$.

Markets clear:

$$K + B = \int k d\phi$$
$$L = \int \left(n\left(k, \beta, a, u, j\right)\right) d\phi$$
$$\int c d\phi + \delta K + G = K^{\alpha} L^{1-\alpha}$$

Whereas in model 2 there are two labor equilibrium conditions for skilled and non-skilled labor that need to be satisfied.

The factor prices satisfy either:

$$w = (1-\alpha)\left(\frac{K}{L}\right)^{\alpha}$$
$$r = \alpha\left(\frac{K}{L}\right)^{\alpha-1} - \delta$$

in model 1 or in model 2:

$$r_t = \left[A_t^{\sigma-1} Y_t\right]^{\frac{1}{\sigma}} \phi_1 Z_t^{\frac{\sigma-\rho}{\sigma\rho}} \phi_2 \left(\frac{1}{K_t}\right)^{\frac{1}{\rho}} - \delta$$
$$w_t^S = \left[A_t^{\sigma-1} Y_t\right]^{\frac{1}{\sigma}} \phi_1 Z_t^{\frac{\sigma-\rho}{\sigma\rho}} (1-\phi_2) \left(\frac{1}{N_t^S}\right)^{\frac{1}{\rho}}$$
$$w_t^{NS} = (1-\phi_1)\left(\frac{A_t^{\sigma-1} Y_t}{N_t^{NS}}\right)^{\frac{1}{\sigma}}$$

The government budget balances:

$$g \int d\phi + G + rB = \int \left(\tau_k r (k + \Gamma) + \tau_c c + n\tau_l \left(\frac{nw(a, u, j)}{1 + \tilde{\tau}_{ss}}\right)\right) d\phi$$

The social security system balances:

$$\Psi \int_{j \geq 65} d\phi = \frac{\tilde{\tau}_{ss} + \tau_{ss}}{1 + \tilde{\tau}_{ss}} \left(\int_{j < 65} nwd\phi \right)$$

The assets of the dead are uniformly distributed among the living:

$$\Gamma \int \omega(j)\, d\phi = \int (1 - \omega(j))\, kd\phi$$

3. Applications

In this section I describe the seven essays that follow as well as any departures from the baseline model that were needed. The first three focus on fiscal multipliers, namely the relationship between fiscal multipliers and labor tax progressivity; the relationship between the speed of consolidation programs and welfare; and the importance of asset liquidity for the fiscal policy transmission mechanism. In all three essays, the experiments are similar to the ones we did in Brinca et al. (2016), Brinca, Ferreira, et al. (2019) and Brinca, Faria-e--Castro, et al. (2019). The transmission mechanism hinges fundamentally on the aggregate response of labor supply to the fiscal shock. Since credit constrained agents behave like hand-to-mouth agents, their labor supply elasticity w.r.t. to income shocks, present and/or future, is different from wealthier agents whose consumption and leisure behavior will respond directly to changes in permanent income. Hence, the share of each type of agents in the economy will be a key factor driving the magnitude of the output response to the fiscal shock.

The second four applications are focused on the impacts of investment-specific technological change on inequality, and optimal tax structures. In this case, the production structure of the economy needs to be augmented to include different types of capital and labor inputs and technological processes. In particular the inclusion of technical change that will change the relative demand of distinct labor inputs according to their different degrees of substitutability/complementarity with capital. This setup is inspired by our work in Brinca et al. (2019). Here, the key insight is that optimal tax structures depend crucially on the degree to which income inequality arises from differences in uninsurable shocks versus permanent differences between individuals from the start (see Heathcote, Storesletten, and Violante (2017)), and that investment specific technological change, to the degree that the majority of workers does not change the type of occupation they perform during their life-course, has an impact on the permanent differences between individuals.

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The Impact of Labor Income Tax Progressivity on the Fiscal Multipliers in the Context of the Fiscal Consolidation

O Impacto da Progressividade dos Impostos Sobre o Trabalho nos Multiplicadores Orçamentais no Contexto de Consolidações Orçamentais

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ABSTRACT

Fiscal multipliers depend on several structural characteristics of each economy. In this study it is argued that labor income tax progressivity lowers the fiscal multipliers of fiscal consolidation programs. By calibrating an incomplete-markets, overlapping generations model for the United States for different values of the labor income tax progressivity, it is shown that as progressivity increases the recessionary impacts of fiscal consolidation are lower in the case of consolidation through decrease of government spending and are more recessionary in the case of consolidation financed with tax hikes.
Keywords: Fiscal multipliers; labor income tax progressivity; government spending; taxation.

JEL Classification: D52; H6; H21.

RESUMO

Os multiplicadores orçamentais dependem de várias características estruturais de cada economia. Neste estudo, argumenta-se que a progressividade do imposto de rendimento do trabalho reduz os multiplicadores fiscais dos programas de consolidação fiscal. Ao calibrar um modelo de gerações sobrepostas e de mercados incompletos para os Estados Unidos e para diferentes valores da progressividade do imposto sobre os rendimentos do trabalho, mostra-se que, à medida que a progressividade aumenta, os impactos recessivos da consolidação orçamental são menores no caso da consolidação por redução dos gastos governamentais, e são mais recessivos no caso da consolidação ser financiada com aumento de impostos.
Palavras-chave: consolidação orçamental; multiplicadores orçamentais; progressividade fiscal sobre os rendimentos do trabalho.

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1. Introduction

The aftermath of the 2008 financial crisis featured the emergence of fiscal consolidation programs across countries, in which the reduction or stabilization of government deficits and public debt derived from increased taxation or decreased government spending, or a combination of the two (Alesina et al., 2019).

The vast literature on the subject confirms the relevance of correctly assessing the impact of those programs on the economy, especially on output, represented by the fiscal multipliers. Even taking in consideration that the short-term effect of fiscal consolidation programs on growth is just one of the many aspects to consider when constructing fiscal policies (Blanchard and Leigh, 2013), an increasing literature related with the impact of fiscal policies on output translates how relevant is to correctly compute fiscal multipliers 1) to better design policies that reduce the risk of setting unachievable fiscal targets or miscalculating the amount of adjustment necessary to control the debt ratio (Eyraud and Weber, 2013); 2) in the context of substantial changes between stimulus and consolidation, fiscal policies may be one of the larger forces impacting output, which means that a correct forecast of the multipliers may lead to a better prediction of output growth. In fact, Blanchard and Leigh (2013) estimated that growth forecast errors were significantly related to under-estimation of fiscal multipliers (Batini et al., 2014).

Notwithstanding, there are great divergences in the size of the fiscal multipliers estimated in the literature. The lack of consensus reflects the degree of difficulty to compute fiscal multipliers, mainly due to the circularity presented in the relationship of the output with fiscal policies (Batini et al., 2014).

Nonetheless, there are already some outstanding results that can be assessed. Fiscal instruments affect differently the economy (more specifically output) according to the states of the economy in which they are employed. The instrument itself used also relates with different impacts in the economy. Also, several distinct aspects of each economy might change how fiscal policies impact output. Altogether, it results in a multiplicity of fiscal multipliers across time and economies (Blanchard and Leigh, 2013).

Jordà and Taylor (2013) documented that austerity has a more recessionary impact on output when applied in times of recession instead in a boom. They estimated that a 1% GDP consolidation represents a loss of 4% of real GDP over five years in the case of the first and only a loss of 1% in the case of the latter.

Gechert and Will (2012) registered that fiscal multipliers also depend on the instrument employed, being that fiscal consolidations based on government spending cuts, instead of tax hikes, are less recessionary. A result also supported by Alesina and Ardagna (2009).

Ilzetzki et al. (2011) study the determinants of fiscal multipliers, however in the context of fiscal stimulus (an increase of government consumption). Nevertheless, their findings still present to be relevant to this analysis. The authors find that the size of fiscal multipliers depend on structural characteristics of each economy, namely degree of openness, exchange regime flexibility, level of development, and level of public debt. More precisely, fiscal multipliers in open economies are lower than the ones on closed economies. The same applies in the case of industrial economies rather than developing ones. For countries with high public debts or operating in a flexible exchange regime, the fiscal multipliers resulting of an increase of government consumption, are close to zero. Openness to trade and public debt as determinants of the size of the fiscal multiplier are also documented in the case of fiscal consolidation by Cugnasca and Rother (2015) who state high degree of openness result in lower multipliers because aggregate demand is diluted through foreign demand and that lower government debt may imply larger multipliers.

Brinca et al. (2017) focus on the impact of income inequality on the multipliers and observed that the higher income inequality, the higher are the recessive impacts of fiscal adjustments.

Even the same measure can have different implications according to the magnitude. Brinca et al. (2019) find that there is no linearity in the response of output to a shock of government spending. More precisely that the fiscal multiplier is increasing with the shock.

This study contributes to the already existent research by raising the question of whether the multiplicity of fiscal multipliers across time and countries may be in part a reflection of differences in labor income tax progressivity. It studies the potential relationship between heterogeneity in labor income tax progressivity and the impact of fiscal policies on output, in the particular context of fiscal consolidation programs.

Such question is motivated by the theoretical relationship study in Brinca et al. (2017). The authors state the inability of constrained agents to smooth consumption facing an increase of future income as a result of lower debt-to-GDP ratio. As labor tax progressivity benefits comparatively the bottom agents by exempt them from paying taxes or to have more reduce rates, these agents have lower incentives to incur in precautionary savings, which entail a higher number of constrained agents. The positive relationship between constrained agents and labor tax progressivity leads, then, to lower multipliers.

The relation between progressivity and fiscal multipliers, in the case of increase government spending financed by an increase in lump-sum taxation, is documented in Brinca et al. (2016). It works again as a result of the limitations of borrowing constrained agents to face a change in income. Since constrained agents are not able to borrow from the future to smooth consumption, the lower disposable income today, due to higher taxes, will stimulate constrained agents to increase labor supply in order to keep consumption. Therefore, higher progressivity leads to larger fiscal multipliers. However, the authors conclude that the effect of tax progressivity on the multiplier is close to zero.

Considering spending multipliers, Ferriere and Navarro (2018) concluded that if the increase of government spending is financed by more progressive taxes, the spending multipliers are higher. That result is explained with the lower response of higher-income earners. Such agents do have a higher opportunity costs by ceasing work, which means that they respond less to tax changes, which in turn leads to smaller crowding-out effects. The authors find that the spending multiplier is positive only when financed with more progressive taxes, with a cumulative multiplier of between 0.8 and 1 after three years. Multipliers are initially negative and roughly zero after three years if taxes are regressive.

In order to study the impact of labor tax progressivity on fiscal multipliers, it is analyzed a model for the United States considering different levels of tax progressivity.

The remainder of the paper is organized as follows. Section 2 states some statistics about progressivity, Section 3 describes the fiscal experiment and transition, Section 4 the calibration method, Section 5, the results obtained and Section 6 concludes.

2. Statistics

Progressivity varies greatly across countries as can be observed in figure 1 in the appendix retrieved from OECD Journal (Joumard et al., 2012). The authors compute the overall progressivity index as well the progressivity of upper and lower ends of the income distribution. Regarding the higher end of the income distribution, Ireland, Sweden and Denmark stand out. While for the lower end the countries that stand out are: Luxembourg, Hungary and Belgium. As for the synthetic index it can be verified that Korea, Japan and Poland have comparatively lower progressivity and that the country of interest, U.S., presents lower progressivity than the OECD average although it has a slightly higher progressivity at the upper end.

Besides, the authors also analysed the evolution of tax progressivity between 2000 and 2009 and concluded that the tax schedule progressivity has been increasing for the majority of OECD countries.

3. Fiscal Experiment And Transition

The standard life-cycle model with heterogenous agents as it is employed in Brinca et al, (2017) and similar to the one developed in Brinca et al. (2016) is calibrated for the U.S. economy. The model follows the model 1 of the introduction. Moreover, in order to study the relationship between labor income tax progressivity and the impact of fiscal consolidation programs on output it is considered a fiscal experiment that consists of a 50 year of reduction in government debt, , financed through a decrease in government spending, G, by 0.2% of benchmark GDP or financed through an increase in labor income tax by 0.1% for all agents, as in Brinca et al. (2017). After 50 periods, regardless the instrument used, it goes back to initial levels.

To capture all the changes of the variables in the maximization problem found in Brinca (2020), another variable is considered, the time state variable (*t*). The method used to find the numerical solution of the model works by maximizing the problem backward after guessing the paths of all variables that depend on time. Afterwards the guess is updated. A similar method is used in Brinca et al. (2016) and Krusell and Smith (1999). A more comprehensive definition of the transition equilibrium after the fiscal consolidation is developed in the appendix.

Definition

The spending fiscal multiplier in the experiment of debt reduction financed by a reduction of G is the ratio of the change in output from period 0 to 1 to the change of government spending from period 0 to period 1:

$$impact\ multiplier\ G = \frac{\Delta Y_0}{\Delta G_0}$$

The impact multiplier resulting from a consolidation financed through increased labor income tax is the ratio of the change in output from period 0 to period 1 to the change in government revenue from period 0 to 1.

$$\textit{impact multiplier } \tau_l = \frac{\Delta Y_0}{\Delta R_0}$$

4. Calibration

The benchmark model delineated in Brinca (2020) is calibrated to match moments of U.S. economy ten times considering ten different levels of labor income tax progressivity θ_1, that are set constructing a uniform distribution between the lowest and one of the highest θ_1 in the data found in Brinca et al. (2017). The lowest θ_1 corresponds to the levels of progressivity of Slovakia of 0.105 and the highest θ_1 considered corresponds to the levels of progressivity of the Netherlands of 0.254. In between it is considered values of θ_1 of 0.1216, 0.1381, 0.1547, 0.1712, 0.1878, 0.2043, 0.2209, 0.2374.

The macro ratio debt-to-GDP (B/Y), the income profile parameters (y_1, y_2, y_3), the Social Security, Consumption and Capital Income Taxes ($\tilde{\tau}_{ss}$, τ_{ss}, τ_c, and τ_k), the parameters related with preferences: Inverse Frisch Elasticity (η) and the Risk aversion parameter (σ), and the parameters related with technology: the Capital share of output (α), the capital depreciation rate (δ), the persistence of the income shock (ρ), and the variance of ability (are all set exogenously complying with their corresponding data.

The macro ratio above mentioned is the average of net public debt from 2001-2008 (IMF) and has a value for the United States of 0.428. The income profile parameters are from the most recent Luxembourg Income Study (LIS) Database (2015) available before 2008 and give the value of 0.265, -0.005 and $3.6 * 10^{-5}$, respectively.

The Social Security Taxes are the average social security withholdings faced by the average earner (OECD) from 2001-7 and take the values of 0.078 and 0.077 respectively while the consumption and capital income taxes have values of 0.047 and 0.364 and are either taken from Trabandt and Uhlig (2011) or calculated using their approach, representing average effective tax rates form 95-07.

The unity inverse Frisch Elasticity complies with the reported values in the literature, such as Trabandt and Uhlig (2011) or Guner et al. (2016). The value of the risk aversion parameter comes as well from the literature and has a value of 1.2. Also, from the literature, are the capital share of output and the capital depreciation rate and take values such as: 0.33 and 0.06, respectively.

A persistence of idiosyncratic shock, ρ, of 0.335 is set according to the data of U.S. from the Panel Study of Income Dynamics (PSID) 1968-1997 and the variance of ability with a value of 0.423 is the corresponding to the European economies average from Brinca et al. (2016).

The logarithmic of the individual wages equation gives the life cycle profile of wages:

$$\ln(w_i) = \ln(w) + y_1 j + y_2 j^2 + y_3 j^3$$

To match the moment variance of log wages, it is calibrated the variance of the idiosyncratic risk, σ_u. Finally, the labor income tax function considered is described in the appendix and follows the equation proposed in Benabou (2002). For the U.S., Hans et al. (2017) estimate θ_0 and θ_1 to be 0.887867 and 0.137185, respectively.

Endogenously Calibrated Parameters

On the other hand, endogenously set using the simulated method of moments are the bequest utility (φ), the three different discount factors (β_1, β_2 and β_3) the disutility of work (χ), the borrowing limit (b) and the variance of risk (σ_u).

The goal is to minimize a loss function that is written as the difference between the moments in the model – *Mm* and the moments in the data – *Md*:

$$L(\varphi, \beta_1, \beta_2, \beta_3, b, \chi, \sigma_u = ||Mm - Md||$$

Since there are seven parameters endogenously calibrated it is necessary to have seven data moments in order to have an exactly identified system. The seven targets are the capital to output ratio K/Y, the fraction of hours worked $\bar{n}$, the variance of log wages Var(ln w), the ratio of the average net asset position of households in the age cohort 75 to 80 year old relative to the average asset holdings in the economy $\bar{a}_{75\text{-}80}/\bar{a}$, and the three wealth quartiles Q_{25}, Q_{50}, Q_{75}.

According to the Penn World Table 8.0, the capital to output ratio for the United States is 3.074 as for the average yearly hours, $\bar{n}$, the source is the OECD Economic Outlook, and it has a value of 0.248. The variance of log wages for the country in analysis is 0.509 retrieved from the LIS database. The share of wealth held by those between the 1st and the 25th percentile (Q_{25}) is 0.0141, the one held by those between the 1st and 50th percentile (Q_{50}) is 0.0044 and the one held by those between the 1st and 75th (Q_{75}) percentile is 0.1200. As the three quartiles, the ratio of the mean wealth detained by those between 75 and 80 years old to the mean wealth of the population is retrieved from the Luxembourg Wealth Study (LWS) and takes the value of 1.51.

For all cases of progressivity considered, the tax level is calibrated as well to keep the average tax rate constant. Table 1 shows the values obtained for θ_0:

Table 1: Values of that keeps average tax rate constant when changing

θ_1	0.1050	0.1216	0.1381	0.1547	0.1712	0.1878	0.2043	0.2209	0.2374	0.2540
θ_0	0.8817	0.8849	0.8879	0.8909	0.8935	0.8962	0.8985	0.9004	0.9026	0.9043

As mentioned above, the variance of idiosyncratic risk is calibrated to match the data moment of the variance of log wages. For all progressivity levels, σ_u is then 0.3065.

Moreover, calibrating such that the model matches the other data moments, the model value of $\bar{a}_{75\text{-}80}/\bar{a}$, K/Y, Var(ln w) and $\bar{n}$ are fitted to the millesimal. However, in the case of the Wealth Quartiles, the calibration fit varies considerably. Table 2 compiles the model values obtained.

Table 2: Calibration fit for the Wealth Quartiles

Q \ θ_1	0.1050	0.1216	0.1381	0.1547	0.1712	0.1878	0.2043	0.2209	0.2374	0.2540
Q_{25}	-0.0097	-0.0094	-0.0094	-0.0106	-0.0105	-0.0102	-0.0104	-0.0090	-0.0104	-0.0095
Q_{50}	0.0024	0.0024	0.0021	0.0002	0.0002	0.0010	0.0004	0.0013	-0.0002	0.0005
Q_{75}	0.1214	0.1210	0.1208	0.1207	0.1209	0.1207	0.1208	0.1208	0.1211	0.1209

Finally, the endogenously calibrated variables take the values as can be seen in Table 3:

Table 3: Parameter Values Estimated by SMM

	β_1	β_2	β_3	χ	b	φ
0.1050	0.9911	0.9370	0.8856	12.68	0.1255	5.645
0.1216	0.9912	0.9360	0.8858	12.495	0.1206	5.673
0.1381	0.9913	0.9356	0.8857	12.310	0.119	5.69
0.1547	0.9915	0.9369	0.8863	12.120	0.133	5.63
0.1712	0.9916	0.9359	0.8900	11.921	0.132	5.64
0.1878	0.9917	0.9238	0.9149	11.71	0.1287	5.661
0.2043	0.9918	0.9243	0.9150	11.505	0.1305	5.661
0.2209	0.99166	0.9310	0.8964	11.28	0.111	5.78
0.2374	0.9919	0.9245	0.9152	11.07	0.129	5.68
0.254	0.99185	0.9237	0.9133	10.843	0.117	5.75

Additionally, it is analysed a different exercise in which the model is not calibrated, but only the values of progressivity are changed as well the level of tax to keep the average tax rate constant, which takes the values outlined in Table 4.

Table 4: Values of θ_0 that keeps average tax rate constant when changing θ_1 when not recalibrating

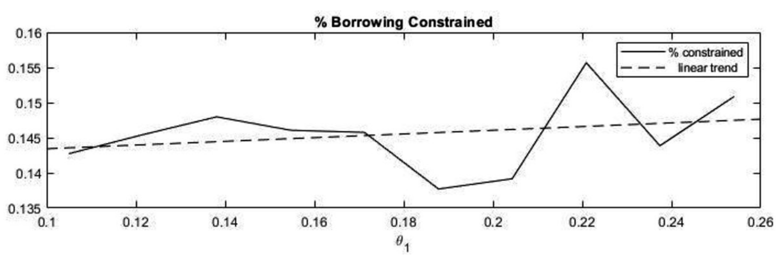
θ_1	.1050	0.1216	0.1381	0.1547	0.1712	0.1878	0.2043	0.2209	0.2374	0.2540
θ_0	0.8817	0.8849	0.8880	0.8909	0.8935	0.8960	0.8983	0.9005	0.9024	0.9042

5. Progressivity and Fiscal Consolidation

The structural model considers a debt-to-GDP reduction obtained to either a reduction of government spending or an increase in taxation. There is a path that occurs at the time of the reduction of government spending. The lower government debt leads households to invest in physical capital instead of saving. The higher physical capital increases the capital to labor ratio which means a higher future marginal product of labor. Then, the expected life-time income increases and, in its turn, it conducts to a decrease of labor supply and consequently a drop in output in the short-run. When tax progressivity increases, so does the percentage of borrowing constrained agents in the economy. Such agents face an impediment to decrease labor today from the higher expected life-time income. All in all, the multiplier, which gives the change in output over the change in spending, will become smaller as tax progressivity increases. An outcome driven from the lower decrease of output over the same change in government spending.

The mechanism study in the model links higher progressivity to lower precautionary savings and, consequently, higher number of constrained agents in the economy who will potentiate the process above mentioned. The model, calibrated for different values of progressivity, yields a weak positive relationship between the percentage of borrowing constrained agents in the U.S. economy and the progressivity of their tax system.

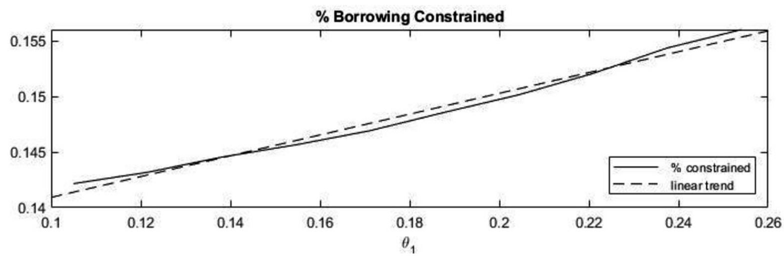
Figure 1: Borrowing constraint and progressivity



Note: Relationship between the percentage of borrowing constrained agents in the economy and progressivity when the model is calibrated.

Such relation becomes more pronounced if the endogenously calibrated parameters are left untouched and only the tax progressivity and the tax level (θ_1 and θ_0) are changed. As progressivity increases, so does the percentage of borrowing constrained.

Figure 2: Borrowing constraint and progressivity

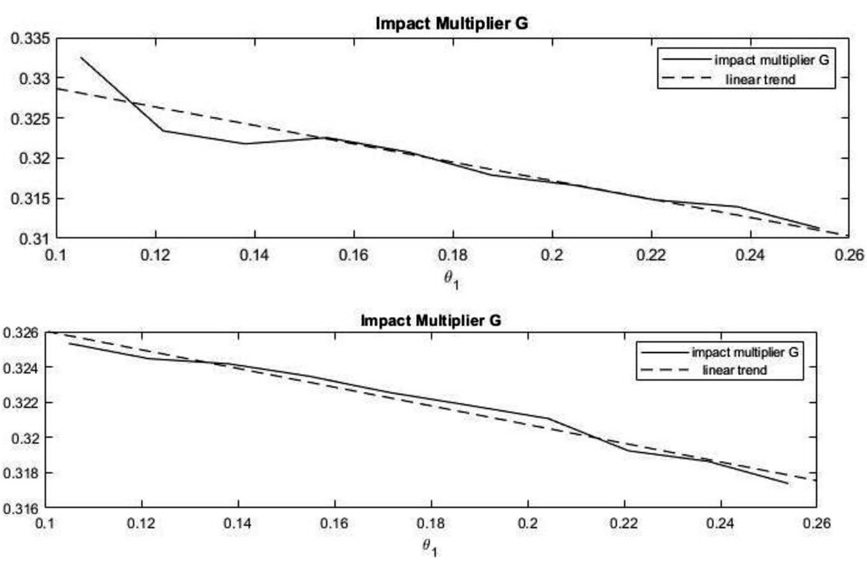


Note: Relationship between the percentage of borrowing constrained agents in the economy and progressivity when not calibrating.

Thus, the model corroborates the assumption that higher progressivity leads to a higher percentage of liquidity constrained agents in the economy.

The following analysis concerns the relation of progressivity with the multipliers. First, it is studied the interaction of progressivity and the spending multiplier in the scope of fiscal consolidation. As can be verified in the graph, as progressivity is increased the fiscal multiplier resulting from a decrease in government spending, decreases. This refers to the mechanism laid before.

Figure 3: Impact multipliers

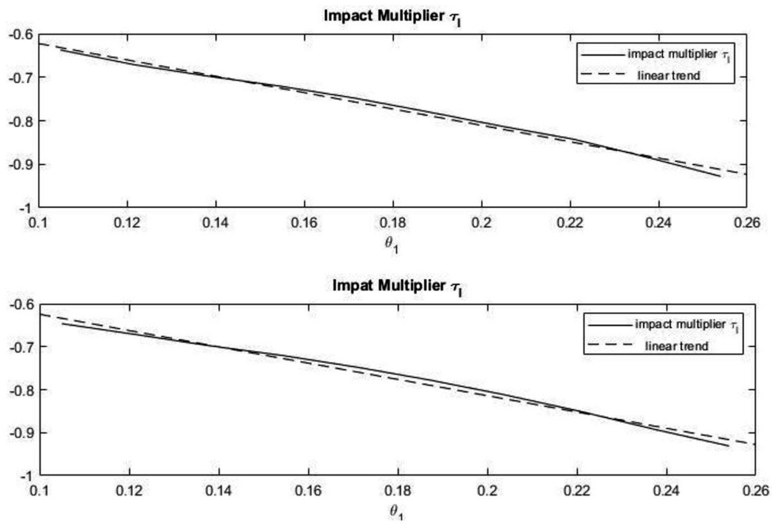


Note: Impact multiplier for the G-consolidation for different values of progressivity measure.
Upper panel: with recalibration. Lower panel: without recalibration.

The negative relationship is obtained in both exercises, calibrating the endogenous parameters (upper panel) and only changing tax progressivity and level (lower panel). That means that as progressivity increases, the recessionary impact of spending reduction is smaller.

As for the case of consolidation achieved through increased taxation, the multiplier is again smaller as progressivity increases, which in this case means that the recessionary impact is stronger. The association can be verified in figure 4.

Figure 4: Impact multipliers

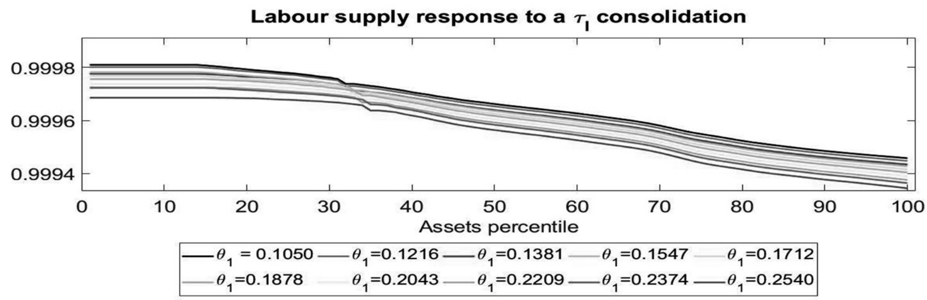


Note: Impact multiplier for the τ_l-consolidation for different values of θ_1 when the model is calibrated (upper panel) and without calibrations (lower panel).

The upper panel illustrates the results of the impact multiplier to a consolidation through tax increase, calibrating endogenously the parameters: φ, β_1, β_2 and β_3, χ, b and σ_u. The lower panel illustrates the results increasing progressivity and altering the tax level to keep the average tax rate constant.

The mechanism operating in this case is different from the one developed before. The labor supply response to a τ_l-consolidation, in other words the percentage of the labor supply after consolidation of the labor supply in steady state, is decreasing as progressivity increases. This means that all percentiles of the economy, from the poorer to the richer ones, decrease more their labor supply after the consolidation relative to the labor supply observed in the steady-state.

Figure 5: Labor supply responses



Note: Labor Supply Response to a τ_l consolidation for different values of progressivity measure.

Additionally, observing the income profile of average earning for each age it can be concluded that the expected life time income decreases for all age groups (Appendix).

The lower multiplier means then, that the higher θ_1 leads to higher distortionary effects in the economy, or in other words it diverges the economy away from optimality.

6. **Conclusion**

In conclusion, labor income tax progressivity lowers fiscal multipliers for both measures: lower government spending and higher taxes. However, if for the decrease of government spending a lower multiplier means that as progressivity increases the recessionary impact of fiscal consolidation programs is smaller, for the increase of taxes, a lower multiplier means that as progressivity increases the recessionary impact of fiscal consolidation are larger. After the analysis undergo by this paper in which a model with overlapping generations and incomplete markets is calibrated to the United States, proposing different values of progressivity and altering the tax level in order to keep average tax rate constant, it can be concluded that as progressivity increases so does the percentage of borrowing constrained agents in the economy. On the one hand, it means that after a debt reduction financed by a decrease in government spending, future income increases. It would mean that individuals would reduce their labor supply today, however borrowing constrained agents cannot borrow from the higher future income so they will not reduce their labor supply today. So, as the percentage of such agents increases, the spending multiplier is lower.

On the other hand, if the consolidation is obtained through an increase of taxes, it means that as progressivity increases the distortionary effects of taxes are larger. In that case the economy distances away from efficiency and the reduction of labor supply is bigger leading to lower fiscal multipliers.

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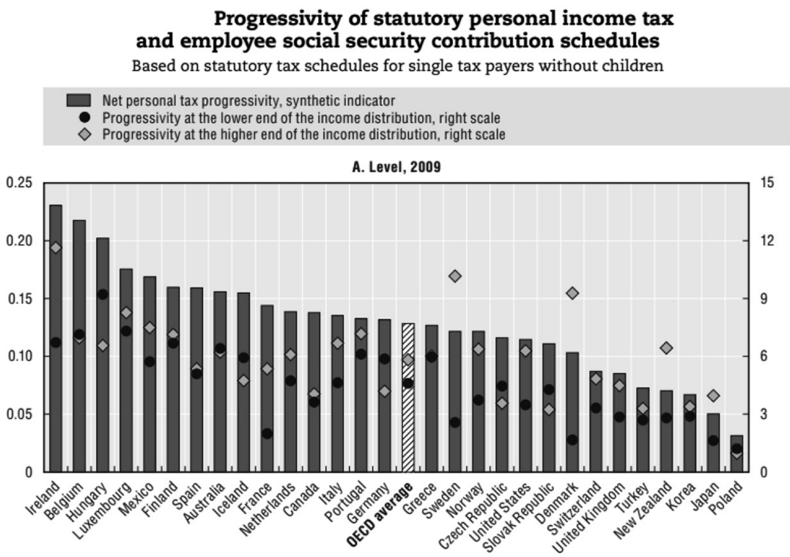
APPENDIX

Statistics

Figure 6: Taxation for a cross section of countries



Progressivity of statutory personal income tax and employee social security contribution schedules: Based on statutory tax schedules for single tax payers without children. Source: Joumard, Isabelle, Mauro Pisu and Debbie Bloch (2012), "Tackling income inequality: The role of taxes and transfers", OECD Journal: Economic Studies.

Tax Function[1]

Given the tax function

$$ya = \theta_0 y^{1-\theta_1}$$

which we employ, the average tax rate is defined as

$$ya = (1 - \tau(y))y$$

[1] This appendix is borrowed from Holter et al. (2019).

and thus

$$\theta_0 y^{1-\theta_1} = (1-\tau(y))y$$

or

$$1-\tau(y) = \theta_0 y^{-\theta_1}$$

$$\tau(y) = 1-\theta_0 y^{-\theta_1}$$

$$T(y) = \tau(y)y = y - \theta_0 y^{1-\theta_1}$$

$$T'(y) = 1-(1-\theta_1)\theta_0 y^{-\theta_1}$$

Thus the tax wedge for any two incomes (y_1, y_2) is given by

$$1-\frac{1-\tau(y_2)}{1-\tau(y_1)} = 1-\left(\frac{y_2}{y_1}\right)^{-\theta_1}$$

And therefore, independent of the scaling parameter θ_0. Thus, by construction one can raise average taxes by lowering θ_0 and not change the progressivity of the tax code, since (as long as tax progressivity is defined by the tax wedges) the progressivity of the tax code[2] is uniquely determined by the parameter θ_1.

Definition of a Transition Equilibrium After the Unanticipated Fiscal Consolidation Shock[3]

We define a recursive competitive equilibrium along the transition between steady states as follows:

Given the initial capital stock, the initial distribution of households and initial taxes, respectively K_0, Φ_0 and $\{\tau_l, \tau_c, \tau_k, \tau_{ss}, \tilde{\tau}_{ss}\}_{t=1}^{t=\infty}$, a competitive equilibrium is a sequence of individual functions for the household, $\{V_t, c_t, k'_t, n_t\}_{t=1}^{t=\infty}$, of production plans for the firm, $\{K_t, L_t\}_{t=1}^{t=\infty}$, factor prices, $\{r_t, w_t\}_{t=1}^{t=\infty}$, government transfers $\{g_t, \psi_t, G_t\}_{t=1}^{t=\infty}$, government debt, $\{B_t\}_{t=1}^{t=\infty}$, inheritance from the dead, $\{\Gamma_t\}_{t=1}^{t=\infty}$, and of measures $\{\Phi_t\}_{t=1}^{t=\infty}$ such that for all t:

[2] Note that $1-\tau(y) = \frac{1-T'(y)}{1-\theta_1} > 1-T'(y)$ and thus as long as $\theta_1 \in (0,1)$ we have that $T'(y) > \tau(y)$ and thus marginal tax rates are higher than average tax rates for all incomes.

[3] This appendix is borrowed from Brinca et al. (2017).

Given the factor prices and the initial conditions of the consumers' optimization problem is solved by the value function $V(k, \beta, a, u, j)$ and the policy functions, $c(k, \beta, a, u, j)$, $k'(k, \beta, a, u, j)$ and $n(k, \beta, a, u, j)$.

Markets clear:

$$K_t + B_t \int k_t d\Phi_t$$

$$L_t = \int \left(n_t (k_t, \beta, a, u, j)\right) d\Phi_t$$

$$\int c_t d\Phi_t + K_{t+1} + G_t = (1 - \delta) K_t + K_t^{\alpha} L_t^{1-\alpha}$$

Factor prices:

$$w = (1 - \alpha)\left(\frac{K_t}{L_t}\right)^{\alpha}$$

$$r = \alpha\left(\frac{K_t}{L_t}\right)^{\alpha - 1} - \delta$$

The government budget balances:

$$g \int d\Phi_t + G_t + r_t B_t$$

$$= \int \left(\tau_k r_t (k_t + \Gamma_t) + \tau_c c_t + n_t \tau_l \left(\frac{n_t w_t (a, u, j)}{1 + \tilde{\tau}_{ss}}\right)\right) d\Phi_t + (B_t + 1 - B_t)$$

The social security system balances:

$$\psi_t \int_{j \geq 65} d\Phi_t = \frac{\tilde{\tau}_{ss} + \tau_{ss}}{1 + \tau_{ss}}\left(\int_{j < 65} n_t w_t d\Phi_t\right)$$

The assets of the dead are uniformly distributed among the living:

$$\Gamma_t \int w(j)\, d\Phi_t = \int (1 - w(j))\, k_t d\Phi_t$$

Aggregate law of motion:

$$\Phi_{t+1} = Y_t(\Phi_t)$$

Expected Life-Time Income Per Age

Income Profile Average										
Age \ θ_1	0.1050	0.1216	0.1381	0.1547	0.1712	0.1878	0.2043	0.2209	0.2374	0.2540
20	0.3145	0.3119	0.3094	0.3069	0.3046	0.3023	0.3001	0.2978	0.2956	0.2933
21	0.3662	0.3629	0.3597	0.3565	0.3535	0.3504	0.3475	0.3445	0.3416	0.3386
22	0.4121	0.4084	0.4047	0.4012	0.3976	0.3941	0.3906	0.3872	0.3838	0.3803
23	0.4534	0.4493	0.4452	0.4412	0.4373	0.4332	0.4292	0.4252	0.4213	0.4173
24	0.4920	0.4875	0.4831	0.4786	0.4742	0.4697	0.4651	0.4604	0.4559	0.4512
25	0.5347	0.5297	0.5248	0.5197	0.5146	0.5095	0.5043	0.4990	0.4937	0.4884
26	0.5724	0.5668	0.5613	0.5557	0.5500	0.5444	0.5386	0.5328	0.5269	0.5209
27	0.6113	0.6050	0.5988	0.5925	0.5862	0.5799	0.5735	0.5671	0.5605	0.5539
28	0.6484	0.6415	0.6346	0.6277	0.6207	0.6137	0.6067	0.5996	0.5925	0.5852
29	0.6848	0.6772	0.6696	0.6620	0.6544	0.6467	0.6390	0.6312	0.6235	0.6156
30	0.7157	0.7074	0.6992	0.6909	0.6827	0.6745	0.6662	0.6579	0.6497	0.6412
31	0.7445	0.7358	0.7270	0.7182	0.7094	0.7006	0.6918	0.6830	0.6742	0.6653
32	0.7723	0.7630	0.7538	0.7444	0.7350	0.7257	0.7164	0.7070	0.6977	0.6883
33	0.7929	0.7833	0.7736	0.7639	0.7542	0.7444	0.7347	0.7250	0.7153	0.7056
34	0.8154	0.8052	0.7951	0.7849	0.7748	0.7646	0.7545	0.7443	0.7342	0.7240
35	0.8336	0.8230	0.8125	0.8019	0.7915	0.7810	0.7705	0.7600	0.7495	0.7390
36	0.8483	0.8374	0.8266	0.8158	0.8050	0.7942	0.7835	0.7727	0.7620	0.7513
37	0.8575	0.8464	0.8354	0.8244	0.8136	0.8026	0.7918	0.7808	0.7699	0.7590
38	0.8672	0.8560	0.8448	0.8335	0.8225	0.8114	0.8004	0.7892	0.7781	0.7670
39	0.8673	0.8560	0.8449	0.8337	0.8227	0.8116	0.8007	0.7896	0.7785	0.7675
40	0.8713	0.8600	0.8488	0.8375	0.8264	0.8153	0.8043	0.7932	0.7820	0.7709
41	0.8711	0.8597	0.8486	0.8374	0.8264	0.8153	0.8044	0.7933	0.7822	0.7711
42	0.8687	0.8575	0.8464	0.8353	0.8243	0.8134	0.8025	0.7914	0.7804	0.7694
43	0.8641	0.8530	0.8421	0.8311	0.8203	0.8095	0.7987	0.7878	0.7769	0.7660
44	0.8558	0.8449	0.8341	0.8233	0.8127	0.8020	0.7914	0.7807	0.7700	0.7593
45	0.8517	0.8409	0.8302	0.8196	0.8090	0.7985	0.7880	0.7774	0.7668	0.7561
46	0.8477	0.8370	0.8264	0.8158	0.8054	0.7949	0.7846	0.7740	0.7635	0.7530
47	0.8353	0.8250	0.8147	0.8044	0.7943	0.7842	0.7741	0.7639	0.7536	0.7434
48	0.8222	0.8121	0.8022	0.7922	0.7824	0.7726	0.7628	0.7529	0.7430	0.7331
49	0.8152	0.8053	0.7956	0.7857	0.7761	0.7664	0.7567	0.7470	0.7373	0.7275
50	0.8062	0.7966	0.7870	0.7774	0.7679	0.7584	0.7489	0.7393	0.7298	0.7202
51	0.7953	0.7859	0.7766	0.7672	0.7580	0.7487	0.7395	0.7302	0.7209	0.7115
52	0.7885	0.7794	0.7702	0.7611	0.7520	0.7429	0.7338	0.7247	0.7155	0.7063

Income Profile Average										
Age \ θ_1	0.1050	0.1216	0.1381	0.1547	0.1712	0.1878	0.2043	0.2209	0.2374	0.2540
53	0.7841	0.7751	0.7661	0.7570	0.7480	0.7390	0.7300	0.7210	0.7119	0.7028
54	0.7810	0.7721	0.7632	0.7542	0.7454	0.7364	0.7276	0.7186	0.7097	0.7006
55	0.7771	0.7683	0.7595	0.7506	0.7419	0.7331	0.7243	0.7154	0.7065	0.6976
56	0.7755	0.7667	0.7580	0.7493	0.7406	0.7319	0.7232	0.7143	0.7055	0.6966
57	0.7788	0.7700	0.7612	0.7525	0.7438	0.7350	0.7262	0.7173	0.7085	0.6996
58	0.7861	0.7772	0.7683	0.7594	0.7506	0.7417	0.7328	0.7238	0.7149	0.7058
59	0.7992	0.7900	0.7809	0.7718	0.7628	0.7536	0.7445	0.7353	0.7261	0.7168
60	0.8160	0.8066	0.7972	0.7878	0.7785	0.7690	0.7596	0.7501	0.7406	0.7310
61	0.8374	0.8276	0.8179	0.8082	0.7985	0.7888	0.7791	0.7693	0.7595	0.7496
62	0.8784	0.8678	0.8574	0.8469	0.8364	0.8259	0.8155	0.8049	0.7944	0.7837
63	0.9281	0.9164	0.9049	0.8934	0.8819	0.8704	0.8589	0.8474	0.8359	0.8242
64	0.9914	0.9781	0.9649	0.9516	0.9386	0.9255	0.9126	0.8996	0.8867	0.8736

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Fiscal Consolidation: Welfare Effects of the Adjustment Speed

Consolidação Orçamental: Impactos no Bem-Estar da Velocidade de Ajustamento

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ABSTRACT
This article studies the response of social welfare to fiscal consolidations, by focusing on a less debated characteristic of fiscal plans: the speed of deleveraging. A neoclassical overlapping generations model is calibrated to the German economy, and a sequence of reductions of the same size in the debt-to-GDP ratio are simulated considering different adjustment periods. Welfare gains are found to be larger in slow, delayed fiscal consolidations, due to the presence of incomplete markets. It is also found that the aggregate welfare response depends on the distribution of wealth and the type of fiscal instrument used.
Keywords: Fiscal consolidation; wealth inequality; incomplete markets.

JEL Classification: E13, E21, E62, H63.

RESUMO
Este trabalho estuda a resposta do bem-estar social à consolidação orçamental, focando-se numa característica menos debatida: a velocidade de desalavancagem. É calibrado um modelo neoclássico de gerações sobrepostas para a economia alemã, e é simulada uma sequência de reduções do mesmo tamanho no rácio da dívida face ao PIB, considerando diferentes períodos de ajustamento. Conclui-se que os ganhos de bem-estar são maiores em consolidações fiscais lentas e atrasadas devido à presença de mercados incompletos. Verifica-se também que a resposta agregada do bem-estar depende da distribuição da riqueza e do tipo de instrumento fiscal utilizado.
Palavras-chave: consolidação orçamental; desigualdade; mercados incompletos.

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1. Introduction

The 2008 Great Recession left behind a legacy in the form of the highest public debt burdens ever registered and[1], as of 2019, some of the world's most important economic areas such as the Eurozone still face debt-to-GDP ratios higher than 100%. These high levels of sovereign debt are associated with several economic issues, such as increased exposure to market sentiment, or the loss of flexibility in the implementation of fiscal policy, especially important as a stabilization mechanism in times where monetary policy is constrained by the low interest rate environment. Furthermore, as discussed in OECD (2010), in the near future government finances will face additional pressures due to the ageing of the population. Considering the issues at hand, there are arguments in favor of a further consolidation effort. However, reducing debt also has downsides, the most important being the recessive impacts it brings on the economy, extensively documented throughout the literature, e.g., Alesina et al. (2015b), Guajardo et al. (2014), Yang et al. (2015).

The design of fiscal plans is then a delicate task for policymakers, which must balance the pros and cons of reducing debt. This paper intends to add to the discussion on plan design, by focusing on an often-overlooked feature of fiscal consolidations, the speed of deleveraging. One can define speed as the decision of how long to extend a consolidation program, after the size of the debt reduction has been chosen. In other words, for a given debt reduction target, authorities can choose to pay debt quickly, or spread out the adjustment for a longer number of periods. The importance of considering this feature in fiscal plan design was highlighted by Blanchard and Leigh (2013). In their article, the authors criticized the lack of discussion on the timing of adjustments, presenting arguments in favor of both fast and slow consolidations. This work intends to bring this debate into formal research, by addressing the following questions: How do fiscal consolidations affect social welfare? What is the optimal speed for fiscal consolidations? Does the fiscal instrument used matters when defining speed?

To answer these questions, this work builds on the neoclassical macroeconomic model of Brinca et al. (2018), featuring heterogeneous agents and incomplete markets, to study the response of social welfare to fiscal consolidations and to different speeds of adjustment. Firstly, the model is calibrated to match key characteristics of the economy of Germany. Secondly, a sequence of fiscal consolidations consisting of 10 percentage points reductions in the debt-to-GDP ratio is performed. The reduction of debt is financed either with a decrease in government spending, or with an increase in the labor income tax. The number of periods (years) of adjustment is changed across simulations, and the social welfare implications of doing so are quantified. The number of years are chosen to vary between 5 and 70 years. This decision is made with basis on historical data on fiscal consolidations, obtained via the creation of a novel dataset, resulting from the merger of data included in Alesina et al. (2015a) and Alesina, Favero and Giavazzi (2015b).

Three main results arise from the experiments: i) Fiscal consolidations are welfare improving on the aggregate, but the welfare effects are heterogeneous across the wealth distribution. More concretely, due to lower real interest rates during the debt reduction path, borrowers

[1] Considering only non-war times.

win and savers lose out. The aggregate response depends on the relative strength of these effects. ii) Welfare improvements are larger in spending-based than in tax-based consolidations. iii) Ideally, the speed of fiscal consolidations should be as slow as possible. This is the case since credit constrained agents are unable to borrow in response to adjustments, and thus benefit from a more gradual adjustment path, which helps them achieve a better smoothing of consumption. The remainder of the paper is structured as follows: Section 2 discusses related literature. Section 3 deals with the calibration procedure along with relevant data sources. Section 4 introduces the dataset used to delimit the experiment range and details the profile of the fiscal experiments. Section 5 portrays the experiments' results while explaining the relevant macroeconomic dynamics that drive them. Section 6 concludes.

2. Literature Review

There are three branches of literature related with this work. i) Firstly, one that relates factors such as country characteristics or the fiscal instrument used with the consequences of fiscal consolidations. ii) Secondly, a more closely related branch that studies the welfare implications of fiscal consolidations, with basis on theoretical macroeconomic modelling. iii) Thirdly, a very narrow selection of papers that address the topic of the speed of fiscal adjustments.

i) Ilzetsky et al. (2013) found that the size of fiscal multipliers depended on country specific characteristics, such as the income level of the country, or the sovereign debt burden. Anderson et al. (2016) used a calibrated Keynesian model with sticky prices to show that economic agents responded differently to fiscal shocks, depending on individual characteristics such as age, income and wealth levels. In turn, Brinca et al. (2018) developed a neoclassical life-cycle economy to find that wealth levels and credit constraints were key factors in explaining heterogeneity in the impacts of consolidations. Alesina et al. (2015b) concluded that taxation-based consolidations originated larger recessive impacts than consolidations with basis on public spending decreases. The main takeaways in the scope of this work are that the impacts of consolidations are contingent on country characteristics, namely on wealth inequality, and also on the instrument used.

ii) The relationship between fiscal consolidations and social welfare is often studied with resource to macroeconomic modelling. Following the seminal contribution of Aiyagari (1994), most theoretical frameworks in nowadays' research admit agent heterogeneity and credit market incompleteness. Aiyagari and McGrattan (1998) built on this contribution to study the welfare implications of public debt, finding that opposite effects appeared. On the benefit side, higher debt loosened borrowing constraints and allowed for a better smoothing of consumption. On the negative side, however, public debt crowded out capital, hence lowering real wages. They finished concluding that the debt-to-GDP ratio that maximized welfare hovered around 2/3. More recently, Röhrs and Winter (2017) revisited this topic, finding that steady state welfare was at the maximum when the debt-to-GDP ratio was negative and around -0.8, in stark contrast with Aiyagari and McGrattan (1998). Their results were unlike since the calibration in Röhrs and Winter (2017) presented more realistic levels of wealth and earnings inequality, again showing the relevance of these variables in determining welfare effects. However, the authors also found that when considering the transition path to the new steady state, fiscal consolidations became welfare reducing, highlighting the importance of transitional analysis, and motivating the focus on this aspect in the present work.

iii) In general, the literature on optimal fiscal policy focuses on the welfare effects of debt, as seen in ii), with other components of the fiscal plan, such as the speed of debt reduction being less discussed. In this essence, Philippon and Roldán (2018) studied paths of reduction in government debt, finding that the optimal speed of adjustment varied amongst agents, depending on their asset position. Finnally, the paper that stands closest to this work is that of Romei (2017), which uses a calibrated, heterogeneous agents, incomplete markets neoclassical economy to study the welfare implications of the fiscal instrument and the speed of consolidation. The main finding is in accordance with Philippon and Roldán (2018), households' preference over the mix of speed and instrument of consolidation hinges on the distribution of wealth. Romei (2017) argued that the real interest path resulting from a certain combination of fiscal instrument and speed of adjustment would determine household preference over the shock. Wealth inequality again played a key role, as savers favoured an increasing path in the interest rate, while borrowers would rather face a decreasing one. In the own words of the author, these results led to the research only taking a positive view, describing the winners and losers, and absconding from commenting on optimal policy.

This paper intends to pick up where Romei (2017) left, by adding a normative facet to the analysis, with the goal to not only characterize the impacts of different plan speeds on welfare, but also to find an optimal policy for the speed of public debt reductions. In order to achieve a better characterization of optimal policy in a societal context, the model used is the one of Brinca et al. (2018), that relaxes the infinitely lived households assumption of Romei (2017) and considers a bequest motive for a better calibration of assets over the life-cycle.

3. Model And Calibration

On the following the model 1 of the introduction is employed. The model is calibrated to match the economy of Germany, using the methodology of Brinca et al. (2018). Germany was chosen as the proxy economy due to its relevance in the context of the EU. The calibration is divided in two steps. Firstly, there is a set of parameters for which there is available data and thus are introduced directly in the model. These are shown in Table 5 of Appendix. Secondly, there are unobserved parameters that must be calibrated endogenously, as there are no direct empirical counterparts. This second step is carried out using the simulated method of moments (SMM), and the resulting values for the parameters are shown in Table 6 of Appendix. The remainder of this section describes the most relevant steps in the calibration process.

Labor Income

The estimation of the life cycle profile of wages, equation 1, was retrieved from Brinca et al. (2018). Using data from the Luxembourg Income Study (LIS), they estimate the following regression for each country:

$$\ln(w_i) = \ln(w) + y_1 j + y_2 j^2 + y_3 j^3 + \epsilon_i,$$

where *j* is the age of individual *i* and the equilibrium real wage as determined by the marginal product. Naturally, there is no available data for the permanent ability, *a*, and idiosyncratic productivity shock, u, which integrate the error term, ϵ_i. The variance of the permanent ability, σ_a, and the persistence of the income shock, ρ, are assumed constant across countries and set equal to the values found by Brinca et al. (2016) in their calibration. Finally, taking these two parameters as a given, the variance of the idiosyncratic income risk, σ_u, is calibrated endogenously to match the model variance of wages with the correspondent value from the data, to be further explained below.

Preferences

The risk aversion coefficient, σ, is set equal to 1.2, a value consistent with the literature. In the same manner, the Frisch elasticity of labor supply is set equal to 1, in accordance with the recent pieces of Trabandt and Uhlig (2011) and Guner et al. (2014). The parameters for the disutility of work, χ, the coefficient of bequest utility, φ, the discount factors, $\{\beta_1, \beta_2, \beta_3\}$ and the borrowing limit, *b*, are all amongst the parameters calibrated endogenously.

Government

The level of taxation and the progressivity of taxes from the labor income tax function, θ_0 and θ_1, were also taken from Brinca et al. (2018), which uses U.S labor income tax data from the OECD for its estimation. The social security taxes paid by the employee and employer were calibrated using the average rates for each country from 2001 to 2007, with data also retrieved from the OECD. The tax on consumption and capital, t_c, t_k, were set for each country according to the values in Trabandt and Uhlig (2011).

Endogenously calibrated parameters

The following parameters don't have a direct empirical counterpart:$\{\varphi, \beta_1, \beta_2, \beta_3, b, \chi, \sigma_u\}$ As previously stated, these parameters must be calibrated endogenously, resorting to the Simulated Method of Moments. The method consists in minimizing the subsequent loss function[2]:

$$L(\varphi, \beta_1, \beta_2, \beta_3, b, \chi, \sigma_u) = || M_m - M_d ||$$

[2] The full expression of the loss function is depicted in appendix.

M_d corresponds to the data moment and M_m to the analogue model moment. The ensuing value of the loss function can be understood as the percentual error in the model calibration i.e. the distance of the model moments to the real-life data. As there are seven unknowns, seven data moments are necessary to have a just identified equation system. The chosen calibration targets, M_d, and the corresponding model moments, M_m are:

Table 1: Calibration Targets and Model Fit

Calibration target	Description	Data value	Model value
$\frac{K}{Y}$	Capital-output ratio	3.013	3.017
$\bar{n}$	Average hours worked per capita	0.189	0.189
Var ln(ω)	Variance of log wages	0.354	0.354
$\frac{\overline{W}_{75-80}}{\overline{W}}$	Mean wealth age 75-80 / Mean wealth	1.513	1.514
Q_1, Q_2, Q_3	Wealth Quartiles	-0.0036, 0.0273, 0.1788	-0.0057, 0.0245, 0.1799

Note: Data for Q_1, Q_2, Q_3 and $\frac{\overline{W}_{75-80}}{\overline{W}}$ was taken from the Luxembourg Wealth Study (LWS), while Var ln(ω) came from the Luxembourg Income Study (LIS). The capital-output ratio was retireved from the Penn World Table 8.0 and from the OECD Economic Outlook.

The targets concerning the wealth distribution, $\{Q_1, Q_2, Q_3\}$ and $\frac{\overline{W}_{75-80}}{\overline{W}}$, were chosen in order for the calibrated model to present a realistic distribution of wealth over the population and the life-cycle, respectively. Hours worked and the variance of wages are necessary to approximate labor market features to reality, especially important considering that in this model most short-run effects from fiscal shocks materialize through variations in the supply of labor. The capital-output ratio characterizes the production sector of the economy. The values of the endogenous parameters are then adjusted until the error given by the loss function is as small as possible. The simulated economy is calibrated with an error of 0.83%. The endogenously calibrated parameters are shown on Table 6 of Appendix.

4. **Fiscal Experiment**

4.1. Description

The calibration of Section 3 describes the steady-state equilibrium. The fiscal experiments depart from this equilibrium, and consist of 10 percentage points reductions in the debt-to-GDP ratio, $\frac{B_t}{Y_t}$, occurring during a different number of periods (years) in each experiment. The number of years in each simulation is denoted by the parameter . The experiment processes as follows: the reduction in government debt will be financed either through a decrease in government spending, G_t, or an increase in the labor income tax, τ_l. The government surplus in each period will correspond to $\frac{10}{N}$ per cent of that year's GDP, ensuring that the debt-to-GDP ratio is reduced at the same rate each year. This constant rate of adjustment will be denoted by "average yearly adjustment", A, and due to the linear relation with N, it is is considered an analogue measure of speed in the context of the experiments. After the N periods of adjustment are concluded, the value of government spending or the labor income tax rate go back to their initial levels. To reach a new steady state, it is assumed that the economy takes an additional $100 - N$ number of years, with the lumpsum transfer, g, set to clear the government budget.

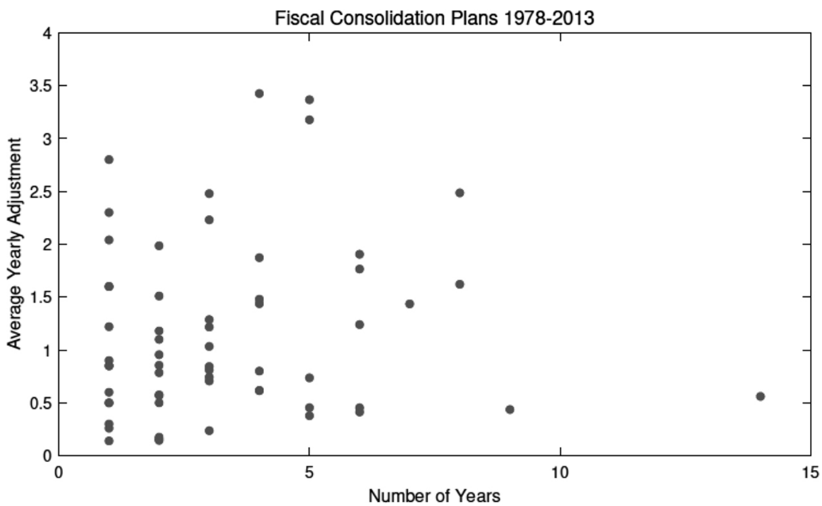
The formal definition of the transition equilibrium during the experiment is stated in Appendix. The difference in relation to the steady-state equilibrium is the presence of the state variable time, t. The numerical solution of the model involves guessing the paths for all time dependent variables, and then solving the maximization problem backwards, after which the guess is updated. This method is in line with Krusell and Smith (1999). The next section will define an empirically plausible range for the parameter governing the number of years of adjustment, N.

4.2. Empirical Background

The range for the parameter N was defined with basis on historical fiscal consolidation data. For that purpose, a dataset was constructed by merging data from Alesina, Favero and Giavazzi (2015b) with data from Alesina et al. (2015a). The first paper's data is based on the Devries et al. (2011) dataset on fiscal consolidations for 17 OECD countries, from the period 1978-2009. The second paper is a complement to the first, since for the same countries it depicts only data for the period 2009-2013, especially relevant due to containing the fiscal programs enforced during the 2010 European sovereign debt crisis. In both pieces, the authors use the "narrative approach" pioneered in Romer and Romer (2010) to identify exogenous fiscal consolidations. This approach selects fiscal consolidation episodes via a review of historical documents, choosing only the improvements in government finances caused by the direct intent to reduce deficits or debt. This way, all the variations in the improvements in government accounts caused by the business cycle or other types of governmental policy are filtered out. The final dataset containing 60 fiscal plans for 17 OECD countries during 1978-2013, along with methodological changes applied, can be consulted in Appendix. Figure 1 summarizes the dataset, by plotting the fiscal plans by both the number of years of consolidation, N, and the average yearly adjustment of each plan[3], A.

[3] From the data, the average yearly adjustment (A), was calculated in each plan by computing the average of the fiscal improvements as a % of GDP throughout the plan's years. It can be interpreted as the average pp reduction in the debt-to-GDP ratio each period, had government accounts been initially balanced and no other changes made to the budget other than the ones depicted by the consolidation data, in the same sense as it was defined in the context of the experiment. Please consult Appendix for a more detailed explanation.

Figure 1: Historical data on the speed of fiscal consolidations



To calibrate the speed of adjustment from empirical data, the average yearly adjustment, A, is chosen to define the upper and lower bounds for the debt repaying periods. It represents the speed of adjustment well since it shows the pace at which governments have reduced debt in a per year basis, in past consolidations. The maximum and minimum values ever registered, correspond to 3.43 in Portugal 2010-2013 and to 0.14 in USA 1978, respectively. Considering these rates of adjustment in the expression pioneered in Section 4.1[4], in the context of the experiment, N will be delimited by:

$$Min_N = \frac{10}{3.425} = 2.91 \qquad Max_N = \frac{10}{0.140} = 71.42$$

To simplify computations, the range will be normalized to $N \in [5; 70]$. Furthermore, due to the amount of time and computational effort to run each simulation, inside the defined range, simulations will be run for $N = \{5,10,20,50,70\}$. These simulations will be made, either with taxation, or spending. The results will be summarized and explained in Section 5.

[4] In the experiment, the average yearly adjustment formula corresponds to $A = 10/N$ and therefore, for a given level of A, the number of periods of adjustment is given by $N = 10/A$.

4.3. Definition of the Welfare Measure

The welfare measure used to compare the impacts of changing the number of years, N, across fiscal experiments, is the expected life-time social welfare at time t, and is defined as:

$$SW_t = E\big[V\big]_t = \frac{1}{\int d\Phi}\left[\int_{j<65} V(k,\beta,a,u,j)_t\, d\Phi + \int_{j\geq 65} V(k,\beta,j)_t\, d\Phi\right]$$

This measure is an average of the sum of life-time utility at time t, for all individuals in all generations. The goal is to compare initial steady-sate welfare at $t = 1$, with the corresponding welfare in $t = 1$ in a state of the world where the consolidation is put in practice. This way, the variation in the social welfare between the two states captures the average life-time utility gain (or loss) from the fiscal consolidation.

5. **Results**

This section details the results of the fiscal experiments, explaining the mechanisms that drive them. On a first stage, Section 5.1 focuses on the welfare effects of debt reductions, both in spending-based and tax-based consolidations. Section 5.2 follows, detailing how the welfare effects vary when the number of years of consolidation, N, is changed.

In the first section, the role of wealth inequality is highlighted as the main factor in explaining welfare gains (or losses) from the consolidations. More concretely, due to changes in the real interest rate during the adjustment, the wealth-poor and wealth-rich have opposite reactions to fiscal consolidations. Furthermore, they also disagree in the preference for the fiscal instrument. The aggregate welfare response will depend on the relative strength of the preferences among the two groups. In the second section, the presence of borrowing constrained agents is argued to be the main dictator of the aggregate response to different speeds of adjustment.

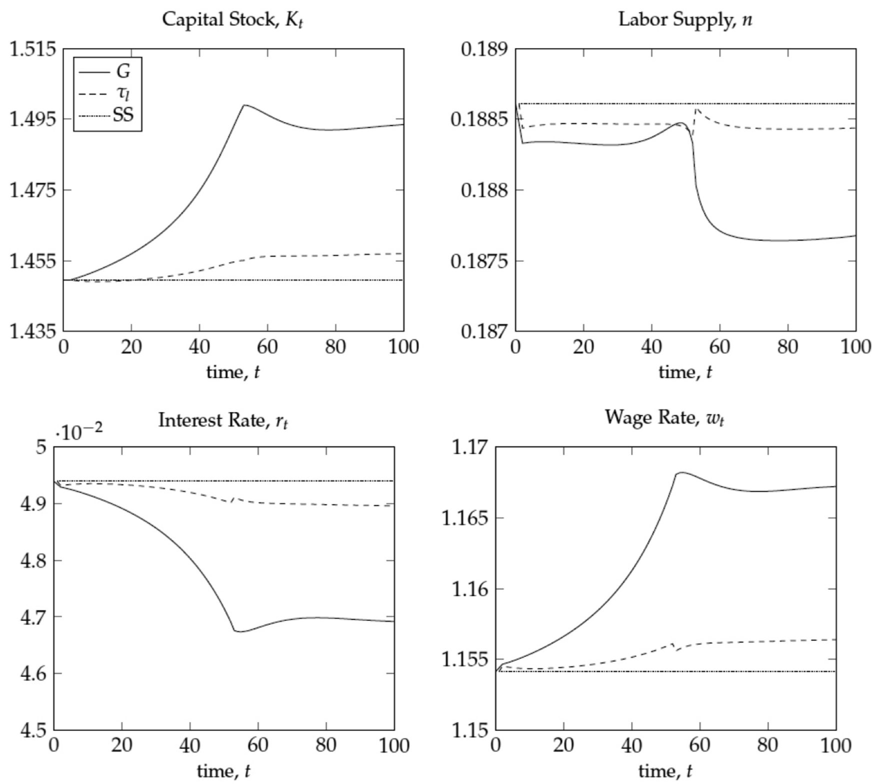
5.1. Welfare Effects Of Reducing Debt

This section will lay out the macroeconomic dynamics behind fiscal consolidations, and the intuition behind the ensuing welfare effects. As stated, to understand the aggregate variation, the welfare changes will be decomposed and evaluated by wealth group. The following discussion begins, considering firstly the case where the fiscal consolidation is spending-based, and then develops. The economy is initially in a steady state equilibrium when the government unexpectedly implements a fiscal consolidation, by decreasing expenditures, G. When authorities start running down debt, the saving pattern of households is affected. Foreseeing higher future income[5], households desire to reduce savings and consume more in each period. However, some of them are credit constrained, and thus, are unable to dissave as much as they wanted. As households can either save in the form of capital or government bonds, with savings decreasing by less than the fall in the amount of bonds, the capital stock will increase. In turn, this drives the economy's capital-to-labor ratio up. There is a crowding--in of capital. When each worker is equipped with a higher level of capital, its productivity increases, and, therefore, according to the market clearing condition, wages will be higher. Thus, the first main consequence of reducing debt is a rising path of wages. In turn, the path of wages generates both an income effect and an inter-temporal substitution effect on the supply of labor. Regarding the income effect, the prospects of a higher lifetime income induces households to decrease their supply of labor in each period, and enjoy more leisure. Besides this, workers will also desire to trade-off hours worked today for hours worked tomorrow, when wages will be higher. This is the inter-temporal substitution effect. Thus, labor supply contracts sharply on the short run, and then trends upwardly accompanying the growth of wages. This results in a fall in output in the short run, but in higher long run output, since both capital and labor will increase across time. Overall, lifetime consumption will be higher. In summary, labor market effects from consolidations increase welfare for the whole working population, since in each period they work less, while still benefiting from higher lifetime levels of consumption.

On the other hand, however, real interest rates are decreasing throughout the consolidation period. Higher levels of productive capital imply that the marginal productivity of the next unit of capital is lower, and, therefore, that the interest rates face a falling path during the consolidation. The relations described above can be observed in Figure 2, which plots the path of the capital stock, labor supply, the interest rate and the wage rate, during the transition period, for both a spending-based, and a tax-based consolidation spanning 50 periods.

[5] Both in spending-based and tax-based consolidations, when the debt repayment period is over, both G, and τ_l go back to the initial levels, while the interest payments of the government, rB_t, are smaller. This implies a higher level of government transfers, g, and thus, higher income.

Figure 2: Comparison between the transition paths of the capital stock, labor supply, interest rate and after-tax wage rate



Note: The comparison is between spending-based plans (smooth dark line), tax-based plans (dashed line) and the state of the world where the economy remains in the initial steady state (lighter straight line). The fiscal plan represented consists in a 10 percentage points reduction in the debt-to-GDP ratio, concluded in 50 periods, $N = 50$.

Contrary to the labor market effects, the impacts of lower interest rates on welfare are not as clear cut, as they depend on agents' asset position. Intuitively, borrowers will desire to face lower rates, while the opposite holds for savers. This way, wealth-poor agents benefit from reductions in debt, while the wealth-rich lose out. The aggregate response of welfare to a fall in the interest rate is then determined by the relative strength of the two groups. In this case, since the wealth-poor are also the consumption-poor, they have a higher marginal utility of consumption, that is, they value more one more unit of income than rich people and consequently their utility responds more strongly to variations in income. However, and by observation of Table 2 below, this effect is countered by the fact that the amount of capital income loss by the rich is also bigger than the capital gains by the poor, as their stock of positive wealth outweighs the negative stock of the poorest. Adding to this, rich individuals also lose via more expensive self-insurance[6]. Considering the opposite forces at hand, the effect of the fall in interest rates in aggregate welfare is ambiguous. Nonetheless, one can conclude that the fraction of the population that enjoyed welfare gains, was the one more reliant on labor income than capital income, corresponding to the first three wealth quintiles depicted below.

Table 2: Welfare Effects in a spending-based plan,

Quintiles	Wealth Level	Welfare
Q_1	-0.09 - 0.00	+0.2795%
Q_2	0.00 - 0.22	+0.2262%
Q_3	0.22 - 0.84	+0.1303%
Q_4	0.84 - 3.64	0.0494%
Q_5	3.64 - 15.13	0.1591%
Total		+0.0760%

Note: The wealth levels are interpretable only on a comparative basis, and not on absolute terms. Δ Welfare represents the response to changing from the initial steady state, to a state of the world where the consolidation is undertaken, with $N = 50$.

Although the individuals in the Q_2 and Q_3 have a positive level of wealth, and thus lose from lower interest rates, the capital losses are offset by the labor income gains they make due to higher wages. This is the case since they derive the primary source of income from working. In conclusion, due to the marginal utility effect, and due to the fact that there is a larger fraction of the population more dependent on labor income, there will be an aggregate welfare gain from the consolidation, despite the rich losing out.

Considering now consolidations where the government increases labor income taxation, τ_l. In this case, household's disposable income is directly affected by the government policy, and will be lower during the transition, in comparison with the spending-based consolidations. Since unconstrained households desire to smooth consumption, they will borrow more in initial periods, and thus savings will decrease. Due to this behavior, savings are reduced further than in spending-based consolidations, and the capital stock will be lower too. In turn, this implies a lower path of wages, and thus, a higher path of interest rates, in comparison with consolidations with G. These relations can be observed in the previously shown Figure 2. As seen from the previous analysis, these dynamics will prejudice the most labor income dependent agents and the wealth-poor, which constitute the larger fraction of society. Therefore, tax-based consolidations have lower aggregate welfare gains than spending-based consolidations. Notice also, that although the wealth-rich prefer tax-based

[6] When markets are incomplete, wealthier agents incur in precautionary behavior, since there are no insurance markets, hence 'incomplete markets'. Lower interest rates imply that agents get rewarded less for self-insurance, and thus lose out, see Aiyagari and McGrattan (1998).

consolidations, their welfare still decreases, as ideally for them the optimal would be for debt to increase. The results are summarized on Table 3 below.

Table 3: Welfare Effects in a tax-based plan, τ_l

Quintiles	Wealth Level	Welfare
Q_1	-0.09 - 0.00	+0.0496%
Q_2	0.00 - 0.22	+0.0400%
Q_3	0.22 - 0.84	+0.0229%
Q_4	0.84 - 3.64	0.0089%
Q_5	3.64 - 15.13	0.0281%
Total		+0.0134%

Note: The wealth levels are interpretable only on a comparative basis, and not on absolute terms. Δ Welfare represents the response to changing from the initial steady state, to a state of the world where the consolidation is undertaken, with $N = 50$.

The findings from the welfare analysis are remarkable: with debt reductions (or increases), governments have substantial redistributive power in hands. Via the wage and real interest rate effects, governments can influence which fraction of society wins or loses. Furthermore, in aggregate terms, consolidations with are more desirable than consolidations with , a finding that is in line with the literature, e.g. (Blanchard and Perotti (2002); Alesina et al. (2015b)), despite the rich and poor disagreeing on the instrument choice.

5.2. Welfare and the Speed of Fiscal Consolidations

Now that the dynamics of consolidations and the ensuing welfare effects are well understood, the explanation moves on to the timing of debt reductions. Straight away, the results from the simulations performed with a different number of adjustment periods are presented in Table 4, for both types of fiscal instruments.

Table 4: Welfare Effect and the Speed of Adjustment

Fiscal Instrument	Number of years of adjustment,				
	$N = 5$	$N = 10$	$N = 20$	$N = 50$	$N = 70$
Government Spending, G	0.0024%	0.0060%	0.0158%	0.0760%	0.1764%
Labor Income Taxation, τ_l	0.0004%	0.0011%	0.0027%	0.0134%	0.0337%

Note: Aggregate welfare variations from the initial steady state in $t = 1$, to the same period in the state of the world where the consolidation is undertaken, for different timings of debt reduction.

From observation, one concludes that welfare gains are at the maximum when the fiscal adjustment is extremely back-loaded, spanning the maximum number of periods available. In the context of the experiments, the optimal occurs when $N = 70$, but due to the corner nature of the solution, the optimal N would always be equal to the maximum number of periods available for deleveraging.

The mechanism that explains the results interlinks three features of the model: credit constraints, wealth inequality and the consumption smoothing hypothesis. As explained on the previous section, in response to the fiscal shock, individuals desire to dissave and to work less hours. While this verifies for unconstrained agents, this does not hold for two types of agents: the borrowing constrained and the wealth-poor. In the case of the constrained, they are unable to borrow anymore and thus are "hand-to-mouth". In the case of the wealth--poor, they respond less to future income changes because after starting to run down savings in response to the shock they will become constrained too. This way, both types of agents have a more rigid elasticity of labor supply, since they can't just decrease hours worked and borrow to compensate for it at will. For example, they are forced to work more hours during the transition path than they desire. Optimally, they would want to work less and borrow to maintain consumption stable, postponing working hours to later when the wage rates would become higher. As they are unable to do so, the trade-off between consumption and leisure is sub-optimal and even though the consolidation is beneficial for them, they lose out on some utility due to this inefficiency.

This is where the government plays a determinant role. By delaying the consolidation, the government makes the debt reduction path and the subsequent response of the macroeconomic variables inherently more smooth. If the adjustment is smoothed out for a longer number of periods, although the hand-to-mouth are still unable to borrow, their desire to do so is much smaller, as the per period shocks to income are lower. The slower the consolidation, the more credit constrained agents' behavior will resemble unconstrained ones, and thus, more optimal is the trade-off between consumption and leisure, increasing their utility. It is also important to revisit the fact that the borrowing constrained are the poorest of all individuals in the economy, and therefore boast the higher marginal utility of consumption. Thus, there are large aggregate gains to be made from a slower consolidation speed, via increased consumption and utility levels for hand-to-mouth agents and the wealth-poor.

6. **Conclusion**

This paper contributed to the literature on fiscal consolidations, by studying the welfare effects of debt reductions, with particular focus on a less studied feature of fiscal plans, the speed of deleveraging *i.e.* the number of years authorities take to achieve a given debt reduction target. To do so, a neoclassical macroeconomic model was calibrated to match key characteristics of the economy of Germany. Then, a sequence of reductions of the same size in the debt-to-GDP ratio was implemented in the simulated economy, with varying speeds of debt reduction in each simulation.

The experiments culminated in three main results: i) Fiscal consolidations have a positive aggregate effect on welfare, but the welfare effects are heterogeneous across the wealth distribution. The reason being that when debt is reduced, there is a positive welfare effect via higher wages, but an ambiguous aggregate effect via lower interest rates, which depends on the wealth position of households. While borrowers win, savers lose out. Overall, in the experimental economy consolidations are found to improve aggregate welfare since there is a larger fraction of the calibrated population reliant on labor income, with this fraction also being the one whose utility responds more strongly to marginal increases in income. The aggregate gains, come, however, at the expense of the the rich, which optimally desire no consolidation. ii) Welfare improvements are larger in spending-based than in tax-based consolidations, albeit the rich and the poor disagree on the preference for the fiscal instrument. iii) Ideally, the speed of fiscal consolidations should be slow, and the adjustment as smooth as possible. It is argued that by spreading the adjustment, the government helps credit constrained agents and the wealth-poor to smooth out consumption, which otherwise would be impossible due to the inability of these agents to borrow. As these individuals derive the most value from an additional unit of income, their utility increases substantially, and thus there are aggregate welfare gains to be made from slowing down the pace of adjustment.

Future expansions of this work will firstly consider relaxing the closed economy assumption. The welfare effects depicted depended on the direct influence of government debt on the economy's macro variables. With most countries nowadays having a large portion of debt owned by foreigners, the significance of this influence could be starkly reduced were the model set for an open economy. Still, there is empirical evidence for the predictions of the neoclassical model regarding government debt holding, see Laubach (2009). Furthermore, some of the next steps in this research would be to test the robustness of the mechanisms by calibrating the model to other economies, or to consider a different mix of fiscal instruments in testing the welfare response, such as capital or consumption taxation. Finally, a more advanced stage of this work could evolve to a New-Keynesian framework with nominal rigidities and a role for monetary policy.

In terms of real life policy implications, firstly, there is evidence for governments holding some redistributive power in debt reductions (or increases) via the real interest rate channel, when debt is nationally owned. This is especially relevant in the context of the 21st century, with wealth and income inequality being amongst the most hotly debated social and economic issues. Furthermore, this work is a further argument for the indebted OECD countries to implement a slow, gradual deleveraging process, and to take advantage of the current favorable market sentiment that will allow them to do so.

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APPENDIX

TAX FUNCTION

Given the tax function:[7]

$$ya = \theta_0 y^{1-\theta_1}$$

which we employ, the average tax rate is defined as

$$ya = (1- \tau(y))y$$

and thus

$$\theta_0 y^{1-\theta_1} = (1- \tau(y))y$$

implying that,

$$1- \tau(y) = \theta_0 y^{-\theta_1}$$

$$\tau(y) = 1- \theta_0 y^{-\theta_1}$$

$$T(y) = \tau(y)y = y - \theta_0 y^{1-\theta_1}$$

$$T'(y) = 1 - (1 - \theta_1)\theta_0 y^{-\theta_1}$$

Thus the tax wedge for any two incomes is given by:

$$1 - \frac{1 - \tau(y_2)}{1 - \tau(y_1)} = 1 - \left(\frac{y_2}{y_1}\right)^{-\theta_1}$$

and therefore independent of the scaling parameter θ_0. Thus by construction one can raise average taxes by lowering θ_0 and not change the progressivity of the tax code, since (as long as tax progressivity is defined by the tax wedges) the progressivity of the tax code.[8]

[7] This appendix is borrowed from Holter et al. (2019).

[8] Note that $1 - \tau(y) = \frac{1 - T'(y)}{1 - \theta_1} > 1 - T'(y)$ and thus as long as $\theta_1 \in (0,1)$ we have that $T'(y) > \tau(y)$ is uniquely determined by the parameter .

Calibration data

Table 5: Germany, Exogenously calibrated parameters

Description	Parameter	Value	Source
Preferences			
Inverse Frisch Elasticity	η	1.000	Trabandt and Uhlig (2011)
Risk aversion parameter	σ	1.200	Literature
Labor Income			
Parameter 1 age profile of wages	y_1	0.176	Brinca et al. (2016)
Parameter 2 age profile of wages	y_2	-0.003	Brinca et al. (2016)
Parameter 3 age profile of wages	y_3	0.000	Brinca et al. (2016)
Variance of permanent ability	σ_a	0.423	Brinca et al. (2016)
Persistence of idiosyncratic risk	ρ_u	0.335	Brinca et al. (2016)
Technology			
Capital Share of Output	α	0.330	Literature
Depreciation Rate	δ	0.060	Literature
Government and Social Security			
Consumption tax rate	τ_c	0.155	Trabandt and Uhlig (2011)
Capital income tax rate	τ_k	0.233	Trabandt and Uhlig (2011)
Tax scale parameter	θ_0	0.881	Brinca et al. (2018)
Tax progressivity parameter	θ_1	0.160	Brinca et al. (2018)
Government debt-to-GDP	$\frac{B}{Y}$	0.489	FRED
SS tax employers	$\tilde{\tau}_{ss}$	0.206	OECD
SS tax employees	τ_{ss}	0.210	OECD

Table 6: Germany: Endogenously calibrated parameters

Description	Parameter	Value
Discount Factor 1	β_1	0.951
Discount Factor 1	β_2	0.997
Discount Factor 3	β_3	0.952
Disutility of work	χ	16.93
Borrowing Limit	b	0.090
Variance of idiosyncratic risk	σ_u	0.439
Bequest utility	φ	0.36

Definition of the Transition Equilibrium

As in Brinca et al. (2018), between the initial and final steady states, the recursive competitive equilibrium is formally defined as follows:

Given the initial stock of capital, the initial distribution of households and tax system, denoted respectively by K_0, Φ_0 and $\{\tau_l, \tau_c, \tau_k, \tau_{ss}, \tau_{ss}\}_{t=1}^{t=\infty}$, a competitive equilibrium is a sequence of: i) individual functions for the household, $\{\widetilde{V}_t, c_t, k'_t, n_t\}_{t=1}^{t=\infty}$; ii) production plans for the firm $\{K_t, L_t\}_{t=1}^{t=\infty}$, factor prices,$\{r_t, w_t\}_{t=1}^{t=\infty}$, government transfers $\{g_t, \Psi_t, G_t\}_{t=1}^{t=\infty}$, government debt, $\{B_t\}_{t=1}^{t=\infty}$, inheritance from the dead, $\{\Gamma_t\}_{t=1}^{t=\infty}$ and of households $\{\Phi_t\}_{t=1}^{t=\infty}$ such that for all t:

Given the factor prices and the initial conditions the consumers' optimization problem is solved by the value function $V(k, \beta, a, u, j)$ and the policy functions $c(k, \beta, a, u, j)$, $k'(k, \beta, a, u, j)$ and $n(k, \beta, a, u, j)$.

Markets clear:

$$K_{t+1} + B_t = \int k_t d\phi_t$$

$$L_t = \int \left[n_t (k_t, \beta, a, u, j) \right] d\phi_t$$

$$\int c_t d\phi_t + K_{t+1} + G_t = (1 - \delta) K_t + K_t^{\alpha} L^{1-\alpha}$$

The factor prices satisfy:

$$w_t = (1 - \alpha)\left(\frac{K_t}{L_t}\right)^{\alpha}$$

$$r_t = \alpha\left(\frac{K_t}{L_t}\right)^{\alpha-1} - \delta$$

The government budget balances:

$$g_t \int d\phi_t + G_t + r_t B_t = \left[\tau_k r_t (k_t + \Gamma_t) + \tau_c c_t + n_t \tau_l \left(\frac{n_t w_t (j, a, u)}{1 + \tilde{\tau}_{ss}} \right) \right] d\phi_t + B_{t+1} - B_t$$

The social security system balances:

$$\Psi_t \int_{j \geq 65} d\Phi_t = \left[\frac{\tilde{\tau}_{ss} + \tau_{ss}}{1 + \tilde{\tau}_{ss}} \left(\int_{j < 65} n_t w_t d\Phi_t \right) \right]$$

The assets of the dead are uniformly distributed among the living:

$$\Gamma_t \int_{j < 65} d\Phi_t + \Gamma \int_{j \geq 65} \omega(j)\, d\Phi_t = \int (1 - \omega(g))\, k_t d\Phi_t$$

Aggregate law of Motion:

$$\Phi_{t+1} = Y_t(\Phi_t)$$

Dataset on Multi-Year Fiscal Plans (1978-2013)

Table 1 illustrates the merger of the data in Appendix of Alesina, Favero and Giavazzi (2015b) with the data on the Web Appendix of Alesina et al. (2015a), along with the modifications introduced in the scope of this work. There are two methodological changes compared with the authors' fiscal plans:

1. Years where the improvement in government finances was 0 were excluded. The authors report in the data years for which fiscal measures were announced for subsequent periods, but in which there was no consolidation. In coherence with the fiscal experiment, only positive shocks are considered as part of fiscal plans. The excluded data points are: Canada 1983, Denmark 2010, France 1988 and 1998, Spain 1991.

2. Years with negative fiscal adjustments were excluded, for the same reason as in point 1. The excluded data points are: France 1989 and 1999-2000, Germany 1998, Portugal 2003, Spain 1990, USA 1979, 1983-1984 and 1987.

In addition to the authors' data, Table 8 presents for each fiscal plan, the measures of speed detailed in Section 4.1, the number of years of the plan, N, and the average yearly adjustment, A. The average yearly adjustment (A), was calculated in each plan by computing the average of the fiscal improvements as a % of GDP throughout the plan's years. Below is an example of the calculations, for the fiscal plan Portugal 2010-2013.

Table 7: Portugal 2010-2013

Fiscal Plan	Years	Fiscal adjustment (%GDP)
Portugal 2010-2013	2010	1.16
	2011	3.94
	2012	5.20
	2013	3.40

$$A = \frac{1.16 + 3.94 + 5.20 + 3.40}{4} = 3.43$$

It can be interpreted as the average pp reduction in the debt-to-GDP ratio each period, had government accounts been initially balanced and no other changes made to the budget but the ones depicted by the consolidation data. This way, in the first period the debt-to--GDP would have improved by 1.16pp, in the second by 3.94 and so on. In these conditions, the debt-to-GDP ratio would improve, on average, 3.43 pp each year of the fiscal episode.

Table 8: Fiscal Plans Data 1978-2013

Fiscal Plans	Years	Fiscal adjustment (%GDP)	Average yearly adjustments	No. years
Australia 1985-1988	1985	0.45	0.6175	4
	1986	1.02		
	1987	0.9		
	1988	0.1		
Australia 1994-1999	1994	0.25	0.41	6
	1995	0.50		
	1996	0.62		
	1997	0.70		
	1998	0.37		
	1999	0.04		
Austria 1980-1981	1980	0.80	1.18	2
	1981	1.56		
Austria 1984	1984	2.04	2.04	1
Austria 1996-1997	1996	2.41	1.99	2
	1997	1.56		
Austria 2001-2002	2001	1.02	0.79	2
	2002	0.55		
Austria 2011-2013	2011	0.69	0.81	3
	2012	0.89		
	2013	0.85		
Belgium 1982-1985	1982	1.66	1.44	4
	1983	1.79		
	1984	0.69		
	1985	1.61		
Belgium 1987	1987	2.80	2.80	1
Belgium 1990	1990	0.60	0.60	1
Belgium 1992-1994	1992	1.79	1.29	3
	1993	0.92		
	1994	1.15		
Belgium 1996-1997	1996	1.30	0.86	2
	1997	0.41		

Fiscal Plans	Years	Fiscal adjustment (%GDP)	Average yearly adjustments	No. years
Belgium 2010-2013	2010	1.03	1.48	4
	2011	0.70		
	2012	2.46		
	2013	1.73		
Canada 1984-1997	1984	0.20	0.56	14
	1985	1.03		
	1986	0.99		
	1987	0.28		
	1988	0.30		
	1989	0.31		
	1990	0.86		
	1991	0.40		
	1992	0.21		
	1993	0.35		
	1994	0.49		
	1995	0.99		
	1996	0.97		
	1997	0.47		

Table 9: Fiscal Plans Data 1978-2013 (cont.)

Fiscal Plans	Years	Fiscal adjustment (%GDP)	Average yearly adjustment	No. years
Denmark 1983-1985	1983	2.77	2.23	3
	1984	2.38		
	1985	1.54		
Denmark 1995	1995	0.30	0.30	1
Denmark 2011-2013	2011	1.00	1.03	3
	2012	0.90		
	2013	1.20		
Finland 1992-1997	1992	0.91	1.91	6
	1993	3.71		
	1994	3.46		
	1995	1.65		
	1996	1.47		
	1997	0.23		

Fiscal Plans	Years	Fiscal adjustment (%GDP)	Average yearly adjustment	No. years
France 1979	1979	0.85	0.85	1
France 1987	1987	0.26	0.26	1
France 1991-1992	1991	0.25	0.18	2
	1992	0.10		
France 1995-1997	1995	0.28	0.71	3
	1996	1.34		
	1997	0.50		
France 2011-2013	2011	2.48	2.48	3
	2012	2.12		
	2013	2.84		
Great Britain 1979-1982	1979	0.27	0.62	4
	1980	0.08		
	1981	1.58		
	1982	0.53		
Great Britain 1994-1999	1994	0.83	0.45	6
	1995	0.28		
	1996	0.30		
	1997	0.79		
	1998	0.31		
	1999	0.21		
Great Britain 2010-2013	2010	0.40	0.80	4
	2011	0.92		
	2012	0.86		
	2013	1.02		
Ireland 1982-1988	1982	2.80	1.44	7
	1983	2.50		
	1984	0.29		
	1985	0.12		
	1986	0.74		
	1987	1.65		
	1988	1.95		

Table 10: Fiscal Plans Data 1978-2013 (cont.)

Fiscal Plans	Years	Fiscal adjustment (%GDP)	Average yearly adjustment	No. years
Ireland 2009-2013	2009	4.80	3.37	5
	2010	4.70		
	2011	3.32		
	2012	1.95		
	2013	2.06		
Italy 1991-1998	1991	2.77	2.49	8
	1992	3.51		
	1993	5.12		
	1994	1.43		
	1995	4.20		
	1996	0.35		
	1997	1.82		
	1998	0.68		
Italy 2010-2013	2010	0.42	1.87	4
	2011	1.47		
	2012	3.40		
	2013	2.20		
Japan 1979-1983	1979	0.12	0.38	5
	1980	0.21		
	1981	0.43		
	1982	0.71		
	1983	0.42		
Japan 1997-1998	1997	1.43	0.96	2
	1998	0.48		
Japan 2003-2007	2003	0.48	0.45	5
	2004	0.64		
	2005	0.28		
	2006	0.72		
	2007	0.15		

Fiscal Plans	Years	Fiscal adjustment (%GDP)	Average yearly adjustment	No. years
Netherlands 1981-1988	1981	1.75	1.62	8
	1982	1.71		
	1983	3.24		
	1984	1.76		
	1985	1.24		
	1986	1.74		
	1987	1.48		
	1988	0.05		
Netherlands 1991-1993	1991	0.87	0.84	3
	1992	0.74		
	1993	0.92		
Netherlands 2004-2005	2004	1.70	1.10	2
	2005	0.50		
Germany 1982-1984	1982	1.18	0.74	3
	1983	0.87		
	1984	0.18		

Table 11: Fiscal Plans Data 1978-2013 (cont.)

Fiscal Plans	Years	Fiscal adjustment (%GDP)	Average yearly adjustment	No. years
Germany1991-1995	1991	1.11	0.74	5
	1992	0.46		
	1993	0.11		
	1994	0.91		
	1995	1.09		
Germany 1997	1997	1.60	1.60	1
Germany 1999-2000	1999	0.30	0.50	2
	2000	0.70		
Germany 2003-2004	2003	0.74	0.57	2
	2004	0.40		
Germany 2006	2006	0.50	0.50	1
Germany 2011-2012	2011	0.43	0.58	2
	2012	0.72		
Portugal 1983	1983	2.3	2.3	1
Portugal 2000	2000	0.50	0.50	1

Fiscal Plans	Years	Fiscal adjustment (%GDP)	Average yearly adjustment	No. years
Portugal 2005-2007	2005	0.60	1.22	3
	2006	1.65		
	2007	1.40		
Portugal 2010-2013	2010	1.16	3.43	4
	2011	3.94		
	2012	5.20		
	2013	3.40		
Spain 1983-1984	1983	1.90	1.51	2
	1984	1.12		
Spain 1989	1989	1.22	1.22	1
Spain 1992-1997	1992	0.70	1.24	6
	1993	1.10		
	1994	2.40		
	1995	0.74		
	1996	1.30		
	1997	1.20		
Spain 2009-2013	2009	0.30	3.18	5
	2010	2.90		
	2011	2.54		
	2012	3.80		
	2013	6.35		
Sweden 1984	1984	0.90	0.90	1
Sweden1993-1998	1993	1.81	1.77	6
	1994	0.78		
	1995	3.50		
	1996	2.00		
	1997	1.50		
	1998	1.00		

Table 12: Fiscal Plans Data 1978-2013 (cont.)

Fiscal Plans	Years	Fiscal adjustment (%GDP)	Average yearly adjustment	No. years
USA 1978	1978	0.14	0.14	1
USA 1980-1981	1980	0.06	0.15	2
	1981	0.23		
USA 1985-1986	1985	0.21	0.16	2
	1986	0.10		
USA 1988	1988	0.85	0.85	1
USA 1990-1998	1990	0.33	0.44	9
	1991	0.58		
	1992	0.53		
	1993	0.32		
	1994	0.90		
	1995	0.53		
	1996	0.29		
	1997	0.30		
	1998	0.15		
USA 2011-2013	2011	0.04	0.24	3
	2012	0.14		
	2013	0.53		

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Asset Liquidity and Fiscal Consolidation Programs

Liquidez dos Activos e Programas de Consolidação Orçamental

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ABSTRACT
We argue that the relationship between wealth inequality and fiscal multipliers depends crucially on the type of fiscal experiment used, and on the measure of wealth distribution. We calibrate an overlapping generations model with incomplete markets for different European economies and use Household Finance and Consumption Survey (HFCS) data to compare fiscal multipliers when models are calibrated to match the distribution of gross vs. net wealth. We find a negative relationship between fiscal multipliers and wealth inequality when considering fiscal consolidation programs, in contrast to fiscal expansion experiments which are standard in the literature. The underlying mechanism relies on the relationship between the distribution of wealth and the share of credit-constrained agents. We examine the role of household balance sheet compositions regarding asset liquidity and find that when calibrating the model to match liquid wealth, the relationship between wealth inequality and fiscal multipliers is much stronger.
Keywords: Fiscal consolidation; wealth inequality; fiscal multipliers.

JEL Classification: E21; E62; H31; H63.

RESUMO
Defende-se neste estudo que a relação entre desigualdade e multiplicadores fiscais depende crucialmente do tipo de instrumento fiscal usado, bem como da medida da distribuição de riqueza. Calibramos um modelo de mercados incompletos e gerações sobrepostas para diferentes economias europeias e usamos os dados do Inquérito às Finanças e Consumo das Famílias (HFCS) para comparar os multiplicadores fiscais quando os modelos são calibrados para corresponder à distribuição da riqueza líquida versus ilíquida. Existe uma relação negativa entre os multiplicadores fiscais e a desigualdade de riqueza ao considerar os programas de consolidação orçamental, em contraste com os experimentos de expansão orçamental que são mais comuns na literatura. O mecanismo subjacente depende da relação entre a distribuição da riqueza e a parcela dos agentes com restrições de crédito. Examinamos o papel das composições do balanço patrimonial das famílias em relação à liquidez dos ativos

e apurou-se que, ao calibrar o modelo para combinar a riqueza líquida, a relação entre a desigualdade e os multiplicadores fiscais é muito mais significativa.
Palavras-chave: Consolidação orçamental; desigualdade de riqueza; multiplicadores orçamentais.

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1. Introduction

The 2008 financial crisis brought a renewed interest in fiscal policy. Until 2008, the debate around monetary policy effects dominated over fiscal policy. One of the reasons, according to Ramey (2011) was the belief that fiscal policy typically has a more substantial implementation lag than monetary policy. When the effects of fiscal policy materialize, the economy can be in a different state of the economic cycle, and the consequences can be opposite to what was intended. However, historically low nominal interest rates limited the role for conventional monetary policy, and fiscal policy was brought back to the center of the policy agenda. At the same time, European economies also faced historically high sovereign debt levels which, combined with the fall in output and the rescue of the financial system in the aftermath of the Great Recession of 2008, threatened the sustainability of public finances and lead to a series of austerity packages which had impacts that were mostly unanticipated and different across countries (see Blanchard and Leigh (2013)).

Alongside the renewed interest in fiscal policy, the topic of inequality has recently raised interest among scholars and the general public. Piketty (2014) in the book *Capital in the Twenty-First Century* presented a historical perspective of income and wealth distribution and its determinants.[1] In fact, wealth inequality has been rising over the past decades. On top of that, there have been significant differences in the increase in income and wealth inequality across countries (see Atkinson and Morelli (2012)).

Recent contributions highlighted the relevance of income and wealth inequality for fiscal policy. Brinca et al. (2016) show that observable differences in income and wealth distributions across countries can lead to economically meaningful differences regarding the impact of a one-time increase in government expenditures financed by a one-time decrease in lump-sum transfers. Higher wealth inequality leads to a distribution with fatter tails and consequently more credit constrained agents, which have a larger labor supply elasticity w.r.t. a current negative income shock. Röhrs and Winter (2017) focus on the welfare implications of reducing government and also find that the optimal path of debt reductions depends on the wealth distribution and the corresponding share of credit constrained agents. Brinca et al. (2017) show that cross-country differences in income inequality can account for significant differences in the observed impacts of fiscal consolidation programs. This same mechanism is behind other theories that have been brought forth in accounting for the observed heterogeneity of output responses to fiscal shocks - Basso and Rachedi (2018) show that differences in population age structures across U.S. states explain differences in fiscal multipliers, precisely because younger agents are more likely to be credit constrained.

However, studies that took into account the nature of the asset composition are limited to the U.S. For European countries, studies have been relying on net wealth distribution,[2]

[1] Although this subject has gain importance in the last years, it is not a new topic. Plutarch, an ancient Greek historian (46-120 AD) said that "An imbalance between rich and poor is the oldest and most fatal ailment of all republics."

[2] According to the Household Finance and Consumption Survey of the ECB, net wealth is the "total household assets including pension wealth from defined contribution plans minus total outstanding household's liabilities."

instead of liquid wealth distribution.[3] The relevance of such distinction arises from the fact that only liquid wealth can be used for consumption smoothing purposes and given the focus of the literature on short-run fiscal multipliers, highly illiquid assets such as pension funds for example, cannot be used to such purposes. Hence, models that are calibrated to match the net wealth distribution will produce aggregate marginal propensities to work and consume in response to the fiscal shocks that are likely to be biased, and therefore affect the size of the output response (see Domeij and Floden (2006)). This difference can now be correctly analyzed since the ECB brought a new dataset, the *Household Finance and Consumption Survey*, that can be used to perform cross-country studies taking into account the asset composition of the wealth distribution.

Carroll et al. (2017) show that marginal propensities to consume in response to a positive income shock can be substantially larger if models are calibrated to match the moments of liquid (as opposed to net) wealth distributions. Kaplan and Violante (2014) and Kaplan, Violante, and Weidner (2014) show that the difference in asset liquidity can explain the difference between empirical results regarding the marginal propensity to consume and the ones stemming from standard macroeconomic models.

The second reason for using liquid wealth rather than net wealth is that the liquid wealth distribution tends to be, for most of the countries, more uneven distributed than the net wealth distribution (see Figure 1), which can lead to a higher share of credit-constrained individuals than what otherwise would be inferred (see Kaplan, Violante, and Weidner (2014)). The relevance of this idea is because the share of credit-constrained individuals is the data moment that is at the heart of many fiscal policy transmission mechanisms proposed in the literature. Using liquid wealth can help to bridge the gap between empirical estimates of the share of credit-constrained agents (see Grant (2007)) and that same share in standard incomplete markets models.

Third and lastly, as we show in Figure 1 for a sample of 15 European countries,[4] liquid wealth and net wealth are not closely associated: the correlation is small (albeit positive) and not statistically significant. These numbers reinforce the idea that targeting liquid wealth instead of net wealth can be very important.

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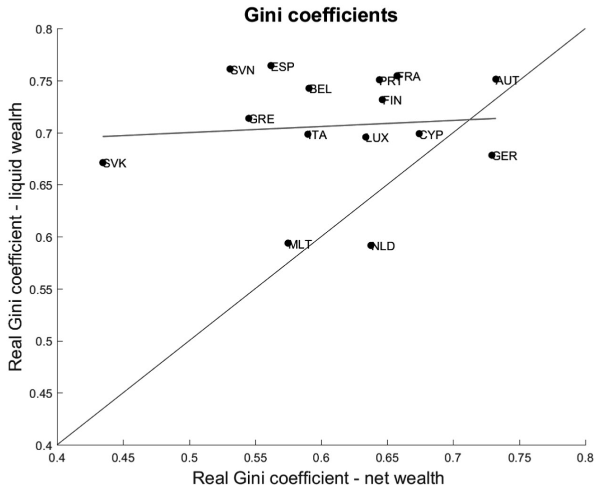
[3] According to the Household Finance and Consumption Survey of the ECB, liquid wealth comprises non-self employment private businesses, sight accounts, savings accounts, mutual funds, bonds, shares, managed accounts, 'other' assets, private lending, voluntary pension plans or whole life insurance contracts plus the current account balances of any defined contribution public or occupational plans the household members own.

[4] The 15 European countries used are Austria (AUT), Belgium (BEL), Cyprus (CYP), Finland (FIN), France (FRA), Germany (GER), Greece (GRE), Italy (ITA), Luxembourg (LUX), Malta (MLT), the Netherlands (NLD), Portugal (PRT), Slovakia (SVK), Slovenia (SVN) and Spain (ESP).

Figure 1: Gini coefficients in comparison



Note: Gini coefficient of the liquid wealth distribution the x-axis and Gini coefficient of the net wealth distribution in the y-axis. Correlation coefficient 0.0820; p-value 0.7715.

In this paper, we focus on output responses to fiscal consolidation programs and the quantitative relevance of taking into account the distribution of liquid vs. net wealth for the size of fiscal multipliers. We use a novel micro-dataset, the Household Finance and Consumption Survey which has detailed household balance sheet data, and analyzes the effects of the same fiscal consolidation shock in a model calibrated to 9 different European countries, comparing fiscal multipliers when calibrating these models using moments of the liquid and net wealth distributions. We use the model 1 illustrated in the introduction chapter, which contains overlapping generations with heterogeneous agents, incomplete markets, exogenous credit constraints, uninsurable idiosyncratic risk and a bequest motive.

We find that output falls in the short-run, as a consequence of the debt reduction policy, despite converging to a higher level at the end of the consolidation program. The mechanism is similar to the one proposed in Brinca et al. (2016): differences in wealth inequality translate to differences in the share of agents that are credit constrained which, in turn, will lead to different aggregate labor supply elasticities for the fiscal shock. The difference to Brinca et al. (2016) is that, for fiscal consolidation shocks, higher wealth inequality implies *lower* multipliers: as debt-over-GDP decreases, there is a crowd-in effect of assets into productive capital, which increases the marginal product of labor and the net present value of agents' lifetime income. In the short run output falls due to inter-temporal income and substitution effects: agents substitute leisure in the future for leisure today as wages are increasing over the transition to the lower debt-to-GDP steady state; and agents can now afford a higher level of leisure due to the increase in the net present value of lifetime income, reinforced by a lower interest rate which discounts less future income. These effects lead labor supply to fall in the short run, but by more in countries with less wealth inequality and smaller share of credit-constrained agents, as their labor supply elasticity to future shocks is much smaller. This generates the inverse relationship between wealth inequality and fiscal multipliers.

We also find that calibrating the models to match moments of the net or liquid wealth distributions has no qualitative implications for the results, but the differences are quantitatively relevant. We find multipliers to be on average 14% higher, in absolute terms, when calibrating the models to match the moments of the liquid wealth distribution. This difference is roughly the same regardless of the consolidation program being financed by a decrease in government expenditures or an increase in labor taxes. Despite the small sample size, the differences are also statistically significant.

To the extent of our knowledge, our paper is the only one that explores the policy implications of a fiscal consolidation shock either financed by austerity or by labor income taxes for Europe in the context of a general equilibrium model using liquid wealth. The rest of the article is organized as follows. Section 2 explains the calibration done for each country according to the model. Section 3 presents the results using cross-country analysis. Section 4 concludes. The appendix shows some model properties and calibration details.

2. Calibration

For this exercise, the model is calibrated following the same methodology of Brinca et al. (2016) and Brinca et al. (2017) to match moments of 9 economies: Austria, France, Germany, Greece, Italy, the Netherlands, Portugal, Slovakia, and Spain.[5] Certain parameters have direct empirical counterparts, and they were calibrated outside of the model. Other parameters are not observable, and so they are calibrated using a Simulated Method of Moments (SMM) approach. Appendix presents all the calibration values.

Wages

To estimate the life cycle profile of wages, we use data from the Luxembourg Income Study (LIS) and run for the below regression separately for each of the nine countries:

$$\ln(w_i) = \ln(w) + y_1 j + y_2 j^2 + y_3 j^3 + \epsilon_i,$$

where w is the wage rate from the firms' competitive equilibrium and j is the age of individual i. This equation was estimated in efficient units and the estimated values of y_1, y_2 and y_3 are in table 2.

The parameter for the variance of the ability, σ_a, is assumed to be unchanged across countries and set equal to the average of the European countries in Brinca et al. (2016). The parameter for the persistence of idiosyncratic shock, ρ, was also set to be unchanged

[5] Sample determined by data availability.

across countries and equal to the value used in Brinca et al. (2016), who use U.S. data from the Panel Study of Income Dynamics (PSID).[6] The variance of the idiosyncratic risk, σ_ϵ is then endogenously calibrated, as we will describe below.

Preferences and the Borrowing Limit

There is a large debate about the value of the Frisch elasticity of labor supply, η, in the literature.[7] We set it equal to 1.0, which is similar to a number of recent studies (Guner, Lopez-Daneri, and Ventura (2014) or Trabandt and Uhlig (2012)). The parameter that determines the disutility of hours worked, χ, the discount factors, $\beta_1, \beta_2, \beta_3$ and the borrowing limit, b, are calibrated so that selected model moments match the respective data moments, as we will describe below. In order to ensure that the age-profile of wealth is empirically plausible, we include a bequest motive as in Brinca et al. (2017) and Brinca et al. (2019) and choose φ accordingly.

Taxes and Social Security

We apply the labor income tax function proposed by Benabou (2002). We use U.S. labor income tax data provided by the OECD to estimate θ_0 and θ_1 for different family types. To obtain a tax function for the single individual households in our model, we take a weighted average of θ_0 and θ_1, where the weights are each family type's share of the population.[8]

The employer social security rate, $\tilde{\tau}_{ss}$, and the employee social security rate, τ_{ss} were set equal to the average tax rates between 2001 and 2007 for each country. The consumption tax rate, τ_c, and the capital tax rate, τ_k, were taken from Trabandt and Uhlig (2012), for each of the analysed countries. Table 2 summarizes the tax rates values for the entire sample.

Parameters Calibrated Endogenously

There are 7 parameters that do not have any direct empirical counterpart: φ, β_1, β_2, β_3, b, χ and σ_ϵ. To calibrate them, we use the simulated method of moments. We minimize the following loss function:

$$L(\varphi, \beta_1, \beta_2, \beta_3, b, \chi, \sigma_\epsilon) = || M_m - M_d ||$$

[6] The value of ρ was set equal to the U.S. because European countries do not have data to perform a consistent estimation.

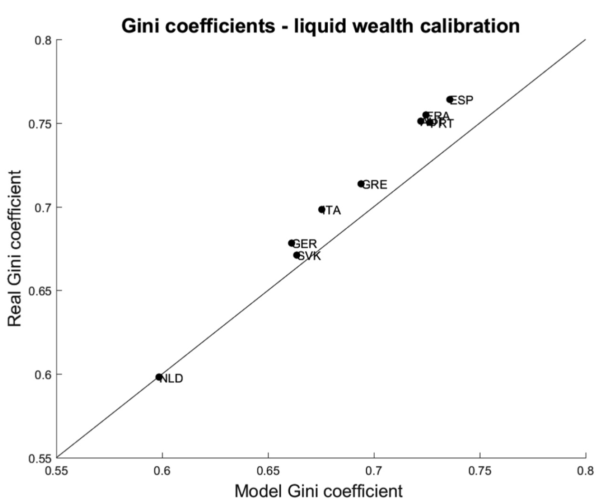
[7] For a complete literature review, see Reichling and Whalen (2012).

[8] The weights used were based in US data as some countries do not have detailed demographic data.

where M_m and M_d are model moments and data moments chosen. As there are seven parameters to calibrate, in order to have a precisely identified system we need 7 data moments. The data moments chose are the same as in Brinca et al. (2017):[9] average yearly hours, taken from the OECD Economic Outlook, the ratio of capital-to-output, $\frac{K}{Y}$, taken from the Penn World Table 8.0, the variance of log wages, taken from the Luxembourg Income Study (LIS) and the three quartiles of the cumulative liquid wealth distribution (the wealth held by those between the 1^{st} and the 25^{th} percentile, between the 1^{st} and the 50^{th} percentile, and between the 1^{st} and the 75^{th} percentile) taken from the Household Finance and Consumption Survey (HFCS), and the mean asset position held by the households with 75 to 80-years old relative to the mean wealth in the economy, from the Luxembourg Wealth Study (LWS).[10] The target moments are calibrated with an average error margin of 1.93%. Table 4 exhibits the target moments and table 5 displays the endogenous calibrated parameters and the calibration error for the nine countries.

Figure 2 compares the Gini coefficient of the liquid wealth distribution in the data with the wealth distribution in the model for the nine economies considered. It ensures that the calibration done mimics the real data since the Pearson correlation coefficient is very close to 1.

Figure 2: Comparison of Gini coefficients



Note: The Gini from the data (Real Gini coefficient) is on the y-axis and the Gini obtained from the model calibration (Model Gini coefficient) is on the the x-axis. It is also represented the 45-degrees line. The Pearson correlation coefficient is 0.9973 with a p-value < 0.01.

[9] In table 3 we summarize the calibration targets.

[10] As we do not have detailed data for the population share of each family for European countries, we use U.S. family shares, as in Holter, Krueger, and Stepanchuk (2019).

3. Results

Our premise is that not only the households' balance sheet composition matters for the effects of a fiscal consolidation policy but also the type of fiscal experiment carried out. This section describes the simulations undertaken, the resultant patterns from these simulations, the implied cross-country relationship regarding fiscal consequences and inequality, the importance of liquid wealth in the context of this policy and tests the robustness of the relationship for other inequality measures.

3.1. Experiment

The results from the calibration for the 9 European countries constitute the steady-state or the benchmark point. Contrary to what is standard in most of the literature, we implement a fiscal consolidation policy similar to the one in Brinca et al. (2017). We departure from the steady-state point and implement the fiscal consolidation policy for 50 years, where countries reduce the debt-to-output ratio. We implement two different kinds of experiments for each country: a fiscal consolidation via austerity, *i.e.* decreases in Government expenditure, G; or a fiscal consolidation via taxation, with increases in the labor tax rate, τ_l.

For a fiscal consolidation financed through a decrease in public expenditure, G, Government cuts G by 0.2% of the steady-state GDP. Alternatively, the Government can implement a fiscal consolidation by increasing labor taxes, τ_l. In this case, the public authority increases the tax rate by 0.1% of the steady-state GDP. Either way, the policy creates enough revenue after 50 years to decrease the debt-to-output ratio by ten percentage points.

3.2. Definition of the Fiscal Multiplier

We define the impact and cumulative multipliers as in Brinca et al. (2017):

$$\text{impact multiplier} = \frac{\Delta Y_0}{\Delta I_0}, \text{ with } I = \{G, R\}$$

where ΔY_0 is the change of output from period 0 to period 1 and ΔI_0 can be the change in Government spending from period 0 to period 1 if $I = G$ or the change in Government revenue from period 0 to period 1 if $I = R$. During a consolidation via G, τ_l and g are kept unchanged and during a consolidation via τ_l, G and g are kept unchanged.

$$\text{cumulative multiplier } I(T) = \frac{\Sigma_{t=0}^{t=T}\left(\Pi_{s=0}^{s=T}\frac{1}{1+r_s}\right)\Delta Y_t}{\Sigma_{t=0}^{t=T}\left(\Pi_{s=0}^{s=T}\frac{1}{1+r_s}\right)\Delta I_t}, \text{ with } I = \{G, R\}$$

where ΔY_t is the change in output from period 0 to period t and ΔI_t can be the change in Government spending from period 0 to period t, if $I = G$ or the change in Government revenue from period 0 to period t, if $I = R$.

3.3. Mechanisms

The mechanisms behind the two types of fiscal consolidation policies are distinct and it is important to characterize them separately. It is also relevant to describe how wealth inequality affects the chain of events. The model has four sources of heterogeneity: the households' age, j, their permanent ability, a, the discount factor, β and the idiosyncratic productivity shock, u. These four factors influence the households' wealth accumulation and consequently the aggregate response to the fiscal consolidation shocks.

While the Government pays its debt, the number of Government bonds in the economy decreases which makes households to change how they save. Households gradually shift savings to physical capital, which drives up the capital-to-labor ratio. An economy with more capital per worker is an economy with higher marginal productivity of labor, in other words, more capital in the economy allows workers to be more productive. Due to the market clearing conditions, the marginal productivity of labor equals the wage rate (see firm's competitive equilibrium). Hence, it also rises. Due to inter-temporal and income effects, households will prefer to have more leisure, as wages are increasing over the 50-years transition. With higher wages and lower interest rates, the net present value of lifetime income is higher, which leads labor supply to fall in the short-run and, consequently output also drops.

However, a country with more wealth inequality has more hand-to-mouth agents, which are financially constrained agents. These agents do not have the chance of smoothing consumption as much as they would like. A country with a higher share of financially constrained agents has a more rigid labor supply, meaning that the labor input does not react as much to negative policy shocks which ultimately gives lower drops in output.

In the case of a consolidation via labor income taxes, , we have that an increase in the tax rate also originates intra-temporal substitution effects on the labor supply. In fact, a higher tax rate leads to a lower after-tax income which reduces the opportunity cost of leisure. As a result, labor supply will decrease, reducing the labor input and causing the output to fall.

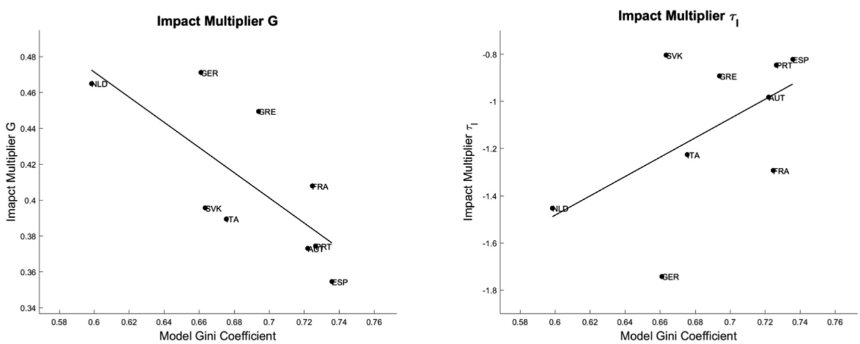
Following the same reasoning, economies with a higher wealth inequality display a more substantial fraction of financially constrained households. These agents will have a relatively modest reaction to the tax rate increase as they are needy agents. These agents would like to reduce the labor supply, but they cannot reduce it. Therefore, countries with higher shares of constrained agents will have less severe reactions to the fiscal consolidation policy, *i.e.* output drops will be smaller.

3.4. Cross-Country Analysis

In Brinca et al. (2016), the authors conclude that the wealth distribution is relevant for fiscal policy. They perform the classical fiscal expansion experiment in the literature where current Government consumption, G, increases financed by a reduction in current Government transfers, g. They conclude that wealth inequality and fiscal multipliers are positively related with a correlation coefficient of 0.623.

As described previously, for a fiscal consolidation shock, countries with higher wealth inequality, have a larger share of financially constrained agents and a more rigid labor supply causing smaller drops in output. In other words, countries with more uneven distribution have smaller fiscal multipliers in absolute values.

Figure 3: Impact multiplier and Gini coefficient



Note: On the left panel we have the cross-country relation for a consolidation via G (correlation coefficient -0.73; p-value 0.026), while on the right panel we have the cross-country data for a consolidation via τ_l (correlation coefficient 0.55; p-value 0.124).

In Figure 3 we plot the impact multipliers for a fiscal consolidation policy either financed by austerity or by taxation and the wealth Gini coefficients across the 9 European countries considered, in the context of a model calibrated for liquid wealth. As countries have more wealth inequality, the impact multipliers are less sizable.

Furthermore, and in accordance to what is standard in the literature, the effects from a fiscal consolidation experiment financed by labor income taxes, τ_l are more severe than the effects from a fiscal consolidation experiment financed by Government expenditure, G.[11] This phenomenon is observable by looking at the absolute value of the fiscal multipliers. For our nine country sample, the fiscal multiplier of τ_l is, on average, 2.7 times larger than the fiscal multipliers of G, in absolute terms.[12]

[11] This is a result that comes from the fact that the consequences of taxation have more direct effects on the economy than austerity. Blanchard and Perotti (2002) estimated different fiscal multipliers for the period 1947-1997 and shows that the multiplier of τ_l tend to be larger than the multiplier of G.

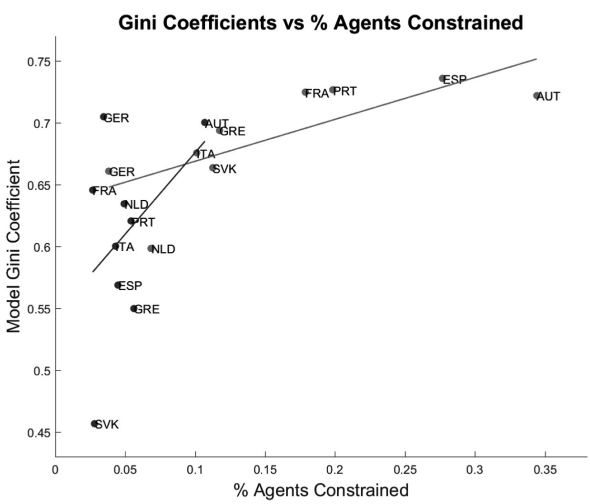
[12] Table 1 has the multipliers' values and the ratio between the τ_l multiplier and the G multiplier of each country.

3.5. Net Wealth vs. Liquid Wealth

The central economic concept behind the mechanisms is the consumption smoothing hypothesis. This hypothesis states that households prefer to consume similar amounts in each period, instead of having a considerable variance in consumption. To keep this behavior during low-income periods, households can resort to their accumulated wealth, convert it into to cash and use it to consume. Yet, not all sorts of assets are right away convertible to cash. Real estate, for instance, is not immediately sold and so households cannot use this particular asset to smooth consumption, in the short-run.

According to OECD (2015), liquid wealth only represents 25.9% of the total wealth for 18 OECD countries. Additionally, the same book shows that net wealth and liquid wealth are not linearly related and that liquid wealth has a more uneven distribution. Therefore, one should use a model calibrated for liquid wealth distribution to explain how an economy responds to a fiscal consolidation shock. To demonstrate this argument, we perform a cross--country analysis for the 9 European economies considered in this paper that illustrate the mechanism of how wealth inequality affects a fiscal consolidation shock. The results show that the mechanism is much stronger for liquid wealth than for net wealth.

Figure 4: Gini coefficient and constrained agents

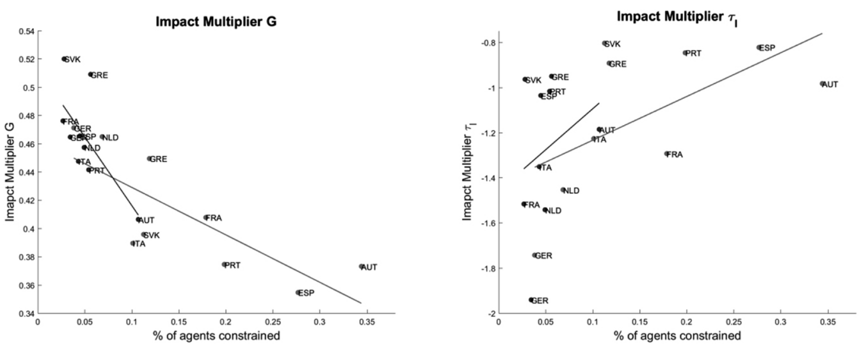


Note: Percentage of agents constrained on the x-axis and Gini coefficient on the y-axis. Red points and lines represent the liquid wealth model and the blue points and lines represent the net wealth calibration (correlation coefficient of liquid wealth 0.76, p-value 0.017; and correlation coefficient of net wealth 0.41, p-value 0.27).

Figure 4 illustrates the relationship between the Gini coefficient and the percentage of agents financially constrained, in a model calibrated for net wealth and liquid wealth.

Although the relation for net wealth is steeper than the relation for liquid wealth, due to the tremendous point-dispersion, there is no statistical significance for the correlation coefficient of net wealth (blue points). In other words, this first step of the mechanism only has statistical power in the model calibrated with liquid wealth (red points).

Figure 5: Impact multiplier and Percentage of agents constrained



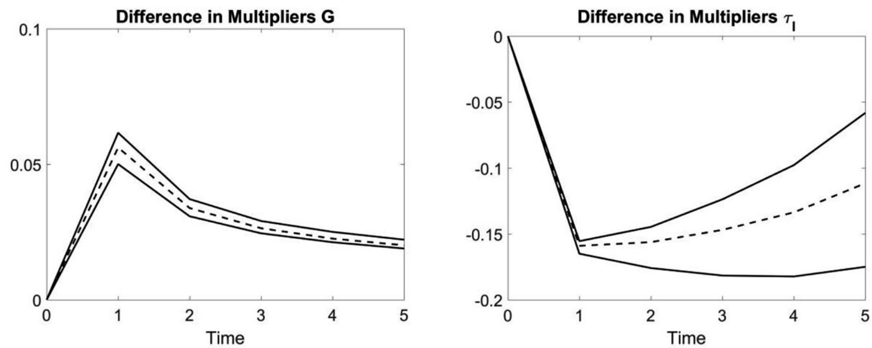
Note: Red points and lines represent the liquid wealth model and the blue points and lines represent the net wealth calibration. On the left panel we have the cross-country data for a consolidation via G (correlation coefficient of liquid wealth -0.79, p-value 0.012; and net wealth -0.68, p-value 0.044), while on the right panel we have the cross-country data for a consolidation via τ_l (correlation coefficient of liquid wealth 0.59, p-value 0.097; and correlation coefficient of net wealth 0.26, p-value 0.502).

Figure 5 shows the other step of the mechanism which states that economies with more financially constrained agents react less to fiscal consolidation policies and so the fiscal multipliers are closer to zero. Indeed, this relation happens independently of the type of wealth used. However, once again, the results have more statistical significance for the model calibrated with liquid wealth. This fact indicates that liquid wealth is, *de facto* the vital measure in what concerns consumption smoothing.

Looking at Figures 4 and 5, one can see that the liquid wealth calibration allowed for higher percentages of credit constrained or hand-to-mouth agents. This is congruent with liquid wealth distribution having a higher Gini coefficient. Several articles estimated the percentage of hand-to-mouth agents for the U.S.[13] (see Kaplan, Violante, and Weidner (2014) or Grant (2007)) and it is significantly larger than the net wealth models exhibit. Liquid wealth models allow achieving a more realistic value of hand-to-mouth agents.

[13] There is no estimation for European countries, to the extent of our knowledge.

Figure 6: Differences in Multipliers



Note: Difference of net wealth cumulative multiplier and liquid wealth cumulative multipliers for a government spending consolidation (left panel) and labor tax consolidation (right panel) in the first five periods. The area between the two solid lines is the 95% confidence interval obtained with sample bootstrapping.

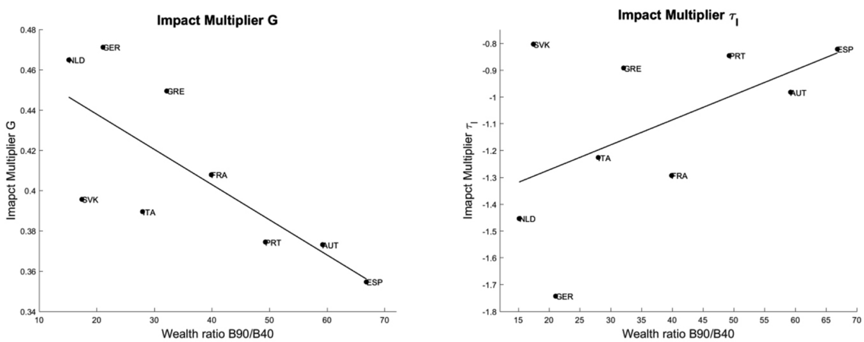
The difference in liquid wealth and net wealth influence not only impact multipliers, but also cumulative multipliers. Figure 6 shows the difference in the cumulative multipliers between net wealth and liquid wealth for the five periods immediately after the shock, computed according to the definition in section 3.1. It reinforces the idea that net wealth multipliers are larger, in absolute value than liquid wealth multipliers but overtime. This occurs precisely because of the mechanism described above where liquid wealth distribution is more unevenly distributed than net wealth which leads to a more significant share os constrained agents and consequently to lower labor supply and output responses to the shocks.

3.6. Robustness of the Mechanism

One possible issue that can arise is the type of measure used to wealth inequality. Allison (1978) presents several measures of income and wealth inequality, including the Gini coefficient. Although Leigh (2007) shows that there is a reliable and statistically significant relationship between top income shares and broader inequality measures, as the Gini coefficient, in this subsection we shall present the relationship of wealth inequality and fiscal multipliers, using the wealth ratios to measure inequality.

Independently of the ratio used, the measure on the numerator corresponds to the share of wealth held by the wealthier households. On the other hand, the denominator corresponds to the share of wealth held by the poorer households. This means that a larger ratio implies a more uneven wealth distribution. In this subsection, we use the wealth ratio B90/B40 – Bottom 90 over Bottom 40. It corresponds to the wealth held by the poorest 90% over the wealth held by the poorest 40%.

Figure 7: Impact multipliers of countries



Note: Impact multiplier and the B90-B40 ratio (B90 is the wealth held by the poorer 90% and B40 is the wealth held by the poorer 40%). On the left panel we have the cross-country data for a consolidation via G (correlation coefficient of -0.76, p-value 0.018), while on the right panel we have the cross-country data for a consolidation via τ_l (correlation coefficient of 0.52, p-value 0.149).

Figure 7 corroborates the same relation described above between fiscal multipliers and wealth inequality. For a fiscal consolidation financed by G, more inequality leads to lower multipliers, and for a consolidation financed by τ_l, more inequality leads to higher multipliers. We also have that the relationship in the case of the experiment financed with taxation is not statistically significant. In the appendix, we include other figures that test the same relation for different wealth ratios.

4. Conclusion

This paper analyzes the impacts of wealth inequality on a fiscal consolidation program financed either by austerity or by taxation. In particular, we assessed the impact of liquid wealth distribution, which is a measure more readily convertible to cash, in a fiscal contraction. We started by documenting that the Gini coefficient of net wealth distribution and liquid wealth distribution have a minimal relation and that the distribution of liquid wealth is more uneven than the one of net wealth.

To explain how wealth inequality affects the recessive impacts of the policy we calibrated an incomplete-markets, overlapping generations model to 9 European economies using the Household Finance and Consumption Survey (HFCS). We calibrated the model for both liquid wealth and net wealth, with the aim of testing the robustness of the mechanism.

We find that the relationship between wealth inequality and fiscal multipliers depend crucially on the fiscal instrument. In a case of fiscal expansion as in Brinca et al. (2016), the relationship is positive. In a case of fiscal consolidation the relationship is inverted, i.e. higher wealth inequality leads to smaller fiscal multipliers in absolute value. This result comes from the share of financially constrained agents in each country. In fact, more wealth inequality is associated with more financially constrained agents and consequently with a more rigid labor supply. Therefore, the output drops will be smaller for a country with higher inequality comparing to a country with lower inequality.

The economic concept behind this mechanism is the permanent-income / consumption--smoothing hypothesis. For this reason, liquid wealth should be preferred over net wealth when analyzing the impacts of fiscal policy, as the possibility of liquidating assets for consumption smoothing is central to the mechanism being used. Furthermore, when calibrating the model to match liquid wealth, the relationship between wealth inequality and fiscal multipliers for calibrated models to different countries is stronger, both in terms of correlation and statistical significance. This means that cross-country differences in these economies along other dimensions (such as tax structures, age profiles of income, etc.) become comparably less important.

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APPENDIX

Tables and additional figures

Table 1: Impact Multipliers for the model calibrated with liquid wealth

Country	Multiplier G	Multiplier τ_l	$\lvert$Mult $\tau_l\rvert$ / $\lvert$Mult $G\rvert$
Austria	0.3731	-0.9829	2.634
France	0.4078	-1.2936	3.172
Germany	0.4711	-1.7431	3.700
Greece	0.4495	-0.8931	1.987
Italy	0.3895	-1.2267	3.149
Netherlands	0.4649	-1.4536	3.127
Portugal	0.3743	-0.8460	2.260
Slovakia	0.3956	-0.8042	2.033
Spain	0.3546	-0.8223	2.319

Table 2: Parameters calibrated exogenously

Country	Age profile parameters			Taxes					
	y_1	y_2	y_3	θ_0	θ_1	$\tilde{\tau}_{ss}$	τ_{ss}	τ_c	τ_k
Austria	0.155	-0.004	3.0e-05	0.939	0.187	0.217	0.181	0.196	0.240
France	0.384	-0.008	6.0e-05	0.915	0.142	0.434	0.135	0.183	0.355
Germany	0.176	-0.003	2.3e-05	0.881	0.221	0.206	0.210	0.155	0.233
Greece	0.120	-0.002	1.3e-05	1.062	0.201	0.280	0.160	0.154	0.160
Italy	0.114	-0.002	1.4e-05	0.897	0.180	0.329	0.092	0.145	0.340
Netherlands	0.307	-0.007	4.9e-05	0.938	0.254	0.102	0.200	0.194	0.293
Portugal	0.172	-0.004	2.6e-05	0.937	0.136	0.238	0.110	0.194	0.293
Slovakia	0.096	-0.002	1.7e-05	0.974	0.105	0.326	0.131	0.181	0.151
Spain	0.114	-0.002	1.4e-05	0.904	0.148	0.305	0.064	0.144	0.296

Note: y_1, y_2, y_3 are estimated according to the wage equation, using the most recent LIS survey available before 2008. Data for Portugal comes from Quadros de Pessoal 2009 database; θ_0, θ_1 are estimated according to the income tax equation; $\tilde{\tau}_{ss}$, τ_{ss} are the average social security taxes paid by the employer and by the employee, respectively, using OECD data of 2001-2007; τ_c and τ_k come from Trabandt and Uhlig (2012) or calculated using their approach. They represent the average effective tax rate from 1995-2007.

Table 3: Parameters held constant across countries

Parameter	Value	Description	Source
α	0.33	Capital share of output	Literature
δ	0.06	Depreciation rate of capital	Literature
ρ	0.335	Persistence of the idiosyncratic shock	PSID-Estimation 1968-1997
σ_a	0.423	Variance of the ability	Brinca et al. (2016)
σ	1.2	Risk-aversion factor	Literature
η	1	Inverse Frisch Elasticity	Trabandt and Uhlig (2012)

Table 4: Calibration Targets - M_d

Country	Q1	Q2	Q3	K/Y	$\bar{n}$	Var ln(w)
Austria	0.0056	0.0395	0.1480	3.359	0.226	0.199
France	0.0045	0.0328	0.1418	3.392	0.184	0.478
Germany	0.0063	0.0544	0.2234	3.013	0.189	0.354
Greece	0.0069	0.0462	0.1831	3.262	0.230	0.220
Italy	0.0087	0.0595	0.2012	3.943	0.200	0.225
Netherlands	0.0106	0.0812	0.3119	2.830	0.200	0.282
Portugal	0.0039	0.0283	0.1399	3.229	0.249	0.298
Slovakia	0.0131	0.0631	0.1399	3.799	0.204	0.250
Spain	0.0041	0.0275	0.1314	3.378	0.183	0.225

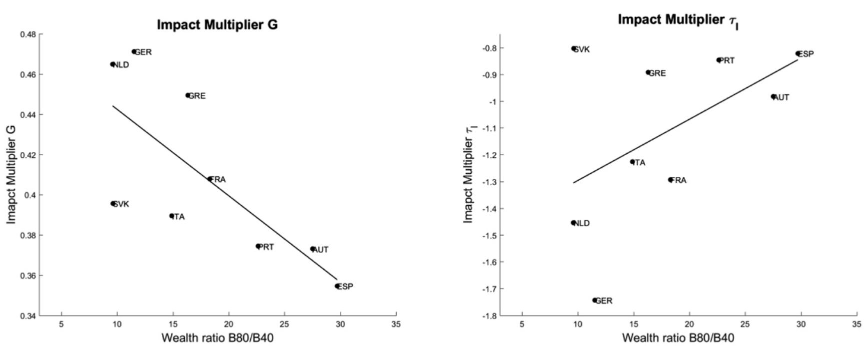
Note: The average share of wealth held by the households in the cohort of 75-80 years old relative to the total population mean is the 7^{th} target. It was used the U.S. measure which is equal to 1.5134; Q1, Q2 and Q3 are the three quartiles of the cumulative distribution of liquid wealth derived from LWS; K/Y is derived from PWT 8.0, average from 1990-2011; $\bar{n}$ is average hours worked per capita derived from OECD data 1990-2011; Var ln(w) is the variance of log wages from the most recent LIS survey available before 2008. Data for Portugal comes from Quadros de Pessoal 2009 database.

Table 5: Parameter Values calibrated endogenously and respective error Estimated by SMM

Country	β_1	β_2	β_3	b	χ	φ	σ_ϵ	Error (%)
Austria	0.9165	1.0008	0.8837	-0.040	14.47	5.99	0.1757	2.55
France	0.9030	1.0145	0.9170	-0.060	18.43	4.19	0.5060	0.59
Germany	0.9560	0.9953	0.9560	0.003	14.42	3.81	0.5386	0.01
Greece	0.9650	1.0045	0.9665	-0.070	16.77	3.35	0.1206	1.58
Italy	0.9750	1.0200	0.9755	-0.078	20.75	5.90	0.2144	5.20
Netherlands	0.9680	0.9856	0.9579	-0.022	14.72	2.99	0.2625	0.23
Portugal	0.8965	0.9921	0.8900	-0.030	11.62	6.70	0.3810	0.73
Slovakia	0.9410	1.0016	0.9410	-0.091	21.15	7.92	0.3269	3.28
Spain	0.8950	1.0005	0.8920	-0.027	25.15	7.05	0.2372	1.92

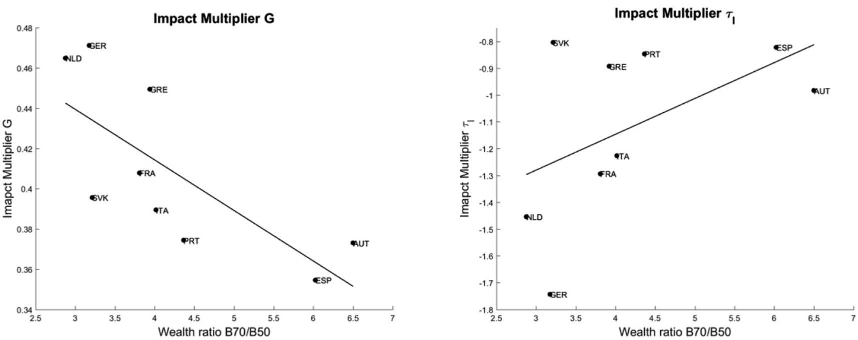
Note: The error corresponds to the value of the Loss function in the calibration section.

Figure 8: Impact Multiplier and Wealth Ratios



Note: Impact multiplier and the B80-B40 ratio (B80 is the wealth held by the poorer 80% and B40 is the wealth held by the poorer 40%). On the left panel we have the cross-country data for a consolidation via G (correlation coefficient of -0.748, p-value 0.021), while on the right panel we have the cross-country data for a consolidation via τ_l (correlation coefficient of 0.515, p-value 0.156).

Figure 9: Impact Multiplier and Wealth Ratio



Note: Impact multiplier and the B70-B50 ratio (B70 is the wealth held by the poorer 70% and B50 is the wealth held by the poorer 50%). On the left panel we have the cross-country data for a consolidation via G (correlation coefficient of -0.739, p-value 0.023), while on the right panel we have the cross-country data for a consolidation via τ_l (correlation coefficient of 0.509, p-value 0.162).

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Skill-Biased Technological Change and Inequality in the U.S.

Progresso Tecnológico Enviesado em Função das Qualificações e Desigualdade nos E.U.A.

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ABSTRACT

Since the 1980s, income inequality has increased markedly and has reached the highest level ever since it started being recorded in the U.S. This paper uses an overlapping generations model with incomplete markets that allows for household heterogeneity that is calibrated to match the U.S. economy with the purpose to study how skill-biased technological change (SBTC) and changes in taxation quantitatively account for the increase in inequality from 1980 to 2010. We find that SBTC and taxation decrease account for 48% of the total increase in the income Gini coefficient. In particular, we conclude that SBTC alone accounted for 42% of the overall increase in income inequality, while changes in the progressivity of the income tax schedule alone accounted for 5.7%.

Keywords: Technical change; income inequality; wealth inequality; heterogeneity; taxation.

JEL Classification: E21; J10.

RESUMO

Desde a década de 1980, a desigualdade de rendimento aumentou acentuadamente e está no nível mais alto desde que foi iniciado o seu registo nos EUA. Este artigo usa um modelo de gerações sobrepostas com mercados incompletos que permite a heterogeneidade do agregado familiar. O modelo é calibrado para a economia dos EUA e tem como objetivo estudar como o *Skill-Biased Technological Change* (SBTC)) e as mudanças na tributação explicam quantitativamente o aumento da desigualdade entre 1980 e 2010. Estima-se que o SBTC e a redução da tributação respondem por 48% do aumento total do coeficiente de Gini. Em particular, concluímos que o SBTC sozinho foi responsável por 42% do aumento geral na desigualdade de rendimento, enquanto as mudanças na progressividade do imposto sobre o rendimento por si só foram responsáveis por 5,7%.

Palavras-chave: Progresso tecnológico; desigualdade de rendimento; desigualdade de riqueza; heterogeneidade; impostos.

1. Introduction

Some argue that we are in the period of a "Forth Industrial Revolution", which moved production function shares. There is an increasing concern in the possible dominance of technology over the human labor: "Automation and AI will lift productivity and economic growth, but millions of people worldwide may need to switch occupations or upgrade skills" (Manyika et al. 2017).

Most of the literature focus on the substitution of low-skilled labor for capital (Autor, Levy, and Murnane 2003; Acemoglu and Restrepo 2018). Although, it is essential to have in mind that high-skilled automation can, and will probably be an issue due to artificial intelligence and machine learning. Acemoglu and Restrepo (2016) describe: "If the long-run rental rate of capital relative to the wage is sufficiently low, the long-run equilibrium involves automation of all tasks".

Hence, as shown by Acemoglu and Restrepo (2018), low skill-automation will increase wage inequality because people are being substituted by machines or losing their job. A social measure to reduce inequality is using taxation. (Saez 2001), claimed that labor tax rates should be U-shaped, separating households with low and higher income distributions, instead of the previous proposed lump-sum taxation (Mirrlees 1971). Furthermore, Aiyagari (1995) ensures that with incomplete markets and uncertainty, optimal capital taxation is positive.

In this manner, the present article pretends to answer *quantitatively* how SBTC and taxation changes account for the paths of income inequality in the U.S from 1980 to 2010. Our contribution is similar to Krusell et al. (2000). The authors show that capital-skill complementary changes account for most of the variations on the skill premium. Other related studies also measure wage inequality through skill premium (Heckman, Lochner, and Taber 1998). We apart from this specification and take into account income and wealth distributions that the authors abstract from. Furthermore, we use income inequality instead of skill premium to account for the changes in wages.

The model developed in this framework is an overlapping generations model with an incomplete markets and an uninsurable idiosyncratic risk that allows skill-biased technological change, which is modeled assuming that agents have different abilities. Thus, households born with different abilities, which are complemented or substitutable by capital. Households can face ex-ante heterogeneity, or they can suffer a posterior income shock, which creates ex-post heterogeneity. Furthermore, taxation plays a crucial role in this model, since labor taxes can distort labor supply (Golosov, Troshkin, and Tsyvinski 2016) and affect the household's skill investment (Heathcote, Storesletten, and Violante 2017). We use a non-linear labor tax function developed by Bénabou (2002), to define the level and the progressivity of the tax schedule.

Our model reproduces simultaneously some phenomenon of the U.S. economy from 1980 to 2010, namely: the skill premium rise; a growth in income and wealth inequality; a rise in skilled labor share, and a reduction on the unskilled labor share. We were able to account for 48% of the total change in income inequality. In particular, we show that SBTC alone account for 42%, while taxation alone accounted for 5,7%.

The rest of the work is organized as follows. In Section 2 we discuss some related literature and empirical facts. In Section 3, we present the model and the calibration method and in Section 4 the results. Section 5, concludes the work.

2. Related Literature and Facts

It is quite a consensus that labor share has been declining since 1980 (Eden and Gaggl 2018; Karabarbounis and Neiman 2013). Some recent models attribute the labor share contraction to the substitutability between capital and unskilled labor in the technological production function. This substitution in the course of investment-specific technological change (ISTC) has been referred as automation.

Particularly, Eden and Gaggl (2018) calibrate an aggregate production function that highlights the interaction between information and communication technology (ICT) and different types of labor for the U.S. economy and find that the decline in the aggregate labor share is explained by the decrease in routine occupations, since the income share of non-routine labor has been rising.[1]

For instance, automation can create distinct effects on the economy. On the one hand, it can increase the aggregate welfare, because it pushes up productivity and, as a result, the factor prices change (Acemoglu and Restrepo 2018; Eden and Gaggl 2018)[2]. But on the other hand, as capital becomes cheaper, or in other words, as investment prices decline, unemployment rates will increase due to a shift in companies' factor demand, which will raise the demand for skilled people and lower the demand for unskilled people (Acemoglu and Restrepo 2016). As demand-supply rule takes place, unskilled households will see their wages decrease, although skilled agents will face an increase in their salaries.

In fact, U.S. wage structure shows that since 1970 there is an increase in dispersion in household earnings, especially in different levels of education, age, and experience. Furthermore, Katz et al. (1999) mentioned that the observed wage structure for U.S. seems to translate an increase in inequality. The author summarises several reasons that are attributed to wage inequality: (i) higher demand for more educated people driven by SBTC; (ii) loss in the wage premium paid to less educated people, due to a rising globalisation pressure; (iii) higher dispersion in skills, due to increase of unskilled immigration; (iv) and changes in wage setting norms.

As a consequence, households will pursue different behaviors when they face income risk. Agents can create an ex-ante response, i.e., in anticipation of the shock they tend to increase their precautionary savings and engage in contracts in which wages are kept constant (Krueger, Mitman and Perri 2016). However, agents can act after they face a shock, i.e., an

[1] It is very important to distinguish between occupation and worker skill type. Some professions are non-routine, although they do not infer a skilled household, i.e., an educated household, for example, an electrician does not have a college degree, although performs a non-routine job. Contrary, diagnosis doctors are skilled, but they perform a routine occupation. Most of the routine occupations are conducted by agents that have a college degree or higher.

[2] Indeed, Krusell et al. (2000) concludes that the increase in inequality occurs jointly with the reduction of the investment prices and recently (Eden and Gaggl 2018) shows that the value of information and communication technology falls considerably after 1982.

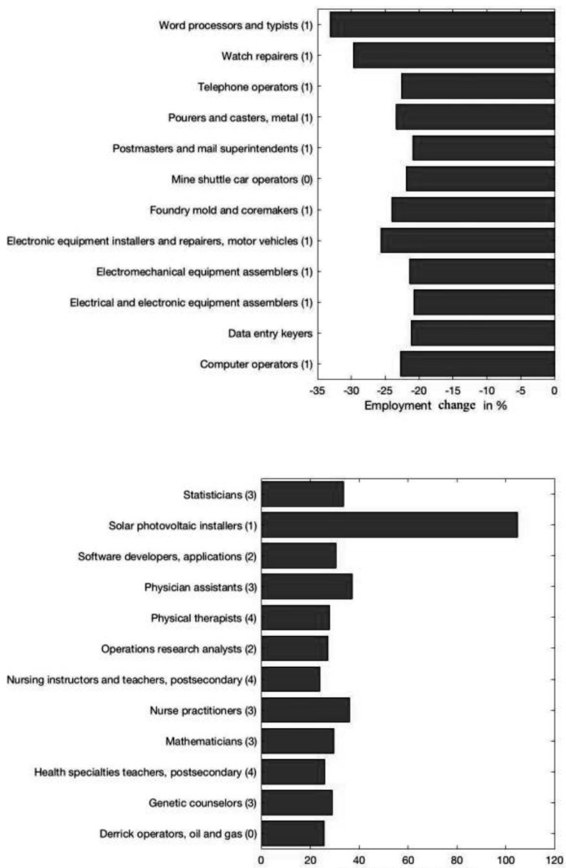
ex-post response to risk. In this case, households will make a consumption revision, which will be lower if the income shock is negative, or higher otherwise (Heathcote, Storesletten and Violante 2014). To smooth the shocks, households can change their skills, this is, they can increase their human capital, becoming skilled (Heathcote, Storesletten and Violante 2017).

The U.S. wage pattern is related to technological development because periods of significant technological developments are correlated with high skill premiums. Indeed, SBTC increased the demand for skilled workers since 1980, and this increase explains part of the rise in education wage premium. Furthermore, the more demanded occupations in 2026 will be those that are less likely to be automated and will be more related to social skills, creative thinking, and problem-solving capacities. These non-routine occupations are related primarily with high-skilled jobs which need higher levels of education and have more significant earnings.

Figure 2 presents a projection for the growing job positions for 2026, which shows that to have access to most of them it is necessary to incorporate in distinct levels of education. In reality, most of those occupations will require college degrees.

These recent projections support (Heckman, Lochner, and Taber 1998) who introduce human capital accumulation in an OLG model in order to explain the rise in the wage inequality, measured by the skill premium, without giving a unique role to capital, and conclude that the higher demand for high skilled labor induces a supply response, thus more and more people will go to college as a response to the required features.

Figure 1: Occupations change for 2026



Note: The chart on the left presents the less demand jobs, and the right figure shows the most demand jobs, where 0 indicates that there is no need for formal education credential; 1 indicates that it is necessary a high school diploma; 2 indicates that it is necessary a Bachelor's degree; 3 for Master's degree; and 4 for Doctoral and advanced degree. Source: U.S. Bureau of Labor Statistics.

The skill premium can be seen as an explanatory variable for the decreasing labor share in the course of SBTC. Murphy and Welch (1992) calculated that the skill premium grows 3,3% each year, ceteris paribus. Furthermore, Krusell et al. (2000) show that there was a decline in 1970 in the skill premium, but in 1980 there was a severe increase. Figure 3 is the representation for the skill premium since 1980 for the U.S. economy, which shows that there is, indeed, an increase that was maintained until 2010, although since then it has been quite steady. The more considerable difference is coming from the college skill premium, calculated as the ratio for bachelor degrees and high school degrees. This problematic of income polarization may continue to increase due to the higher demand for high-wage occupations that can grow more than middle-wage jobs.

As this trend continues, the problem can appear because not everyone has the same opportunity to access to higher education. Thus, inequality surges, because automation leads to unemployment in low-skilled people ((Acemoglu and Restrepo 2018)) and because wealthier agents tend to be more educated and older (Krueger, Mitman, and Perri 2016).

Figure 4 compares the Gini Index for pre-tax and post-tax income and shows that inequality is rising since 1980. Thus, although taxes are taking influence in reducing inequality, it seems that this has not been entirely effective. Indeed, the income share of the bottom 90% is dropping in the same period. Of course, distinct levels of income correspond to different levels of experience, skills, and productivities, as it will be clarified in section 3.

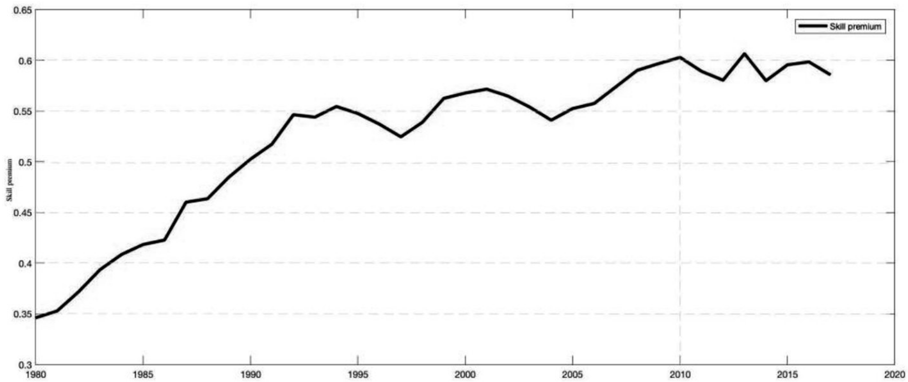
Taxation can be a force to increase output and consumption because it affects government spending (Ferriere and Navarro 2018). The Mirrlessian approach concludes that individuals with highest skills have optimal taxation of zero (Diamond 1998). However, recent studies show that there are welfare gains when we move to a non-linear tax function especially when the government does not observe the skills of the citizens (Gorry and Oberfield 2012). Thus, the government should set different taxation on workers with different abilities and, in consequence, with different elasticities towards capital. Heathcote, Perri, and Violante (2010) find that the optimal income taxation structure to maximize social welfare is only a two-parameter function, that embraces the level of taxation and the progressivity of tax, as it will be clarified in section 3. Using this, and also, other income taxation approaches, Guner, Kaygusuz, and Ventura (2014) find that it is possible to reduce the Gini Index from 0,56 to 0,55 only by using labor taxation.

Although this is a useful measure to reduce income inequality, taxation can create an adverse effect. As the government increases progressive taxation, agents have less incentive to work, and they prefer to invest less in skills, which can create even more heterogeneity ((Stiglitz 1982)).

Progressive taxation is essential to redistribute after-tax income across ex-ante heterogeneous households. Thus an optimal policy can create beneficial effects on society. (Krueger, Ludwig, and others 2013) found optimal labor taxation of 34,1% taking into account skilled and unskilled households and, concluded that this taxation leads to a lower Gini index, higher GDP and consumption, and more people deciding to go to college.

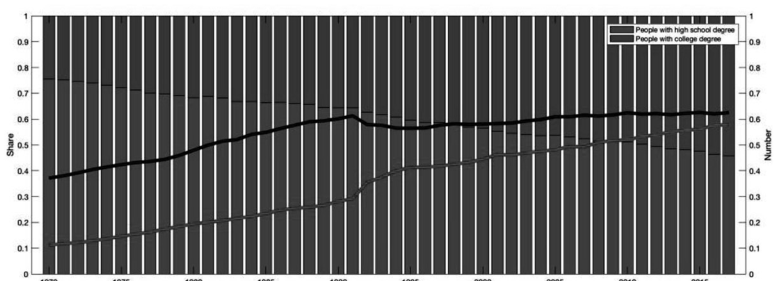
Figure 6 shows the results for labor tax progressivity in the U.S. since 1946 using the methodology of (Ferriere and Navarro 2018). The average progressivity tax is 11,9% (s.e. 0,029) between 1980 and 2010. In the 80's progressive tax rate achieved its maximum, however since the 90's the progressivity tax has been established close to 10%, resulting in a decrease comparing 1980 with 2010.

Figure 2: Log Skill Premium



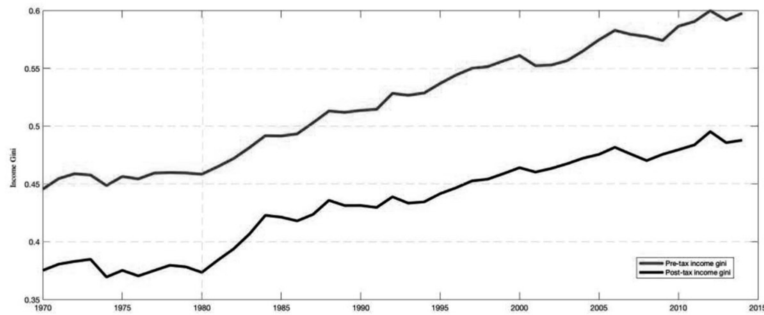
Note: Calculated as the ratio between skill and unskilled wages. Skilled wages are considered for those who have a bachelor degree, or higher and unskilled wages are those coming from a high-school degree. Own calculation. Data source: Bureau of Labor Statistics.

Figure 3: Number of people with higher education background



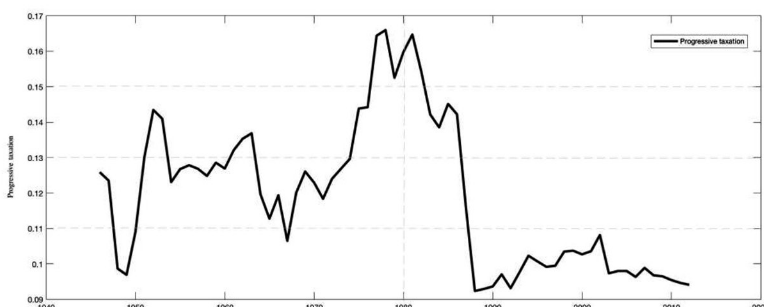
Note: Division of people that completed High school and College with 25 years and over, the lines are the number of people that completed these degrees divided by 1 x 10^8. Data source: Census Bureau.

Figure 4: Inequality



Source: World Inequality Database (WID).

Figure 5: Progressive Taxation



Note: Own calculation following the method of Ferriere and Navarro (2018). More details on annexes.

3. **Model and Calibration**

This paper uses the model 2 as outlined in the introduction chapter. The model is calibrated to match the U.S. economy in 1980, in light with the method used by (Brinca et al. 2016) and (Brinca et al. 2018). Preferences and age profile of wages, ρ_u and σ_ϵ are setting according to (Brinca et al. 2016). The first discount factor is set to match the capital-output ratio in 1980 and the second discount factor is set to match the income share of the bottom 90%.

The distribution parameters, Φ_1 and Φ_2 are fixed to 0,55 and 0,8, respectively, so that the skill premium and the quantities of labor supplied are close to levels observed in 1980 (Eden and Gaggl 2018). Furthermore, the elasticity of substitution between capital and skilled labor is 0,43, and the elasticity of substitution between capital and unskilled labor is 2,33.

The disutility of work, χ, and the variance of ability, σ_a, are set using the Simulated Method of Moments (SMM). Furthermore, risk aversion was set to 1,2. We, also assume that capital depreciates at 0,06 and the share of non-routine skills is set to 40%.

Wages

The wage profile through life-cycle is calibrated directly from the data. We run equation (1) illustrated below using data from Luxembourg Income and Wealth Study (LWS).

$$\ln(w_i) = \ln(w) + y_1 j + y_2 j^2 + y_3 j^3 + \epsilon_i$$

where j is the age of individual i. To calculate ρ_u and σ_ϵ we use PSID data and regressed the wage equation, then we use the residuals in order to estimate both parameters. These parameters are kept constant across steady-states.[3]

Preferences

There has been an extensive debate in the literature relative to the value of Frisch elasticity of labor supply, η. The estimates for are comprehended between 0,5 to 2.[4] We set the Frisch elasticity to 1 as Trabandt and Uhlig (2011), to ensure that the labor supply is not affected by technological shocks.

Taxation

We use the labour income tax function, to capture the progressively of both the tax schedule and government transfers. In order to estimate θ_1 and θ_2 we follow the method of (Ferriere and Navarro 2018). Thus we fix $\theta_1 = 0,85$ and $\theta_2 = 0,16$, for 1980. For 2010 the values of θ_1 and θ_2 are set to 0,87 and 0,095, respectively.

The rates for social security are set assuming no progressivity, the taxes on behalf for employer and employee are set to 7,65% for both steady states. Furthermore, capital taxation and consumption taxation are set according to the values obtained by (Mendoza, Razin, and Tesar 1994), which are $\tau_c = 5{,}4\%$ and $\tau_k = 46{,}9\%$. For 2010 these values are 5,5% and 36% for consumption and capital, respectively, following Brinca et al. (2016).

[3] The values are: $y_1 = 0{,}2647$; $y_2 = -0{,}00539$ and $y_3 = -0{,}000036$; $\rho_u = 0{,}335$; $\sigma_\epsilon = 0{,}3066$.

[4] For a more detailed view see Reichling and Whalen (2012).

ENDOGENOUS CALIBRATED PARAMETERS

Since some parameters do not have an empirical counterpart, they are calibrated using SMM. These parameters are calibrated to match the target values in Brinca et al. (2016), as in Table 1. We choose β_1, β_2, χ, σ_a and φ to minimize the loss function:

$$L(\beta_1, \beta_2, \chi, \sigma_a, \varphi) = || M_m - M_d ||$$

M_m is the moment in the data and M_d refers the moments in the model. We have five instruments, and five moments in the data to have an identified system. Table 2 displays the values of the parameters calibrated by SMM.

Table 1: Calibration fit

Data moment	Description	Source	Target	Model value
$\frac{K}{Y}$	Capital-to-output ratio	PWT 8.0	3,3	3,3
B90	Income share of the bottom 90%	WID	0,3287	0,33
$\bar{n}$	Fraction of hours worked	OECD	0,3	0,3
IGini	Income Gini	WID	0,485	0,46
$Q_{75\text{-}80}/all$	Av wealth of 75-80/Av wealth of all	LWS	1,513	1,51

Table 2: Parameters calibrated using SMM

Parameter	Values	Description	Target
β_1	0,27	Beta 1	$\frac{K}{Y}$
β_2	1,0043	Beta 2	Income share of the bottom 90%
χ	8,3	Disutility of work	Fraction of hours worked
σ_a	0,15	Variance of ability	Income Gini
φ	13,43	Bequest motive	Av wealth of 75-80/Av wealth of all

4. Results and Discussion

The supply of skills is shaped by many variables, such as demographic trends, preferences and education shifts. Due to technological changes, workers may want to upgrade their skills, as the skill demand increases. Initially, technical change was viewed as factor-neutral, this is, improvements in the TFP leave marginal rates unchanged. However, empirically, we observe a rise in the skill premium, as well as the increase in skilled labor supply, as we show in section 2. Even with a higher supply of skilled people since 1970, wages for skilled people kept rising, which can be observed as pieces of evidence of skill-biased technological change. In fact, Acemoglu and Autor (2011) argue that technical changes are by its nature skill-biased.

Thus, some argue that the changes in production are not just an effect of the decrease in the price of investment, but also an increase in the skill supply. As society keeps getting more educated, employers will prefer to use people's ability to make them even more productive and, as they gain experience they can be more profitable more rapidly than unskilled households. Furthermore, skilled households have an advantage compared with unskilled households, since they give less uncertainty to the employer.

For simplicity, most of the studies assume that production function elasticity of substitution between capital and labor is equal to 1. However, recently, a departure from this assumption has taken place. If the elasticity of substitution between capital and unskilled labor is higher than 1, firms will substitute labor for capital. In this manner, we guarantee that the growth of skilled labor is greater than the growth of unskilled labor. In this sense, if $\sigma > 1$, then the two inputs are substitutes. Thus, the economy will be endogenously augmented through capital, because an increase in A_{kt} will increase the marginal productivity of capital. This effect occurs jointly with an increase in the skill premium and marginal productivity of skilled labor. However, the unskilled labor has lower productivity. Contrary, if the elasticity of substitution between capital and unskilled labor is lower than 1, the two factors will be complements and the demand shift will decrease the skill premium, and thus, the factors are complements. This goes according with the results reported by Acemoglu and Autor (2011), Autor, Levy, and Murnane (2003), Karabarbounis and Neiman (2013) and Krusell et al. (2000).

Krusell et al. (2000) show that the values for the elasticity of substitution between skilled labor and capital are between 0 and 1,2 and the values for the elasticity of substitution between unskilled labor and capital are between 0,5 and 3. Therefore, skilled labor and capital tend to be complements and unskilled labor and capital tend to be substitutes. This interpretation has consequences for taxation because taxes depend on the heterogeneous characteristics of the households. Hence agents with higher skill level should face higher taxes and unskilled households should face lower taxes, that is, the lower the substitution between factors the higher should be the tax rate imposed, and vice-versa.

To capture the SBTC, we use capital-augmenting technology, A_{kt}, as a substitute. We use an elasticity of substitution for skilled labor and capital lower than 1. Thus these factors are gross complements. Contrary, we set an elasticity of substitution for unskilled labor and capital higher than 1, stating that these factors are gross substitutes.

Our experiments are as follows. First, we calibrated the model for the U.S. to match the capital-output ratio, average hours, and moments of income and wealth distributions for 1980. Then, we changed the tax system according to 2010 values, as referred in section 3.

After this change, we compute the changes in the total factor productivity (TFP) and skill-biased technological change to replicate the growth in PIB per capita between 1980 and 2010. We follow (Greenwood, Hercowitz, and Krusell 1997) and keep the contribution the TFP and SBTC constant and equal to one-half.[5]

With this model, we capture several aspects of the U.S. economy since 1980 to 2010, such as: (i) rising skill premium; (ii) increase in income and wealth Gini coefficient; (iii) decrease in the wealth share owned by the bottom 90% of families (iv) an increase in skilled labor share; (v) a reduction in unskilled labor share; (vi) and, an increase in wage dispersion. Furthermore, our model recognises, as expected, that people spend more hours working and the supply of skilled households increased in 2010, due to a decrease in progressive labor taxation.

Our model accounts for 48% of the total increase in the income Gini Index for the period. Then, we access the contribution of changes in the tax system and changes in the investment-specific technological change separately, by changing each factor at a time. We find that changes in the tax system account for 5,7% of the total increase in income inequality, while changes in investment-specific technological change account for 42%.

5. **Conclusion**

Most of the economists believe that the U.S. wage structure is influenced predominantly for technological shifts, especially since 1980. We use an overlapping generations model with incomplete markets, featuring skill-biased technological change to answer *quantitatively* how skilled-biased technological change and taxation explain income inequality in the U.S. from 1980 to 2010. To generate SBTC we assume that agents born with different abilities, whereby some are endowed with abilities that are complemented by capital and others are endowed with capabilities that are substituted by capital, i.e., we use the substitution of unskilled labor for capital as a reasonable mechanism to explain the skill-biased technological change ((Karabarbounis and Neiman 2013; Krusell et al. 2000)).

We calibrated our model to match the U.S. economy in 1980. The model captures the rise in the skill premium, the increase in income inequality, as well as the increase in the share of the skilled population, opposing to the decrease in the share of unskilled labor. This shows that high-skilled workers have, indeed, an advantage in the labor market because they give less uncertainty to the employers. More importantly, we find that changes in taxation and capital-skill complementary jointly account for 48% of the increase in income Gini. Furthermore, we find that SBTC account for 42%, while taxation alone accounted for 5,7%.

An essential introduction to the model can pass for add an endogenous education choice in light with (Ábrahám 2008). Before entering in the economy, a household can observe its ability and decide whether to begin to work as an unskilled worker or to attend college. This decision will depend not only on the distribution of agents ability, but also on the initial wealth distribution, taking into account a costly educational choice. Moreover, it is also possible to study an optimal taxation across the transition path between steady-states.

[5] With this approach the authors conclude that the growth in output is mostly explained by investment-specific technological change.

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Appendix

Tax function

Given the tax function[6]

$$ya = \theta_1 y^{1-\theta_2}$$

which we employ, the average tax rate is defined as

$$ya = (1 - \tau(y))y$$

thus

$$\theta_1 y^{1-\theta_2} = (1 - \tau(y))y$$

$$1 - \tau(y) = \theta_1 y^{1-\theta_2}$$

$$\tau(y) = 1 - \theta_1 y^{1-\theta_2}$$

$$T(y) = \tau(y)y = y - \theta_1 y^{1-\theta 2}$$

$$T'(y) = 1 - (1 - \theta_2)\theta_1 y^{-\theta 2}$$

In this sense, the tax wedge for any two incomes (y_1, y_2) is given by

$$1 - \frac{1 - \tau(y_2)}{1 - \tau(y_1)} = 1 - \left(\frac{y_2}{y_1}\right)^{-\theta_2}$$

and therefore independent of the scaling parameter θ_1. In this manner, one can raise average taxes by lowering θ_1 and not the progressivity of the tax code, since the progressivity is uniquely determined by the parameter θ_2.

Labor tax function calculation

In order to estimate θ_1 and θ_2 we follow (Ferriere and Navarro 2014). The authors calculated the progressive tax rate as:

$$\theta_2 = \frac{AMTR - ATR}{1 - ATR}$$

[6] This first part of the appendix is borrowed from (Holter, Krueger, and Stepanchuk 2019).

We use data from (Mertens and Montiel Olea 2018) for AMTR (Annual Marginal Tax Rate). ATR (Annual Tax Rate) is equal to:

$$ATR = \frac{TotalTaxLiability}{TotalIncome}$$

The data for Total Tax Liability is retrieved from Statistic of Income and Total Income data is retrieved from (Piketty and Saez 2003).

Noticing that AMTR is equal to the sum of AMIITR (Average Marginal Individual Income Tax Rate) and AMPTR (Average Marginal Payroll Tax Rate), the formula was changed using only AMIITR, which incorporates solely tax rate series for the federal individual income tax, because the presented model already incorporates the taxation for social security.

The level of tax rate can be seen as a quantitatively close measure of the average tax rate (Ferriere and Navarro 2014). Thus, if we use $y = 1$ we are assuming that the household income equals to the mean income and we obtained the same values for both measures.

Table 3: Tax function estimations

Year	θ_1	θ_2	θ_2 with AMTR
1980	0,849	0,159	0,354
2010	0,869	0,095	0,214

Table 4: Parameters held constant across steady states

Parameter	Value	Description	Source
Technology			
α	0,36	Capital share to output	Literature
δ	0,06	Capital depreciation rate	Literature
ρ_u, σ_ϵ	0,335, 0,3066	$u' = \rho_u u + \in, \in \sim N(0, \sigma_\in^2)$	PSID
Preferences			
η	1	Inverse Frisch Elasticity	(Trabandt and Uhlig 2011)
σ	1,2	Risk aversion	Literature
Taxation			
$\tilde{\tau}_{ss}$, τ_{ss}	7,65%	Social security taxes	-

Table 5: Parameters change across steady states

Parameter	Description	1980	2010
Taxation			
τ_k	Capital tax	0,469	0,36
τ_c	Consumption tax	0,054	0,05
Φ_1	Level of labor tax	0,849	0,869
Φ_2	Progressivity of labor tax	0,159	0,095

Note: For capital and consumption taxation in 1980 we use the values from (Mendoza, Razin, and Tesar 1994) and for 2010 we use the values from (Brinca et al. 2016). For labor taxes we use (Ferriere and Navarro 2014) method.

Table 6: Inequality measures

Parameter	1980	2010	Source
Inequality			
Income Gini	0,4585	0,586	WID
Wealth Gini	0,8085	0,8842	WID
Bottom 90%	0,3287	0,243	WID

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Universal basic income and skill-biased technological change

Rendimento Básico Universal e progresso tecnológico Enviesado em Função das Qualificações

José Coelho

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ABSTRACT
In the last decades, income inequality has been on the rise in the U.S. The growing skill premium suggests the pivotal role of skill-biased technological change (SBTC) in promoting the observed increase in inequality levels. In this context, labor income tax structures have been central to the policy debate. We have developed an overlapping generations model to perform a welfare evaluation of Universal basic income (UBI) tax structures and verify how these interact with SBTC. I find that an UBI system would have improved social welfare in 2010 when compared to the existing tax system and determine that this result is primarily motivated by SBTC.
Keywords: Income inequality; skill premium; optimal taxation; universal basic income.

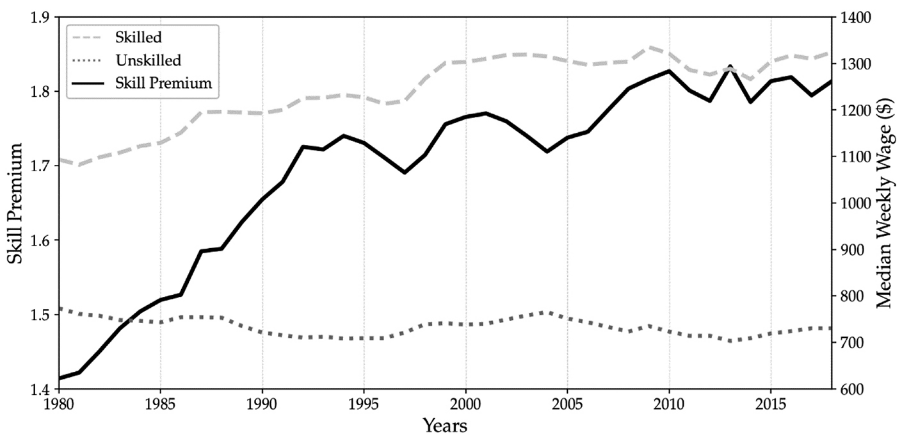
JEL Classification: E24; E62; H21.

RESUMO
Nas últimas décadas, a desigualdade de rendimento tem aumentado nos EUA. O crescente prémio salarial para trabalhadores qualificados sugere o papel central do *Skill-Biased Technological Change* (SBTC) na promoção do aumento observado nos níveis de desigualdade. Neste contexto, as estruturas do imposto sobre o rendimento do trabalho têm sido centrais para o debate político. Este artigo utiliza um modelo de gerações sobrepostas para avaliar o bem-estar das estruturas tributárias de rendimento básico universal (UBI) e a interação com o SBTC. Os resultados mostram que um sistema UBI teria melhorado o bem-estar social em 2010 quando comparado ao sistema tributário existente, resultado esse motivado principalmente pelo SBTC.
Palavras-chave: Desigualdade de rendimento; prémio salarial de trabalho qualificado; taxação ótima; rendimento básico universal.

1. Introduction

More and more, society is faced with the everyday reality of automation as it has become an issue of outmost relevance. With many of the discussions regarding it being centered around its political and ethical implications, one of the key subjects to these debates is the one of technological unemployment. The process of job destruction due to technological progress has been mentioned since long ago. Keynes (1930) commented that new ways of economizing on labor were increasingly being found faster than new uses for labor itself and even way before, Ricardo (1821) had already discussed this issue voicing his worries for the class of laborers. In addition to this, automation has also been linked to a process named skill-biased technological change (SBTC)[1]. Through this process, the development of new technologies ends up favoring skilled workers in detriment of non-skilled ones and generating a skill premium that has been on the rise as seen in Figure 1. This increase happens at a time when the U.S. is also facing a problem of rising income inequality.

Figure 1: Comparison of earning levels



Note: Constant-dollar median weekly earnings of full-time wage and salary workers, 25 years and over. Skilled workers correspond to those with a Bachelor's degree or higher. Non-skilled ones are the others. This skill premium is calculated as the ratio between the two without accounting for composition changes related to gender, sex, etc. Data for the U.S. from: BLS Current Population Survey.

This possible relationship between skill-biased technological change and income inequality has been well established and documented in the literature (e.g. Mincer (1991), Autor, Katz, and Krueger (1998), Katz and others (1999)). Furthermore, the negative impact of inequality on social welfare is also extensively well reported with it being associated with poorer growth, higher poverty, social and political instability and other negative social and

[1] The issue of skill-biased technological change is central to this article and therefore, will be better analyzed and explained in the subsequent sections.

economic factors. Dabla-Norris et al. (2015) IMF report has a comprehensive summary of the negative socioeconomic consequences of income inequality.

On the other side of the coin, technological change is also largely considered a main proponent of economic growth and consequently, its overall welfare impact can be rather ambiguous as concluded by Eden and Gaggl (2018). All in all, conflicting views on the short and long-run consequences of technological development have been emerging for a long time but due to the higher speed of technological progress experienced recently, this topic has become of much higher importance in recent years.

In the middle of this context, a particular type of tax structure has gained notoriety, that is universal basic income (UBI). UBI consists of a cash transfer from a country's government to all its citizens and it can be either conditional on some requirements or totally unconditional. Its proponents focus their arguments on the fact that it helps low-wage workers by giving them the necessary flexibility to avoid the unemployment trap and make optimal career and life choices, therefore improving literacy and productivity, decreasing crime and stabilizing the economy during economic downturns. Contrarily, its opponents argue that it discourages work and productivity and puts a huge burden on the government budget. Through contrasting lenses of analysis, different articles have weighed these pros and cons (eg: Van Parijs (2004), Van Parijs and Vanderborght (2017)). Furthermore, some pilot programs and experiments have already been tested in countries like Brazil, Canada, Finland, Kenya and even the U.S., with conflicting results being documented, mostly likely due to the difficulty of a full large-scale trial of such system.[2]

This research proposes to compute the optimal level of an UBI system financed with a flat labor tax rate for an economy resembling that of the U.S. in 1980 and 2010. Through this analysis, the article intends to evaluate whether an unconditional basic income could encompass a social welfare improvement over past tax systems, and then, verify whether this pertains to SBTC or not. This will be done by developing an overlapping generations model, similar to that of Brinca et al. (2016), featuring agent heterogeneity, uninsurable idiosyncratic earnings risk and incomplete markets. Additionally, the model will divide labor into skilled and non-skilled categories, a framework akin to that of Krusell et al. (2000), Autor, Levy, and Murnane (2003) and Ferrreira (2019). Since the model sets a steady-state, full-employment is assumed and consequently, the issue of job destruction will not be addressed. Instead, the focus will be on the issue of rising inequality and wage dispersion in the context of SBTC.

It is found that an UBI system would have improved U.S.'s social welfare in comparison to 2010's tax-transfer system and that the optimal level of UBI would actually consist of a lump-sum transfer of around 8% of and a flat income tax rate of 28.5%. Moreover, it was also determined that this result is mainly driven by the process of skill-biased technological change. The rationale behind these conclusions is that, in the modeling choice used, technology is factor-augmenting, therefore creating a positive shock to the permanent component of skilled workers productivity. This raises the skill premium and consequently inequality, therefore motivating the case for more redistribution. The reasoning presented is very similar to the one of Heathcote, Storesletten, and Violante (2017).

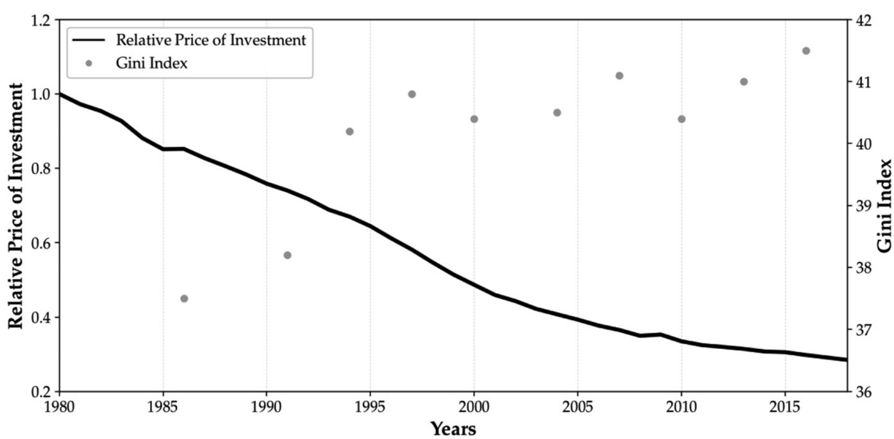
[2] Examples of these experiments in the U.S. include the the Negative Income Tax (NIT) experiments in the 60s and 70s or the Permanent Fund Dividend (PFD) paid to Alaska residents.

The article will be organized as follows. Section 2 surveys the relevant literature; section 3, describes the model and explains the calibration procedure; section 4 details the fiscal experiment; Section 5 reports the quantitative results; and section 6 presents the conclusions.

2. Related Literature

This paper develops on the existing literature on skill-biased technological change which builds on the notion that low-skill jobs tend to be more easily automated as they are substitutable by capital, in contrast to high-skill ones which are generally more complementary to capital. Taking that into consideration, as the price of investment decreases due to new and cheaper technology being developed, there will consequently be decreased demand for lower-skilled workers associated with higher demand for high-skilled ones. This is then, largely considered one of the main factors behind increasing skill wage premiums which in turn, are responsible for increasing income inequality (e.g. Krusell et al. (2000), Autor, Levy, and Murnane (2003)). Brinca et al. (2019) find that both SBTC and decreases in tax progressivity since the 80's account for more than 30% of the observed increase in income inequality. Figure 1 shows the evolution of income inequality and the price of investment for the U.S. since 1980. It can be promptly seen that the relative price of investment declined from 1 in 1980 to 0.285 in 2018, strongly demonstrating the degree of technological transformation seen in the last decades.[3]

Figure 2: Gini Index and investment price



Note: Gini index (world bank estimate) and relative price of investment calculated as the ratio between the CPI and the implicit price deflator on fixed investment on equipment – 1980 is normalized to 1. Data for the U.S. from: The World Bank; BEA

[3] The relative price of investment was normalized to 1 in 1980 for simplicity purposes.

To further deepen this idea, UK's Office for National Statistics provides some data on the probability of automation occurring to certain professions. From this list, the least probable workers to face automation are medical practitioners with a probability of 18.1%, while the most probable are waiters with a probability of 72.8%. By analyzing the full data table, it is clear that jobs that require no degree have, on average, a much higher probability of being automated than the ones who require such degree.[4]

This article is also linked to literature on the decline of the labor share that demonstrates the substitution of labor for capital in the production process. In relation to this, both Karabarbounis and Neiman (2013) and Eden and Gaggl (2018) conclude with the same result, that the fall in investment price is responsible for around half of the decline in labor share.

Additionally, the present article also builds on the research on optimality of fiscal policy measures. With respect to this, many different tax structures have been researched and suggested with most focusing on taxation of labor and capital.[5]

Concerning optimal labor taxation, Heathcote, Storesletten, and Violante (2017) concludes that it would be possible for welfare to be improved with a decrease in tax system progressivity. It follows, nonetheless, by suggesting that the model has limiting forces and that optimal progressivity varies with the level of inequality. On the other hand, Saez (2001) concludes by stating that marginal tax rates ought to be raised between the middle and top of the income distribution, a conclusion similar to that of Krueger, Ludwig, and others (2013) which, in a model with endogenous education decisions, states that the labor income tax should be rather progressive. Further relevant literature regarding this topic includes the work of Conesa and Krueger (2006) which concludes that the optimal income tax system can consist of a flat tax rate with a considerable deduction.

Relatively to capital taxation, Chamley (1986) concludes that in the short-run, optimal capital taxation might be positive but in the long-run it should be zero. In contrast Aiyagari (1995) reasons that it should always be positive, including the long-run. In addition, Conesa, Kitao, and Krueger (2009) conclude that the optimal consists of a heavy capital tax.

Another policy which has been largely suggested as a solution to inequality and has gained considerable mediatic attention recently is the one of protectionism and rising trade barriers. Krusell et al. (2000) conclude, however, that this is not adequate and add that to narrow inequality, the focus should be on improving training and education for non-skilled workers.

Relatively to the disparities found in the conclusions of optimal taxation papers, it can be verified that one of the major reasons behind them regards the attribution of different causes to income inequality. With regard to this, the present article will also contribute by studying SBTC as one of these possible causes.

To end up with, this paper contributes to the research done on the role of universal basic income as a redistributive policy. Most of this research has been empirical and focused on specific national or regional applications of quasi-UBI programs. In this regard, Marinescu (2018) reviews the possible impact of unconditional transfer implementation in developed countries, more particularly the U.S. Based on the Alaska PFD, she concludes that unconditional transfers affect little the labor supply but might improve children's education.

[4] An excerpt of the full table can be found in Appendix.

[5] Most of research on optimal taxation is built on the work of Ramsey (1927) and Mirrlees (1971).

From Hanna and Olken (2018), evidence from Peru and Indonesia suggests that targeted transfer methods dominate universal transfer ones in terms of welfare gains and suggest this evidence might be relevant for developing countries in general. In Iran, Salehi-Isfahani and Mostafavi-Dehzooei (2018) found that the cash transfer program of 2011 entailed a positive impact in labor supply of women and self-employed men and either a positive or non-significant impact in the labor supply of the overall population. For Finland, Koistinen and Perkiö (2014) conclude that the implementation of basic income has been shown to be of great difficulty as it has failed repeatedly.

Finally, in a more recent series of papers, Guerreiro, Rebelo, and Teles (2017) using a task-based framework confirms the relationship between automation and income inequality and suggests changes ought to be made to the existing U.S. tax system. This article follows by suggesting the implementation of a universal basic income system with lump-sum transfers financed by a tax on robots. Additionally, and in a more similar fashion to the current paper, Lopez-Daneri (2016) analyzes the effects of a negative income tax system implementation through a life-cycle model calibrated to the U.S. and finds the negative income tax to be better in performance than a simple flat tax on labor.

3. Model and Benchmark Economy Calibration

This work employs the model 2 of the introduction chapter. The model was calibrated to match moments of the economy of the U.S. in 1980, the benchmark economy, using a method similar to that of Brinca et al. (2016). Some parameters can be calibrated outside of the model as they have direct empirical counterparts, these are described in table 1. The remaining of parameters are endogenously calibrated using the Simulated Method of Moments (SMM) approach.

Preferences

The value of the Frisch elasticity of labor supply varies greatly in the literature, η. In this calibration it is set to 1, according to a variety of recent studies (e.g. Trabandt and Uhlig (2011)). In addition, risk aversion was set to 1.1. The parameters φ, governing the utility of leaving bequests, χ, governing the disutility of working an additional hour, and the discount factors $\{\beta_1, \beta_2\}$ are calibrated so that the model output matches empirical data moments. This part will be discussed further below.

Labor and Wages

To estimate the life cycle profile of wages, data from the Panel of Study of Income Dynamics (PSID) is used and the following regression is run:

$$\ln(w_i) = \ln(w) + \gamma_1 j + \gamma_2 j^2 + \gamma_3 j^3 + \epsilon_i,$$

where j is the age of individual i. The persistence of idiosyncratic risk is set to 0.335 in light of Brinca et al. (2016). The variance of idiosyncratic risk, σ_ϵ is calibrated through SMM to match the variance of $\ln(w_i)$ to that of the data. The parameter for the variance of ability, σ_a is also calibrated through SMM so that the model's income Gini also matches the corresponding data moment.

Technology

In relation to the calibration of technology and the production function, firstly the depreciation rate δ is fixed in 0.06 following Brinca et al. (2016). Relatively to the CES production function parameters, firstly the share of capital in the capital/skilled-labor composite, Φ_2, is set to 0.805 and the share of the composite in the composite/non-skilled-labor equation, Φ_1, is set to 0.550. These go in line with the analogous parameters used in Eden and Gaggl (2018). Then, the elasticity of substitution (EOS) between skilled labor and capital, σ, inside the composite is set to 0.670 and the EOS between the composite and non-skilled labor, ρ, is set to 1.670. These values were found to be adequate in order to allow for the process of skill-biased technological change to be modeled. With a $\rho > 1$ and a $\sigma < 1$ the degree of substitutability between non-skilled labor and capital is considerably higher that that between skilled labor and capital.

Table 1: 1980 Calibration Summary

Description	Parameter	Value	Source
Preferences			
Inverse Frisch elasticity	η	1.000	Trabandt and Uhlig (2011)
Risk aversion parameters	λ	1.100	Literature
Labor and Wages			
Parameter 1 age profile of wages	y_1	0.265	Brinca et al. (2016)
Parameter 2 age profile of wages	y_2	-0.005	Brinca et al. (2016)
Parameter 3 age profile of wages	y_3	0.000	Brinca et al. (2016)
Persistence of idiosyncratic risk	ρ_u	0.335	Brinca et al. (2016)
Technology			
Depreciation rate	δ	0.060	Brinca et al. (2016)
Share of the composite	ϕ_1	0.550	Eden and Gaggl (2018)
Share of capital	ϕ_2	0.805	Eden and Gaggl (2018)
EOS non-skilled / composite	ρ	1.670	Authors' calculations
EOS skilled / capital	σ	0.670	Authors' calculations
Total factor productivity	A	1.000	Normalization
Government and Social Security			
Consumption tax rate	τ_c	0.054	Mendoza et al. (1994)
Capital income tax rate	τ_k	0.469	Mendoza et al. (1994)
Tax scale parameter	θ_1	0.940	Implied by clearing condition
Tax progressivity parameter	θ_2	0.160	Ferriere and Navarro (2018)
Government debt to GDP	B/Y	0.320	FRED
Military spending to GDP	G/Y	0.053	World Bank
SS tax employees	$\tilde{\tau}_{ss}$	0.061	Social Security Bulletin, July 1981
SS tax employers	τ_{ss}	0.061	Social Security Bulletin, July 1981

Taxes and Social Security

The tax schedule is modeled according to a progressive schema as illustrated before. From this equation, the progressivity parameter θ_2 is fixed in 0.160 following the method of Ferriere and Navarro (2018). By setting the lump-sum transfer g to 0.000, the value of θ_1 implied by the government budget clearing condition was 0.940. Additionally, the consumption tax rate τ_c and the capital income tax rate τ_k are set to 0.054 and 0.469 consecutively to match the values obtained in Mendoza, Razin, and Tesar (1994). For the social security taxes, both values are set to 0.061.

Endogenously Calibrated Parameters

To calibrate the parameters that do not have direct empirical counterparts, discount factors $\{\beta_1, \beta_2\}$, disutility of work χ, utility of leaving bequests φ, variance of ability σ_a and variance of idiosyncratic risk σ_ϵ, the simulated method of moments (SMM) was used. Through it, the following loss function was minimized:

$$L(\beta_1, \beta_2, \varphi, \chi, \sigma_a, \sigma_\epsilon) = || M_m - M_d ||$$

where M_m and M_d are the moments in the model and in the data respectively. For the system to be just-identified and since there are six model parameters to be calibrated endogenously, the need for six data moments arises. These data moments that will be used as targets are described in Table 1 The parameters calibrated with these targets are presented in Table 2.

Table 2: Calibration Fit

Data Moment	Description	Source	Data Value	Model Value
$\bar{a}_{75-80}/\bar{a}$	Mean wealth age 75-80 / Mean wealth	LWS	1.51	1.51
K/Y	Capital-output ratio	BEA	3.00	3.00
Var(ln$w$)	Variance of log wages	CPS	0.29	0.29
$\bar{n}$	Fraction of hours worked	OECD	0.33	0.33
Q_{90}	Income share of the bottom	WID	0.66	0.65
Gini	Gini Index	WID	0.46	0.46

Table 3: Parameters Calibrated Endogenously

Parameter	Value	Description	Data Target
Preferences			
φ	5.850	Bequest utility	$\bar{a}_{75-80}/\bar{a}$
β_1	0.978	Discount factor 1	K/Y
β_2	0.100	Discount factor 2	Q_{90}
χ	8.200	Disutility of work	$\bar{n}$
Labor and Wages			
σ_a	0.355	Variance of ability	Gini
σ_ϵ	0.100	Variance of risk	Var($\ln w$)

Besides the calibration of the benchmark economy, the model was later calibrated to match the tax-transfer system, social security, level of debt, government expenditure and TFP of the U.S. in 2010. All other parameters were kept constant between steady-states. For the exogenously calibrated values of government and social security parameters, these are presented in table 6 in Appendix.

Relatively to TFP, this is the model's representation of technological change, and a crucial element of this paper's analysis. The TFP was calibrated for 2010 to replicate the growth of from 1980 to 2010. Since the TFP is normalized to 1.000 in 1980, the resulting TFP for 2010 was 1.720.[6]

Additionally, to substantiate the good performance of the model, some of the statistics were verified to check whether they match the empirical data. The model predicted that from 1980 to 2010, both the income and wealth Gini increased, the wage premium for skilled workers increased and wage dispersion increased. All these match the empirically observed data and therefore support the model's robustness.

4. **Fiscal Experiment**

The focus of this experiment is centered on the evaluation of the welfare effects deriving from the implementation of a universal basic income system. Consequently, the design of this UBI system ought to be clarified. In this paper, the analyzed system will be comprised of a universal and unconditional lump-sum transfer which is paid for by consumption and capital taxes and also by a flat labor tax with no progressivity. Consequently, the experiment consists of a steady-state analysis comparing the optimal level of UBI for the years of 1980

[6] The data used for GDP per capita was taken from: World Bank national accounts data, and OECD National Accounts data files.

and 2010 in the U.S. These years were chosen grounded on the literature and also due to the fact that the gap between them is considerably representative of the high increase in U.S.'s income inequality. Taking into account the main purpose of this analysis, the fact that more recent years were not used is decidedly not detrimental to results.

It is relevant to note that in both of the analyzed years, 1980 and 2010, the tax system has no universal transfer to households, $g = 0$, but has some degree of progressivity, $\theta_2 > 0$. Therefore, firstly the optimal lump-sum transfer (and associated labor tax level), will be calculated for a hypothetical UBI system in both years. This will tell whether the optimal level of UBI changed from 1980 to 2010 in light of the process of skill-biased technological change. Secondly, a baseline comparison will be done between the actual 1980 and 2010 tax systems and the UBI one. This will then answer the question on whether the implementation of UBI would entail a welfare gain in one, both or none of the years. The procedure used will be further explained in the following subsections.

4.1. Welfare Criteria

With the purpose of comparing different lump-sum transfer levels and whether they are beneficial or not to society, a proper welfare measure is needed. In this paper, two different ones are used. The first one is the expected social welfare which can be expressed as follows:

$$SW_t^1 = E[V]_t = \frac{1}{\int d\Phi}\left[\int_{j<45} V(h, \beta, a\ u, j)_t d\Phi + \int_{j\geq 45} V(h, \beta, j)_t d\Phi\right]$$

This is the criteria which determined the results. However, for completeness and confirmation, a second measure is also employed which was borrowed from McGrattan and Aiyagari (1997) and can be expressed as:

$$SW_t^2 = \Omega = \int\int V(h, \beta, a, u, j)\, dH(h, \beta, a, u, j)$$

With regard to notation, V is the optimal value function and H is the steady-state joint distribution of assets and productivity.

4.2. Optimal Evaluation

To compare the optimal level of UBI in 1980 and 2010, the evaluation procedure undergone was the following:

Computation of social welfare for the benchmark economy (U.S. 1980) with the existing tax system.

Computation of the optimal lump-sum transfer with the UBI system in 1980, through a welfare evaluation.

Computation of social welfare for the U.S. 2010 economy with the existing tax system.

Computation of the optimal lump-sum transfer with the UBI system in 2010, through a welfare evaluation.

4.3. Causality

It is highly relevant to note that after comparing the optimal UBI levels for 1980 and 2010, one can not immediately conclude that this difference is attributed to technological change. As previously mentioned, the year of 2010 was calibrated to match not only the technological development but also the tax system, social security, debt and government spending of that year. Therefore, to avoid the identification problem that would arise from this analysis, an intermediate step was done in the process. This involved re-calibrating 1980's economy to include the value of 2010's technology parameters and then calculating the optimal UBI level. This procedure was able to establish a causal relationship between technological change and UBI and accordingly, the rest of the analysis followed. The full results of this procedure are displayed in Appendix.

5. Results and Discussion

In this section, results from the aforementioned experiment will be presented and the main economic mechanisms explained. Firstly, the optimal evaluation procedure was conducted with its main results being displayed in figures 3 and 4.

To begin with, the most immediate result is that, considering an UBI system implementation, the optimal lump-sum transfer level rises from $g = 0$ in 1980 to $g = 0.125$ in 2010. For 1980, what this effectively means is that the optimal is actually the nonexistence of an UBI system. Therefore, one can say that in this year, for a system with a flat labor tax rate without progressivity, society's welfare would be maximized with no lump-sum transfer and a tax on labor income of as low as 8%.[7]

Figure 3: Optimal UBI level: 1980 and 2010

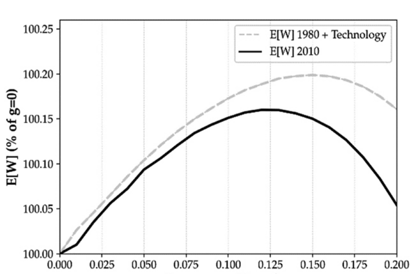
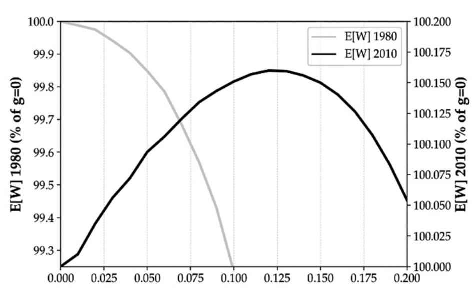


Figure 4: Optimal UBI level: 1980+Tech. and 2010



[7] Henceforth, it is relevant to take into account that all social welfare comparisons are done in % terms of a baseline level that should be indicated (e.g. an 100.1% of a $g = 0$ baseline means that that point entails a 0.1% improvement over a system with $g = 0$).

The striking difference for 2010 is that the optimal is actually positive with society's welfare being maximized with a lump-sum transfer of $g = 0.125$ corresponding to around 8% of $Y/Capita$. This, in turn, leads to an optimal government budget clearing labor tax of 28.5%. The welfare gain from this optimal over a $g = 0$ is of 0.163%.[8]

Table 4: 2010 Optimal Evaluation Results

					Optimal			
g	0.00	0.04	0.08	0.12	0.125	0.14	0.16	0.20
$1-\theta_1$	13.0	17.0	22.0	27.7	28.5	30.6	33.7	40.4
$Y/Capita$	1.66	1.64	1.60	1.57	1.56	1.54	1.52	1.47
$g\%(Y/Capita)$	0.0	2.4	5.0	7.7	8.0	9.1	10.5	13.6

By analyzing the results presented in table 4, one can infer on the economic intuition behind this optimal solution. As stated in section 3, the differences between the 1980 and 2010 steady-states are the government and tax system, and technological level measured through the TFP and SBTC. Even though all these parameter changes affected optimality, through the curves presented on figure 3, one can conclude that it is the technological change driving most of this result. The technology change, in this case, winds up being factor-augmenting since it generates a positive shock to the permanent component of skilled worker's productivity. Through market clearing conditions, this will, in turn, permanently increase their average earnings over non-skilled workers which explains the observable skill premium rise from 1980 to 2010. Accordingly, this skill premium rise increases wage dispersion and income inequality. By taking into account the concave profile of agent's utility, it becomes clear how an additional unit of consumption benefits the poor more than the rich and therefore, for a utilitarian social planner, having an economy with high inequality ends up being detrimental to social welfare.

In this type of context, it is straightforward to understand why in an UBI system, the optimal lump-sum transfer level is actually positive and equal to 8% of GDP per capita. Since the productivity shock from technological growth is permanent, the social planner has a higher motive for the application of redistribution. Taking this into account, from $g = 0$ until $g = 0.125$, the gains from redistribution are large and social welfare improves. However, from that point onwards, the fact that the labor tax level starts rising above the 30% mark, generates an intense distortion of agent's choices and discouragement of work which ends up being detrimental to welfare. Since the most productive agents are the ones paying an higher labor tax net of transfer, these are the most discouraged and as a consequence, the economy will tend do produce less and $Y/Capita$ will decrease, as seen in table 4. This clearly shows the trade-off between social equity and efficiency since higher redistribution comes associated with lower output.

[8] Full results of the welfare evaluation procedure are displayed in Appendix.

With regard to the result observed in figure 3, one can see that while the optimal level of the UBI system for 2010 is comprised of a g = 0.125, the one for an economy with 2010's technology inputted into 1980's characteristics, consists of a g = 0.150 corresponding to 9.55%of GDP per capita. The main takeaway from here is that 2010's social security, capital and consumption taxes, debt and government spending, decrease, in some away, the necessity for a high lump-sum transfer.

Table 5: Government parameters in the optimal: 2010 and 1980 + ΔTechnology

	g	$1-\theta_1$	τ_c	τ_k	B/Y	$Y/Capita$	$g\%(Y/Capita)$
1980 + ΔTechnology	0.150	20.4	0.054	0.469	0.320	1.57	9.55
2010	0.125	28.5	0.050	0.360	0.879	1.56	8.00

By looking at table 5, it is possible to construct an explanatory hypothesis for this result. In 1980, both consumption and capital income taxes are higher than in 2010 while the debt is lower. As in the model, the tax level $1-\theta_1$ is responsible for the clearing of the government budget constraint, with 1980's more balanced government budget, even if g is rather high, the level of labor tax needed to pay for it will be fairly lower. Thus, it may be optimal for this economy to have a higher lump-sum transfer than in the 2010 case since the associated labor tax level is not as high, which means that it is feasible to attain an higher level of UBI without as much distortion in terms of labor choices.

5.1. Ubi vs. Actual Tax System

It is imperative to reinforce that the optimal evaluations of the preceding section were merely focused in computing the optimal level of the lump-sum transfer for an UBI system with no progressivity on labor taxation. Even though this facilitated the comparison of these optimal values, the actual tax systems of 1980 and 2010 have some degree of progressivity to them. As a consequence, the question of whether the implementation of UBI would result in a welfare improvement over the actual systems still remains unanswered. This subject will be approached in this part of the paper.

Figure 5 presents the social welfare comparisons between 1980's tax system (the baseline) and an UBI system with different levels of lump-sum transfers. Figure 5 presents the social welfare comparisons between 2010's tax system (the baseline) and an UBI system with different levels of lump-sum transfers.[9]

[9] Note that in these figures, the grey lines just represent the baseline level of welfare with that year's actual tax system, they do not depend on the lump-sum displayed in the x-axis. The areas where the black line is above the grey line represent UBI levels that would entail an welfare improvement over the actual systems. Vice-versa for areas where the black line is below.

Figure 5: UBI vs. Actual Tax System (1980)

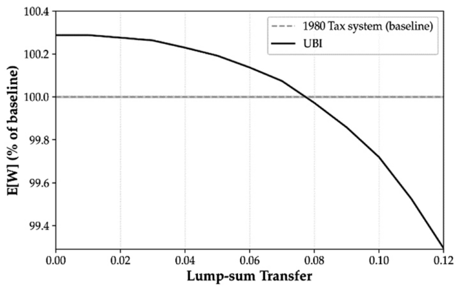
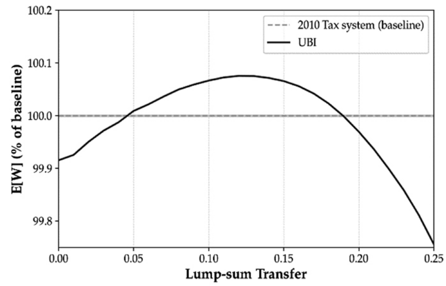


Figure 6: UBI vs. Actual Tax System (2010)



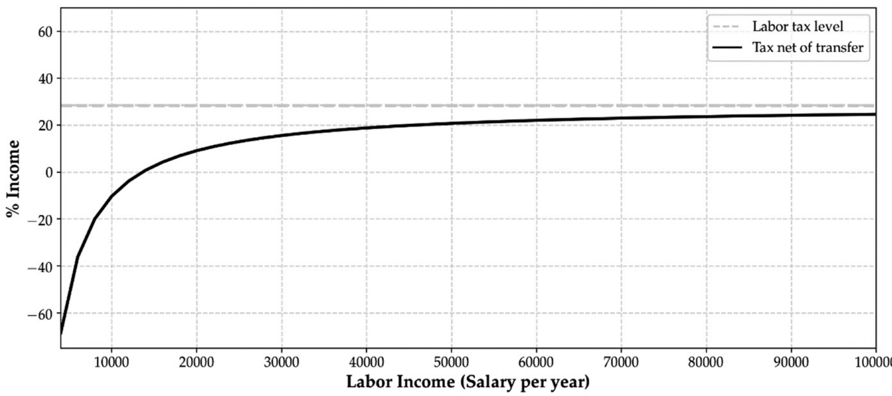
From these results, one can conclude that according to the model used, an UBI system would improve societal welfare both in 1980 and 2010. For 1980, as concluded above, the optimal would be to have neither a progressive labor tax nor UBI. However, if the UBI lump-sum does not surpass the level of g = 0.078 or 7.62% of *GDP/Capita* with an associated labor tax of 33%, society in 1980 would still be better off with an UBI system than with the existing system at the time.

More importantly, for 2010, even though the optimal is the aforementioned lump-sum of g = 0.125 corresponding to 8% of *GDP/Capita*, society would be better off with anywhere in the interval of $g \in [0.050; 0.188]$ corresponding to $g(\%) \in [3.07\%; 12.85\%]$ of *GDP/Capita* and with associated labor tax levels of $1-\theta_1 \in [18.5\%; 38.7\%]$, in comparison to the existing system at the time.

5.2. Application To Reality

This section will analyze the results found by translating them to a real-world application. The main result gathered from the above-mentioned experiment is that an UBI implementation with the right level of labor tax and lump-sum transfer would be optimal as a way of mitigating negative social welfare effects from skill-biased technological change. This optimal, for 2010, would consist of a lump-sum corresponding to 8% of *GDP/Capita* with an associated labor tax level of 28.5%. Applied to the U.S. economy of 2010, this would mean an annual transfer of around 3,877$ per person. The tax schedule in figure 6 depicts this system.

Figure 7: Tax schedule with the optimal UBI system



Looking at the represented schedule, one can see the labor tax level of the optimal, $1 - \theta_1 = 0.285$ and then the actual shape of the tax rate net of the lump-sum transfer. What can be concluded is that this UBI system with a flat labor tax rate and fixed universal lump--sum transfer, ends up creating a tax schedule similar to one of a system with a progressive labor tax. The main difference is that in this case, the tax rate can reach negative values, which happens when the tax rate paid on labor is inferior to the aforementioned transfer of 3,877$.[10] This is very identical to a negative income tax schedule, except for the fact that in the UBI fiscal system everyone pays the same tax in percentage, and everyone receives the same transfer in absolute terms.[11]

It is worth of notice that the value of 3,877$ for the lump-sum transfer appears to be rather small. For contextualization, U.S.'s median household income in 2010 was 49,445$ and presidential candidate Andrew Yang's "Freedom Dividend" proposal consists of a transfer of 1,000$ per month. This indicates that this paper's value would, most likely, be rather smaller than the amount needed to attain the main objectives of universal basic income. The reasoning behind this might be that the model should be expanded for a more complete analysis of these mechanisms. One relevant aspect regards the fact that UBI is generally discussed within the context of unemployment, something which is not modelled here. Nevertheless, this does not, in any way, invalidate the main results that were found, mainly the relationship between an optimal positive lump-sum transfer and the process of skill-biased technological change. The following section will summarize these results while concluding the research.

[10] This would be the case of workers earning an income below 13,603$.

[11] Some author's argue that in psychological terms this is beneficial since it reduces the stigma of social support from the state. Since everyone pays and everyone receives, the ones benefiting more would not feel as wrongly in doing so.

6. Conclusion

This research intended to analyze whether a universal basic income system could improve social welfare in the context of skill-biased technological change and additionally, evaluate the optimal level of this UBI system. With this purpose, a life-cycle model was calibrated to resemble the economy of the U.S. in 1980 and 2010 and within this framework, two major results were found.

Firstly, it was found that a UBI system comprised of a flat tax rate on labor and a lump-sum transfer could have improved social welfare in 2010 in relation to the existing tax-transfer system at the time. In addition, the optimal level would actually consist of a lump-sum transfer of 8% of GDP per capita paid for by a flat labor tax rate of 28.5%. Even though there are disparities between 2010 and today's economy, it can be logically hypothesized that today's optimal transfer would not differ exceedingly and if so, it would most likely be fairly higher.[12]

Secondly, it was also established that the above-mentioned result is primarily motivated by the process of skill-biased technological change. This was concluded through an analysis of technological progress alone, which predicted an optimal UBI transfer consisting of an even higher value of 9.55% of GDP per capita. This result is of great relevance as it establishes a strong positive relationship between SBTC and universal basic income which can be further examined in future work.

The mechanism found to be driving these results was mainly the factor-augmenting technological growth. This process occurs when technological progress ends up widening the gap between skilled and non-skilled workers' productivity. This, in turn, also widens the gap between their wages, elevating the skill premium and consequently, income inequality.

In light of these results, there are some thoughts worth of discussion. First of all, as referred earlier, redistributive policies in general, with UBI being no exception, highlight the trade-off between efficiency and equity. When applying this paper's results to reality, the optimal policy might change considerably. This is due to the fact that the weight the social planner attributes to equity or efficiency varies a great deal, depending on many other socioeconomic factors not reviewed in this paper. Additionally, one might ask whether another redistributive system such as increased tax progressivity or a negative income tax would entail an even higher welfare gain than UBI. Even though that type of comparison was not as deeply approached in this article, it is in fact a compelling point for future research. To end up with, as UBI is deeply discussed in association with social support for the unemployed, an extension of this model to relax the full-employment assumption would also be of great interest for posterior work.

[12] The basis for this statement is that income Gini has increased even more since 2010, giving strength to the argument in favor of redistribution.

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APPENDIX

Parameter Shifts

Table 6: Government and SS calibration 1980-2010

Description	Parameter	1980	2010	Source
Consumption tax rate	τ_c	0.054	0.050	Mendoza et al. (1994)
Capital income tax	τ_k	0.469	0.360	Mendoza et al. (1994)
Tax scale parameter	θ_1	0.940	0.895	Implied by clearing condition
Tax progressivity parameter	θ_2	0.160	0.095	Ferriere and Navarro (2018)
Government debt to GDP	B/Y	0.320	0.879	FRED
Military spending to GDP	G/Y	0.053	0.045	World Bank
SS tax employees	$\tilde{\tau}_{ss}$	0.061	0.077	Social Security Bulletin, July 1981
SS tax employers	τ_{ss}	0.061	0.077	Social Security Bulletin

Causality Inference

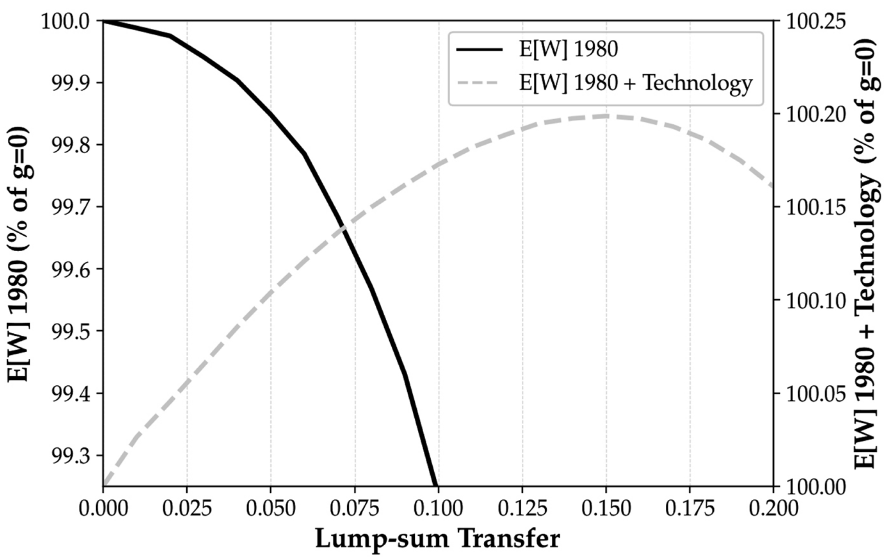
Table 7: Welfare evaluation for 1980's characteristics with 2010's technology

g	0	0.01	0.02	0.03	0.04	0.05
$E[W]$	1.00000	1.00026	1.00046	1.00065	1.00085	1.00104
g	0.06	0.07	0.08	0.09	0.10	0.11
$E[W]$	1.00121	1.00136	1.00150	1.00162	1.00173	1.00182
Optimal						
g	0.12	0.13	0.14	0.15	0.16	0.17
$E[W]$	1.00189	1.00195	1.00197	1.00199	1.00197	1.00193
g	0.18	0.19	0.20			
$E[W]$	1.00186	1.00175	1.00161			

Table 8: Welfare evaluation for 1980

	Optimal					
g	0	0.01	0.02	0.03	0.04	0.05
$E[W]$	1.00000	0.99988	0.99975	0.99941	0.99904	0.99849
g	0.06	0.07	0.08	0.09	0.10	0.11
$E[W]$	0.99785	0.99683	0.99569	0.9943	0.99235	0.99003

Figure 8: Welfare evaluation for causality experiment



Detailed Welfare Evaluation Results

Table 9: Welfare evaluation for 1980 with UBI

	1980 (UBI System)										
g	0.000	0.010	0.020	0.030	0.040	0.050	0.060	0.070	0.080	0.090	0.100
$E[W]$	1.00000	0.99988	0.99975	0.99941	0.99904	0.99849	0.99785	0.99683	0.99569	0.99430	0.99235
Labor Tax	0.080	0.115	0.135	0.170	0.198	0.230	0.260	0.300	0.337	0.375	0.420
$Y/Capita$	1.020	1.007	1.000	0.987	0.976	0.963	0.950	0.933	0.915	0.896	0.872
$g\%$ $(Y/Capita)$	0.000	0.010	0.020	0.030	0.041	0.052	0.063	0.075	0.087	0.100	0.115

Table 10: Welfare evaluation for 1980 with 2010 technology and an UBI system

	1980 with technological change (UBI system)										
g	0.000	0.010	0.020	0.030	0.040	0.050	0.060	0.070	0.080	0.090	0.100
$E[W]$	1.00000	1.00026	1.00046	1.00065	1.00085	1.00104	1.00121	1.00136	1.00150	1.00162	1.00173
Tabor Tax	0.030	0.045	0.054	0.064	0.075	0.086	0.097	0.108	0.119	0.130	0.142
$Y/Capita$	1.681	1.672	1.667	1.661	1.655	1.648	1.642	1.635	1.628	1.622	1.614
$g\%$ $(Y/Capita)$	0.000	0.006	0.012	0.018	0.024	0.030	0.037	0.043	0.049	0.055	0.062
g	0.110	0.120	0.130	0.140	0.150	0.160	0.170	0.180	0.190	0.200	
$E[W]$	1.00182	1.00189	1.00195	1.00197	1.00199	1.00197	1.00193	1.00186	1.00175	1.00161	
Tabor Tax	0.154	0.165	0.179	0.191	0.204	0.217	0.231	0.245	0.260	0.275	
$Y/Capita$	1.607	1.600	1.591	1.583	1.574	1.566	1.556	1.547	1.536	1.525	
$g\%$ $(Y/Capita)$	0.068	0.075	0.082	0.088	0.095	0.102	0.109	0.116	0.124	0.131	

Table 11: Welfare evaluation for 2010 with UBI

2010 (UBI system)											
g	0.000	0.010	0.020	0.030	0.040	0.050	0.060	0.070	0.080	0.090	0.100
$E[W]$	1.00000	1.00010	1.00035	1.00056	1.00072	1.00093	1.00106	1.00121	1.00134	1.00143	1.00151
Tabor Tax	0.130	0.135	0.148	0.160	0.172	0.185	0.195	0.208	0.220	0.234	0.247
$Y/Capita$	1.661	1.658	1.650	1.643	1.636	1.627	1.620	1.612	1.603	1.595	1.586
g% ($Y/Capita$)	0.000	0.006	0.012	0.018	0.024	0.031	0.037	0.043	0.050	0.056	0.063
g	0.110	0.120	0.130	0.140	0.150	0.160	0.170	0.180	0.190	0.200	
$E[W]$	1.00157	1.00160	1.00160	1.00156	1.00150	1.00140	1.00126	1.00107	1.00083	1.00054	
Tabor Tax	0.262	0.277	0.293	0.306	0.322	0.337	0.353	0.370	0.387	0.404	
$Y/Capita$	1.576	1.565	1.554	1.543	1.532	1.521	1.508	1.495	1.481	1.466	
g% ($Y/Capita$)	0.070	0.077	0.084	0.091	0.098	0.105	0.113	0.120	0.128	0.136	

UK ONS's Table Excerpt

Table 12: UK ONS's probability of automation by professional group for the UK in 2017

Lower Probability		Higher Probability	
Medical practitioners	0.181	Industrial cleaning process occupations	0.640
Higher ed. teaching professionals	0.203	Fork-lift truck drivers	0.644
Senior professionals of ed. establishments	0.206	Textile process operatives	0.646
Secondary ed. teaching professionals	0.206	Food, drink and tobacco process operatives	0.650
Dental practitioners	0.208	Other elementary services occupations n.e.c.	0.653
Psychologists	0.209	Elementary agriculture occupations n.e.c.	0.654
Medical radiographers	0.210	Retail cashiers and check-out operators	0.655
Physiotherapists	0.212	Van drivers	0.655
Occupational therapists	0.215	Elementary administration occupations n.e.c.	0.657
Primary and nursery ed. teaching professionals	0.220	Agricultural machinery drivers	0.658
Clergy	0.221	Launderers, dry cleaners and pressers	0.662
Physical scientists	0.221	Leisure and theme park attendants	0.665
Natural and social science professionals n.e.c.	0.221	Weighers, graders and sorters	0.672
Research and development managers	0.222	Packers, bottlers, canners and fillers	0.672
Speech and language therapists	0.222	Vehicle valeters and cleaners	0.678
Architects	0.225	Tyre, exhaust and windscreen fitters	0.681
Education advisers and school inspectors	0.225	Cleaners and domestics	0.681
Solicitors	0.226	Sewing machinists	0.686
Biological scientists and biochemists	0.228	Farm workers	0.690
Town planning officers	0.229	Kitchen and catering assistants	0.692
Senior police officers	0.230	Bar staff	0.707
Officers in armed forces	0.230	Elementary sales occupations n.e.c.	0.707
Further education teaching professionals	0.231	Shelf fillers	0.717
Actuaries, economists and statisticians	0.232	Waiters and waitresses	0.728

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Routinization and Covid-19: A Comparison Between the United States and Portugal

Rotinização e COVID-19: Uma comparação entre os EUA e Portugal

Piero De Dominicis

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ABSTRACT
The purpose of this study is to identify the role of automatization in increasing wage inequality, by comparing the United States to Portugal. Using the PSID and Quadros de Pessoal (Personnel Records), we find that labor income dynamics are strongly determined by the variance of the individual fixed component. This effect is drastically reduced by adding information on workers' occupational tasks, confirming that a decreasing price of capital and the consequent replacement of routine manual workers have deepened wage inequality. During the current crisis, we find that the ability to keep working is strongly related with the kind of occupation. As such, we foster the impact of a permanent demand shock using an overlapping generations model with incomplete markets and heterogeneous agents to quantitatively predict the impact of Covid-19 and lockdown measures on wage premium and earnings inequality. We find that wage premia and earnings dispersion increase, suggesting that earnings inequality will increase at the expense of manual workers.
Keywords: Routinization; wage inequality; Covid-19; income processes; teleworking.

JEL Classification: E21; E24; J24.

RESUMO
O objetivo deste estudo é identificar qual o papel da automatização no aumento da desigualdade salarial, fazendo uma comparação entre os Estados Unidos e Portugal. Usando PSID e Quadros de Pessoal, constate-se que a dinâmica dos rendimentos de trabalho é fortemente determinada pela variância da componente fixa individual. Este efeito é drasticamente reduzido ao adicionar informação sobre as tarefas ocupacionais dos trabalhadores, confirmando que a diminuição do preço do capital e a consequente substituição de trabalhadores manuais que executam tarefas rotineiras aprofundaram a desigualdade salarial. Durante a crise atual, constatamos que a capacidade de continuar a trabalhar está fortemente relacionada com o

tipo de ocupação. Como tal, simulamos o impacto de um choque de procura permanente usando um modelo de gerações sobrepostas com mercados incompletos e agentes heterogéneos para prever quantitativamente o impacto da Covid-19 e das medidas de bloqueio no prémio salarial e na desigualdade de rendimentos. Conclui-se que que os prémios salariais e a dispersão dos rendimentos aumentam, sugerindo que a desigualdade de rendimentos aumentará em detrimento dos trabalhadores manuais.
Palavras-chave: Rotinização; desigualdade salarial; Covid-19; teletrabalho.

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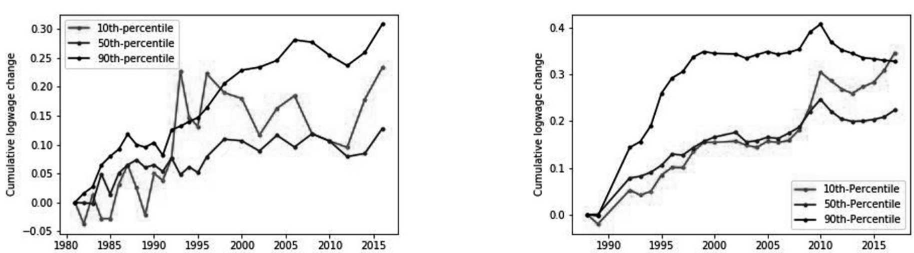
1. Introduction

Technological progress is considered one of the main drivers behind earnings inequality. Factor-biased technological change and skill-biased technological change represent two main sources of wage inequality. To this extent, we explore empirically the differences between workers in different categories, according to their occupation tasks, to assess how labor market has been impacted by task premia changes. This paper provides two main contributions to the existing literature. First, we use a 10-rolling window to estimate the evolution of determinants of dispersion in the labor income processes to investigate whether changes in task-premia represent a major source of labor income inequality. Second, we implement an overlapping generations model with incomplete markets to study the role of skill-based technological change in increasing wage inequality and to assess the potential impact of Covid-19 when people ability to continue working is mostly determined by the type of task they perform. We calibrate the model in order to match US and Portuguese economies using 2010 as benchmark year and we repeat the exercise targeting different working hours ratio per cognitive and manual workers in order to simulate the impact of demand side shocks.

Figure 1: Real wage increase per percentiles



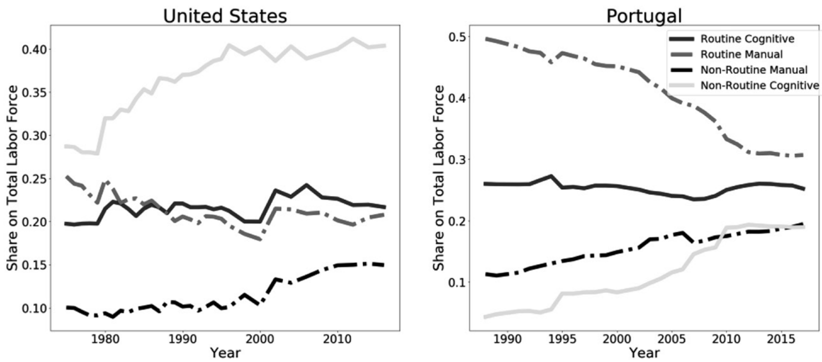
a) Portugal: 57.354 Observations

b) US: 24316 Survey-Weighted Observations

Figure 1 shows the steady rise in wage inequality and wage growth at different percentiles suggesting that both Portugal and U.S. experienced wage polarization at two different time periods. In Portugal, low wages in routine task intensive occupations, combined with the same price of computer capital may limit the gains of substituting workers by machines. We separate agents into non-routine and routine, according to their abilities substitutability with machines, and cognitive and manual, depending on the level of skills required to perform daily tasks. In this framework, we expect the wage premium of non-routine workers to increase, following the drop in investment price and the decrease in tax progressivity[1], this mechanism is triggered by a drop in routine labor demand by firms and by cheaper capital accumulation. The trends in labor force composition, figure 2, confirms that Portugal experiences similar patterns of labor market polarization of the U.S., explained by technology advances such as computerization and automation which displace routine tasks, and complement cognitive tasks.

[1] Ferriere, and Navarro (2018), and Nóbrega (2020).

Figure 2: Labour force composition



There is a clear increase in employment share of non-routine cognitive occupations, these workers are indeed complementary to capital and less likely to be substitute by machines. Both countries show a decrease in routine manual occupations, in Portugal the change is bigger decreasing from 50% of the labor force in 1987 to 30% in 2017. Routine cognitive occupations remained approximately at the same level in both countries, driven by the increasing importance of the service sector. Non-routine workers, both cognitive and manual, show an upward sloping trend, steeper for cognitive occupations. The differences between US and Portugal are evident in terms of share of composition of the labor force as for U.S. there is a steady increase in non-routine cognitive employment share from 30% in 1976 to 40% in 2017, in Portugal the same occupation category increases from 3,5% in 1987 to 20% in 2017. The increase in demand for non-routine occupation confirms that Portugal is experiencing labor market polarization but is lagging behind the United States in the adoption of computer capital. Fonseca et al. (2018) claims that routinization is the main cause of this shift in labor force composition in Portugal.[2]

Literature Review

Autor et al. (2003) first introduced the concept of routinization hypothesis as the decrease in labor input of routine manual tasks and the increase in labor input for non-routine cognitive tasks. Autor et al. (2006) pointed out that US wages structure widened due to an increase in demand for skills that was driven by skill-biased technical change and a slowdown in the growth of the relative supply of college workers. Acemoglu, and Restrepo (2017) argues that difference in education are important source of inequality and Krusell et al. (2000) found that factor-biased technological change has the strongest impact in determining the increase in wage inequality. Acemoglu, and Restrepo (2018) discuss the impact of increasing demand

[2] Workers in the two sample are unlikely to change occupation across the panel, meaning that changes in labor composition are driven by replacement with machines. This can be checked also in transition matrices 18-20 in the Appendix B.

for skilled workers, who are able to perform more abstract tasks, outlining how automation can replace manual tasks in the long-run if the rental rate of capital remains less costly than wages. Also Guerreiro et al. (2017) found that substitutability is higher for routine occupations requiring low skills. Recent improvements in Artificial Intelligence brought astonishing changes in different fields and is expected to be even more disrupting in the future, Acemoglu, and Restrepo (2018) investigate on the trade-off between the displacement effect, change in labour supply cause by automation of tasks which reduces demand for labor, and the overall increase in labor demand triggered by productivity-enhancing technologies. On the other side the creation of new tasks where human capital has a comparative advantage relative to machines, the reinstatement effect, may counterbalance the displacement effect. These mentioned effect do not grow equally faster, and different economies require different time to absorb efficiently and smoothing these processes, Goos, and Manning (2007) argue that the "routinization" hypothesis is the driving factor of the increase in highest and lowest wage occupations in the United kingdom since 1975 and Goos et al. (2009) extend the study to Western European group countries explaining job polarization using both routine biased technological change and offshoring. In the spirit of Fonseca et al. (2018) we replicated figure 7: it shows that wage inequality is mainly determined by skills level but, more importantly, the increase in minimum wage had a positive impact for Portugal on the 10^{th} percentile as it may have impacted the wage convergence observed and the growth in wages for manual workers. For U.S. we cannot argue the same as the difference in wage still is clearly not impacted by the raise in minimum wage. Krusell et al. (2000) and Karabarbounis and Neiman (2014) argues that the more recent decline in relative price of investment has been triggered by the investment-specific technological change. Eden and Gaggl (2018) shows that the previously mentioned drop in demand for routine occupations was concurrent to the decrease in price of information and communication technology capital goods: this drop is responsible for of the drop in labor share.

2. **Data**

To divide the workers in different categories according to the level of automation of their job we followed Cortes et al. (2014). The main data sources for this work are Quadros de Pessoal (QP) for Portugal and Panel Study of Income Dynamics (PSID) for the US.

Quadros de Pessoal

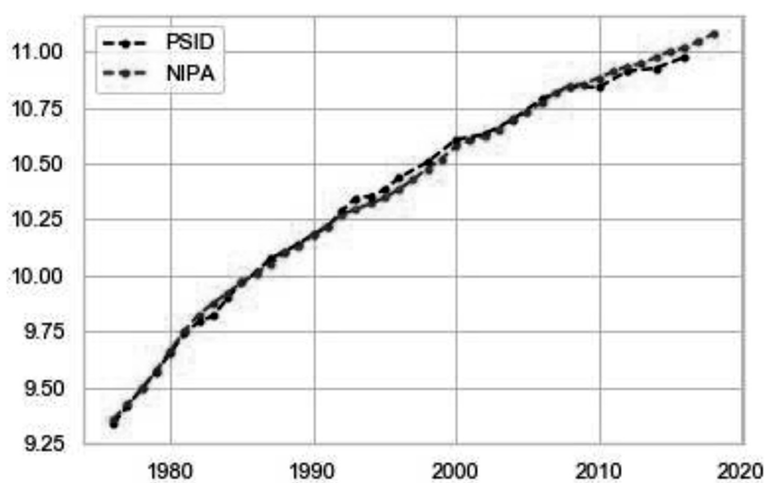
This database is a matched employer-employeee dataset created by the Portuguese Ministry of Labor in the 1980s, it includes Portuguese firms with at least one employee and does not take into account self-employed workers. The dataset covers the time period going from 1987 to 2017. The original occupations map was made by Cortes et al. (2014) on Census Occupational Codes, to map the Portuguese occupations we use different algorithms and crosswalks, details can be found in the Appendix. We propose a 4 digits mapping after 2007 and 3 digits between 1987 and 2006.

PSID

The Panel Study of Income Dynamics (PSID) is one of the longest longitudinal study as it includes almost families followed from 1968 to 2017. Data are collected every year from 1968 to 1997 and biannually from 1997 to 2017. All the information collected are referred to the previous year. The survey contains information both at individual level and family level, in this work we focused on individuals. In particular, to define the sample used for the estimation of the labor income processes we followed Heathcote et al. (2010) approach. The only difference is that we split households to create a panel for singular individuals and we generate individual characteristics splitting variables based on household composition. Figure 3 shows that PSID sample, despite two minor divergences between 1995-1999 and after 2008, is representative for the US labor market[3]. The sample is made of only heads and spouses of the families where the greatest level of accuracy in the data is guaranteed.

Observations with a wage lower than half of the minimum wage[4] have been dropped, also individual working less than yearly hours have been dropped out of the samples. Table 1 and table 2 report the two samples that we use for our analysis. For Quadros de Pessoal we followed the approach of Fonseca et al. (2018) re-adapting their method to Heathcote et al. (2010) to have consistency between the two samples.

Figure 3: PSID and NIPA in comparison



[3] Series for National Income and Product Account have been obtained from Bureau of Economic Analysis website. The series is obtained as the ratio between National Income from Wages and Salaries and Full-time equivalent employees, which includes employees on full-time schedules plus the number of employees on part-time schedules converted to a full-time basis.

[4] Minimum wage is calculated hourly for US and monthly for Portugal, source: Federal Reserve Economic Data (US) and OECD Labour Data (Portugal).

Table 1: PSID Sample Selection (Survey years 1969-2017)

	Dropped	Remaining
Initial Sample 1969-2017		453,969
Hourly Wage ≤ 0.5 x min. wage	10,784	443,185
Age 25-64	126,072	317,113
Workers only/Wage = o	62,909	245,816
≥ 10 years in the panel	83,165	162,651
Year ≤ 1997	36,269	126,382
Only males	63,571	62,667

Table 2: QP Sample Selection (Database years 1987-2017)

	Dropped	Remaining
Initial Sample 1969-2017		76,555,445
Missing Age	441,822	76,113,629
Age 25-64	11,550,875	64,562,754
Miscoded Infos/Wage = o	6,156,393	57,212,865
Praticante/Ajudante/Estagiario	1,524,276	55,688,589
Monthly Hours ≤ 260/12	96,458	53,850,578
≥ 10 years in the panel	17,064,774	36,785,804
Only males	16,095,688	20,690,116

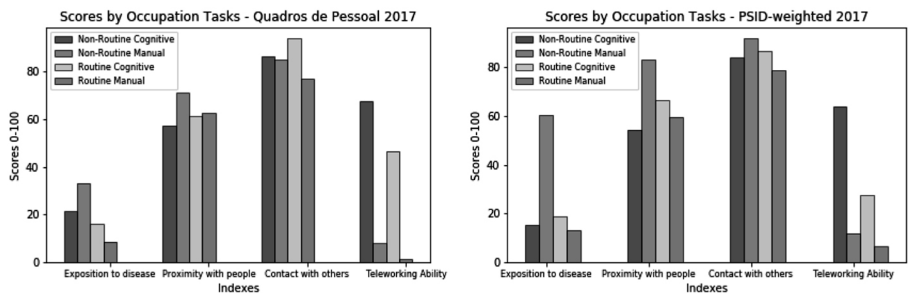
Impact of Covid-19

The current pandemic situation and the lockdown measures adopted by governments in many countries obliged people to work from home but, simply, many occupations cannot be done from home. To understand and link our results to the recent developments in people working conditions we replicate and improve the mapping made by Dingel and Neiman (2020)[5] conforming it to the PSID and Quadros de Pessoal samples in order to define whether occupations can be performed at home or not. For U.S. we used the same crosswalk between SOCs and Census made for mapping occupation categories, for Portugal the method is described in details in the appendix. The teleworking index we use is based on two O-NET surveys questioning the "work context" and "generalized work activities" and in case that respondents' job need to be done outdoor, or require the use of specific machines for which the use of other facilities is needed, then that occupation cannot be performed at home and the occupation receives a teleworking index equal to 0. We also mapped every

[5] They propose a mapping 6-digits code SOCs to 2-digit ISCOs and work with 2-digits occupational data for countries other than US using country-level data from ILOSTAT.

worker with three other indexes obtained from O-NET surveys: i) exposition to diseases or infections, ii) contact with others and iii) proximity with the others[6].

Figure 4: Scores by Occupation for both surveys



a) Portugal: 57,354,268 b) US: 245,316 Survey-Weighted Observations

For both Portugal and the U.S. we observe large differences with respect to the possibility of working from home across types of occupations. This difference motivates our choice to delve into the sources of inequality generated by skill-biased technological change[7]. Within cognitive occupations the routine component of the occupation task has an important role in determining the possibility of teleworking; this effect is stronger for the US where the difference between non-routine cognitive and routine cognitive is approximately 40*p.p*. Among the other measures of infection riskiness, non-routine manual results the category most exposed to viruses and diseases due to many occupations involved in the health care industry, as for example dental hygienists, critical care nurses, hospitalists and respiratory therapists. Table 14 shows that for Portugal teleworking feasibility of tasks is increasing with wage, this is not the same for U.S., table 15, where there is no clear correlation between wage and teleworking ability[8]. The effects of restriction measures are not symmetric across sectors, figure 11 confirms that for Portugal many manual occupations cannot be performed at home. Moreover, manual workers in manufacturing, wholesale, retail trade, construction and food service industries comprehend large part of the national labour force and produce a remarkable component of the national value added in GDP. This could have dramatic consequences for the economy if the restrictions continue to be strict.

For the U.S. (in Figure 12), there is a clear separation between the non-routine cognitive share of each sector and the others categories; this difference in teleworking could further increase the demand for non-routine cognitive labor and decrease the demand for manual and routine workers. Furthermore, considering that a large part of the labor force is at the

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[6] More details about these surveys and indexes can be found in Appendix B. For a comprehensive description of the teleworking index refer to Dingel and Neiman (2020) appendix.

[7] Coelho (2020) and Ferreira (2019).

[8] Unfortunately, PSID does not capture efficiently the heterogeneity between occupation as only a sample of families is chosen.

bottom of the teleworking scale, earning inequality is very likely to increase. Susceptibility index[9] is quite heterogeneous across sectors, both for the U.S. and Portugal.

Estimation of the labor income processes

One of the main contributions of this work is the estimation of the permanent component dispersion over time both using the previously described samples from PSID and Quadros de Pessoal. We estimate the evolution of the dispersion on the permanent and transitory components of labor income processes overtime following Brinca et al. (2016) and Chakraborty et al. (2015). Different characteristics determine the number of efficient units of labour the individual is endowed with, namely age j plus a set of year dummies $D'_t\xi_i$:

$$w_{i,t} = e^{y_1 j + y_2 j^2 + y_3 j^3 + D'_t \xi_i + u_{i,t}}$$

The productivity shock u follows an AR(1) process given by:

$$u_{i,t} = \rho_u u_{i,t-1} + \alpha_i + \epsilon_{i,t}$$

where $\alpha \sim N(0, \sigma_\alpha^2)$ represents the individual permanent ability and $\epsilon_{i,t} \sim N(0, \sigma_\epsilon^2)$ the idiosyncratic shock to the productivity shock process. Thanks to this specification, we are able to separate the permanent component from the individual fixed effect and the random noise in the productivity process. This specification outlines the same sources of heterogeneity of Heathcote et al. (2017): (i) the individual fixed effect defines innate individual ability; (ii) the realization of idiosyncratic efficiency shocks determines individual fortune in labor market outcomes and (iii) experience of the individual in the labour market.[10] We inflation adjust the nominal wages using CPI inflation series from OECD with 2015 as base year. We found that the individual fixed component contribution to wage dispersion is increasing overt time, as the ratio between the variance of individual ability and the variance of idiosyncratic shock increases.

To understand their evolution over time, we estimated the above equation using a rolling window of 10 years, including year dummies in the wage equation:

$$\ln(w_{it}) = D'_t \xi_i + y_1 j + y_2 j^2 + y_3 j^3 + u_{i,t}$$

To assess the impact of skill-biased and factor-biases technological change, we included dummies for different occupation categories in the above equation and it becomes:

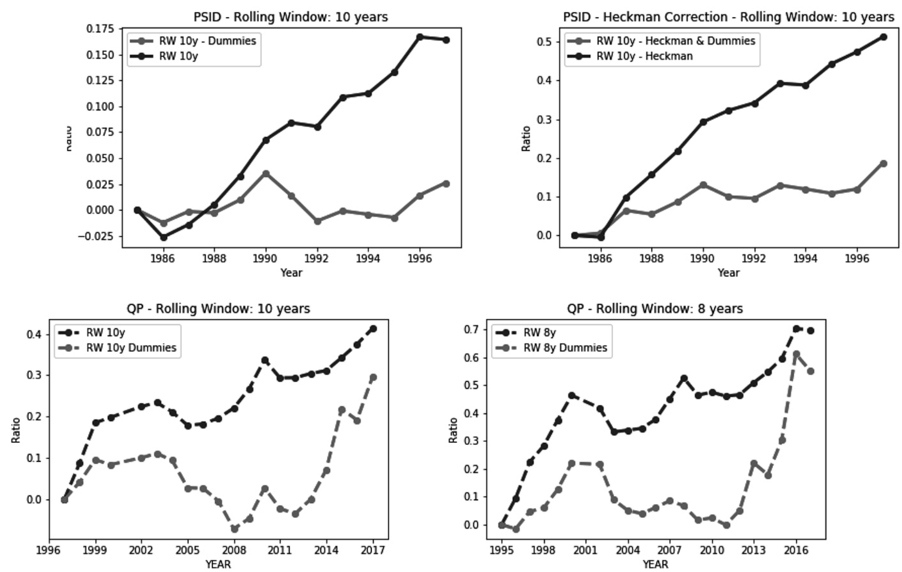
$$\ln(w_{it}) = D'_t \xi_i + y_1 j + y_2 j^2 + y_3 j^3 + NRM_{it} + NRC_{it} + RC_{it} + RM_{it} + u_{i,t}$$

[9] Obtained as a combination of the previously stated 3 measures of infection riskiness.

[10] In Heathcote et al. (2017) they use individual working effort instead of labor market experience.

This result is robust to different specification: for the US, having also non-workers in the initial sample, we use the Heckman estimation method used in Chakraborty et al. (2015) that use a two step approach to control for selection into the labor market, as described in Heckman (1976) and Heckman (1977). For Portugal, having only workers in the dataset, we use different size for the rolling window as robustness check. More information on the Heckman selection equation can be found in the Appendix.

Figure 5: PSID and QP over time



Note: The blue lines represent are obtain using the base specification, the red lines are obtained from the wage equation that includes dummies. On the y-axis, we plotted the logchange in the ratio between the variance of the permanent component and the variance of the idiosyncratic shocks resulting from the residual of the wage equation.

This change in wage dispersion determinants is originated by different dynamics for U.S. and Portugal. For the U.S. (in Tables 6 and 7), the variance of individual ability is increasing over time more than the variance of the residual idiosyncratic shock. This increase, together with a decrease in permanent component persistency and the lower impact of individual experience on wage, is likely to have a large effect on long-run earnings, as suggested by Autor et al. (2006) and Acemoglu, and Restrepo (2017). Including dummies for different tasks, the increase in individual ability dispersion is much lower meaning that different occupation categories can explain two thirds of the total increase in the relative variance of labor income.

For Portugal (in Tables 9 and 10), the same increase in the ratio is driven by different dynamics[11] as now the noisy component dispersion is decreasing more than individual ability variance, the persistency of the residual increases across years. The impact of individual experience increases particularly from . When we include dummies in the wage regression these trends do not change, but the dispersion of individual ability decreases in size whereas the variance of transitory component remains approximately the same. This underlines the impact of investment-specific technological change (Brinca et al., 2019) and the drop in the relative price of investment plays in explaining increases in wage premia and consequently income and earnings inequality.

3. **Model and Calibration**

This paper uses the model 2 as introduced in the introduction chapter. However, the households are segmented into the two groups Cognitive and Manuel rather than Skilled and Non-Skilled. The benchmark calibration of the model matches the US and Portuguese economies in 2010. The exogenous parameters are set to match the data, the endogenous parameters are estimated through simulated method of moments (SSM).

Preferences

The Frisch elasticity parameter follows Brinca et al. (2016) and is set to 1.0, at the same level of the risk aversion parameter.

Taxes and Social Security

We use the previously described labor income tax function proposed by Bénabou, and Tirole (2002) for both US and Portugal, and estimate tax income level and progressivity parameters, respectively θ_0 and θ_1, using labor income tax data provided by the OECD. We then compute the weighted average over the population of θ_0 and θ_1 for different individuals, depending on whether they are single or married and on the number of children. Social Security parameters, $\tilde{\tau}_{ss}$ and τ_{ss}, are estimated from OECD Tax Data and τ_c and τ_k are taken from Trabandt, and Uhlig (2011).

Parameter calibration using SMM

We use simulated methods of moments to calibrate parameters that do not have an empirical counterpart. This method is used to estimate ψ, β_1, β_2, β_3, β_4, h, χ, T_C, T_M, σ_C and

[11] We capture dynamics from 1987 for Portugal, period for which U.S. estimates are different.

σ_M minimizing the loss function between moments from the model and moments observed in the data:

$$L(\psi, \beta_1, \beta_2, \beta_3, \beta_4, h, \chi, T_C, T_M, \sigma_C, \sigma_M) = || M_m - M_d ||$$

used to match 75-100/all, $\bar{n}_c$, $\bar{n}_M$, K/Y, w_C/w_M, $\sigma_{\ln(w);C}$, $\sigma_{\ln(w);M}$, Q_{20}, Q_{40}, Q_{60}, and Q_{80}. Table 3 and table 4 contains the estimated parameters and table 5 the endogenously calibrated parameters.

Table 3: Calibration Fit – United States

Data Moment	Description	Source	Target	Model Value
75-100/all	Average wealth of households 75 and over	US Census	1.31	1.33
$\bar{n}_c$	Fractions of hours worked – Cognitive	PSID	0.489	0.489
$\bar{n}_M$	Fractions of hours worked – Manual	PSID	0.501	0.51
K/Y	Ratio between capital and output	BEA	3.0	3.0
w_C/w_M	Wage Premium	PSID	0.519	0.518
var ln(w) *Cogn./Man.*	Variance of the log wages	PSID	0.707/0.651	0.7067/0.651

Table 4: Calibration Fit – Portugal

Data Moment	Description	Source	Target	Model Value
75-100/all	Average wealth of households 75 and over	Assumption	1.31	1.295
$\bar{n}_c$	Fractions of hours worked – Cognitive	QP	0.472	0.479
$\bar{n}_M$	Fractions of hours worked – Manual	QP	0.527	0.532
K/Y	Ratio between capital and output	PWT	3.229	3.20
w_C/w_M	Wage Premium	QP	0.623	0.624
var ln(w) *Cogn./Man*	Variance of the log wages	QP	0.388/0.154	0.374/0.155

Table 5: Parameters Calibrated Endogenously – US & Portugal

Parameters	Description	Value – US	Value – PT
ψ	Bequest utility	4.15	4.8
$\beta_1, \beta_2, \beta_3, \beta_4$	Discount factors	0.979; 0.9355 0.9235; 0.9235	0.981; 0,942 0.940; 0.925
h	Borrowing limit	0.115	0.075
χ	Disutility from work	2.55	2.0
T_C	Lab. Augmenting tech. Cognitive	1.1	1.0
T_M	Lab. Augmenting tech. Manual	0.9	1.1
σ_C, σ_M	Standard Deviations of ability	0.4725; 0.773	0.520; 0.291

4. Quantitative Results

Our main experiment consists in estimating how wage and earnings inequality change following the demand shocks caused by the pandemic outbreak. We argue that demand for many jobs that cannot be performed from home, as occupations in the hospitality and leisure services sector, will drop in the long run. Brinca et al. (2020) separate between demand and supply shocks, finding evidence of a predominant negative supply shock in the short run and correlation between both demand and supply shocks and teleworking ability for occupations. In this context, we estimate the impact of COVID-19 outbreak by applying the drop in working hours aggregating the drop in demand for each sector and weigthing occupations by teleworking ability, as we expect firms to adapt to the new social distancing norms. We found a large decrease in monthly hours worked for manual workers in almost every sector and a modest drop in hours worked by cognitive workers. Quadros de Pessoal, for structural reasons, gives a better representation of the effects on the whole labor market, as it includes employees from every industry, PSID includes only a panel of selected families so it does not capture entirely the heterogeneity of demand shocks.

Aggregating results, we found that for Portugal the share of cognitive workers increases from 47.2% to 93.1% of the labor force, whereas manual workers decreasese to 6.8% from the pre-covid 52.7%. For the U.S., the impact has the same magnitude, going from 48.9% to 88.1% for cognitive workers and from 51.07% to 11.9% for manual workers. The effects in the short run (in Figure 7) are quite strong although we expect that once the restrictions measures are relieved the effects become smoother and, in the long-run, many occupations will be readapted such that they can be performed from home. This will reduce the overall impact on hours worked but many manual occupation may be permanently replaced. The objective of this experiment is to study the heterogeneous impact of Covid-19 on cognitive and manual workers, and to do that we assume that only 20% of the observed demand shock will be permanent[12], so the demand shock will be

[12] Calculated on the shock estimated from data.

–15.6% for the U.S. and –17.4% for Portugal and the share of hours worked by manual workers will respectively drop to 43.1% and 43.5%. Recalibrating the model to match the decrease in working hours for manual workers, we find that wage premium between cognitive and manual workers increase from the initially observed 0.518 to 1.83 for the U.S. and from 0.624 to 2.19 for Portugal, and the variance of log-earnings from 0.63 to 1.81 for the U.S. and from 0.44 to 1.49 for Portugal. The U.S. are characterized by higher inequality within same occupation-task group but are more advanced in the adoption of technological capital and have a higher share of skilled human capital. Portugal delay in using new technologies will foster a higher demand for cognitive-task occupations, which, in turn, will raise wage premium for cognitive workers.

5. **Conclusions**

In this paper we study the role of task complementarity in explaining an important component of earnings inequality, namely the task wage premia. As the relative price of capital drops, workers whose tasks are complementary[13] with capital tend to observe an increase in demand, whereas workers whose main tasks are substitutable[14], observe a drop. Empirical findings show that Portugal is experiencing the same labor market trends but is still lagging behind behing the U.S. due to the lower supply of skilled human capital which slows down the adoption of computer capital. We estimate income processes for US and Portugal, based on PSID and Quadros de Pessoal respectively, and find that in both countries, the variance of wages that is explained by an increase in the variance of permanent differences across individuals relative to the variance of transitory shocks is increasing over time. Under the assumption that workers tend to say in the same task-type occupations over their life course, the impact of changes in the relative demand of routine vs non-routine type of work on wage premia is going to be captured mainly through individual fixed effects. When we include dummies for the type of occupation the worker has, we can explain about two thirds of the total increase in the relative variance of earnings for the US and about 30% of the same increase for Portugal in the overall sample. This stresses the role that investment-specific technological change and the drop in the relative price of investment plays in explaining increases in wage premia and consequently income and earnings inequality. The recent Covid-19 pandemic is also likely to have an impact on earnings inequality, as low wage manual and routine workers are being disproportionally affected, since these tasks typically involve physical contact and cannot be performed from home. In order to study the impacts that social distancing may have on inequality in the future, we simulate a permanent change in the demand for workers in those occupations. We study these counterfactuals in a structural model and find that wage premium and variance of log-earnings increase significantly for both the US and Portugal, even if only a fifth of the observed drop in the relative demand for manual workers is observed in the long run. This relative drop in demand is justified by the fact that manual workers tend to be over-represented in jobs that are most affected by

[13] In our taxonomy, workers who perform mostly non-routine tasks involving cognitive work.

[14] Workers who perform mostly routine tasks involving manual work.

social distancing policies and less doable from home. In future works, we want to study the effects of the pandemic on wage and earnings inequality from the supply side and divide workers according to the four categories initially used in the empirical analysis. This would allow us to capture entirely the heterogeneous effects of demand and supply shocks on different workers categories.

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APPENDIX A

Figure 6: Decomposition of demand shocks between sectors in April 2020

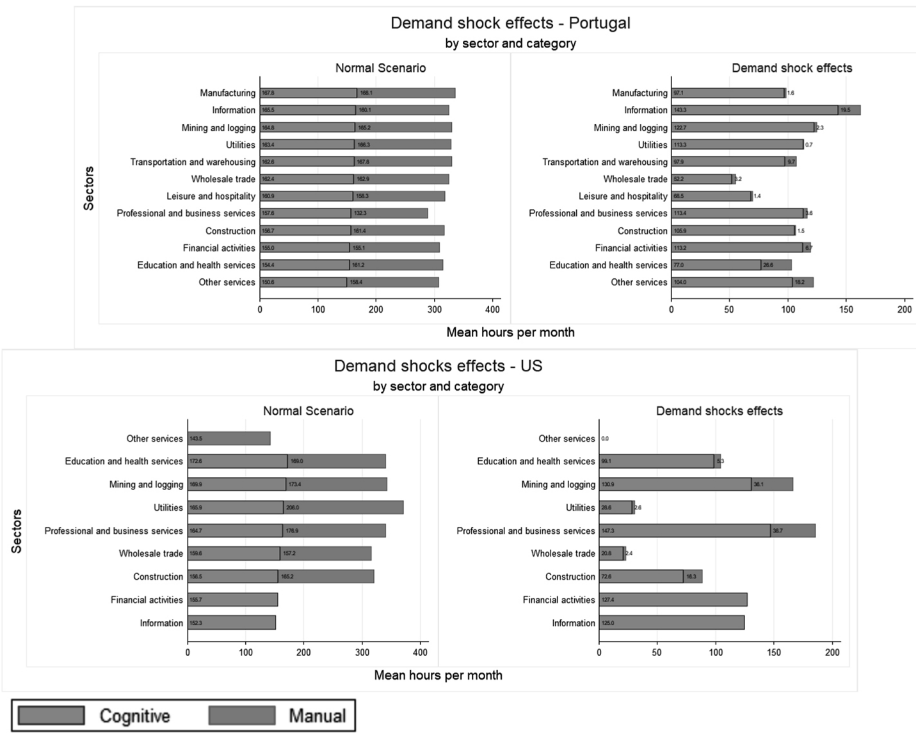

Figure 7: Task wage percentiles and minimum wage

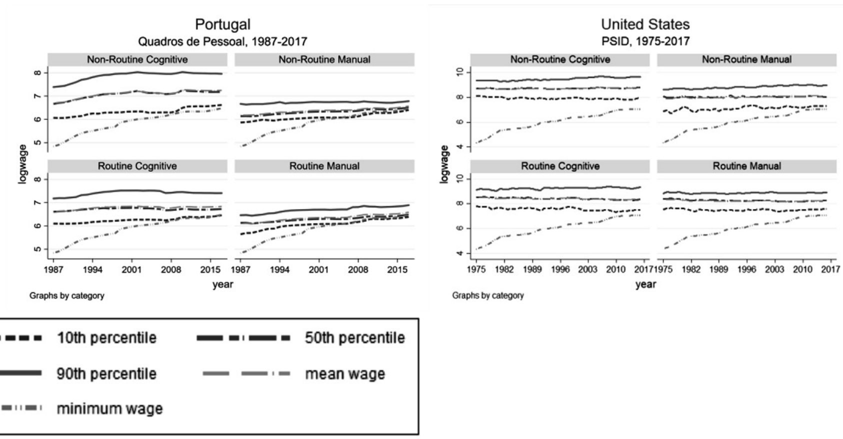

Table 6: U.S. – Heckman

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
σ_{α}^{2}	0.401	0.401	0.424	0.437	0.454	0.473	0.475	0.485	0.504	0.505	0.519	0.525	0.540
σ_{ϵ}^{2}	0.316	0.317	0.318	0.319	0.321	0.322	0.319	0.322	0.327	0.328	0.328	0.327	0.330
ρ	0.278	0.282	0.267	0.267	0.258	0.242	0.246	0.238	0.220	0.215	0.202	0.186	0.165
y_1	0.237	0.213	0.201	0.181	0.155	0.141	0.130	0.112	0.0864	0.066	0.0562	0.048	0.038

Table 7: U.S. – Heckman with Dummies

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
σ_{α}^{2}	0.386	0.389	0.400	0.397	0.404	0.418	0.417	0.424	0.438	0.440	0.443	0.446	0.466
σ_{ϵ}^{2}	0.278	0.279	0.279	0.278	0.279	0.282	0.286	0.291	0.296	0.299	0.303	0.303	0.306
ρ	0.225	0.220	0.227	0.225	0.219	0.205	0.211	0.207	0.201	0.198	0.191	0.170	0.147
y_1	0.188	0.162	0.153	0.140	0.133	0.125	0.117	0.105	0.087	0.767	0.075	0.077	0.076

Table 8: 2010 Benchmark calibration for US

Description	Parameter	Value	Source
Preferences			
Inverse Frisch elasticity	η	1.000	Brinca et al. (2016)
Risk aversion parameters	λ	1.000	Brinca et al. (2016)
Labor Productivity			
Depreciation rate equipment	δ_e	0.105	BEA
Depreciation rate structures	δ_s	0.033	BEA
Parameter 1 age profile of wages	y_1	0.236	Authors' Calculations
Parameter 2 age profile of wages	y_2	-0.0012	Authors' Calculations
Parameter 3 age profile of wages	y_3	1.58e-06	Authors' Calculations
Variance of idiosyncratic shock	σ_u	0.330	Authors' Calculations
Persistence of idiosyncratic risk	ρ_u	0.335	Authors' Calculations
Technology			
Share of income which goes to structures	α	0.151	Authors' Calculations
Share of the ICT cap/Cognitive composite	ϕ_1	0.469	Eden and Gaggl (2018)
Share of the ICT cap in the ICT Cognitive composite	ϕ_2	0.300	Eden and Gaggl (2018)
Elasticity of substitution of the ICT cap / Cognitive composite	ρ	1.558	Eden and Gaggl (2018)
TFP	A	1	Normalizationi
Relative price of investment	I_p	1.000	Normalization
Employment share (headcount) Cognitive group	emp_c	0.650	Authors' Calculations
Government and Social Security			
Consumption tax rate	τ_c	0.054	Trabandt and Uhlig (2011)
Capital income tax rate	τ_k	0.469	Trabandt and Uhlig (2011)
Tax scale parameter	θ_0	0.85	Implied value from
Tax progressivity parameter	θ_1	0.160	Ferriere and Navarro (2018)
Government debt to GDP	B/Y	0.880	(FRED) Average 2008-2012
Government spending to GDP	G/Y	0.213	FRED
SS tax employees	$\tilde{\tau}_{ss}$	0.077	OECD Tax Data
SS tax employers	τ_{ss}	0.078	OECD Tax Data

Table 9: QP 10 years RW

Year	σ^2_α	σ^2_ϵ	ρ	y_1
1997	0.450	0.238	0.110	0.0284
1998	0.459	0.232	0.109	0.0147
1999	0.468	0.226	0.105	0.00280
2000	0.463	0.222	0.122	-0.00827
2002	0.467	0.221	0.125	-0.0131
2003	0.457	0.215	0.151	-0.0106
2004	0.441	0.210	0.188	-0.00412
2005	0.428	0.207	0.216	0.00650
2006	0.422	0.204	0.232	0.0192
2007	0.420	0.201	0.239	0.0336
2008	0.423	0.200	0.236	0.0493
2009	0.428	0.198	0.229	0.0654
2010	0.439	0.196	0.210	0.0810
2011	0.426	0.194	0.237	0.0974
2012	0.422	0.193	0.246	0.112
2013	0.420	0.191	0.251	0.123
2014	0.415	0.188	0.257	0.131
2015	0.416	0.185	0.257	0.138
2016	0.415	0.182	0.260	0.142
2017	0.414	0.178	0.261	0.146

Table 10: QP 10 years RW with dummies

Year	σ^2_α	σ^2_ϵ	ρ	y_1
1997	0.366	0.255	0.129	0.0312
1998	0.370	0.252	0.133	0.0218
1999	0.371	0.246	0.136	0.0144
2000	0.364	0.243	0.155	0.00729
2002	0.366	0.242	0.150	0.00358
2003	0.363	0.239	0.162	0.00510
2004	0.353	0.234	0.194	0.00889
2005	0.337	0.232	0.239	0.0159
2006	0.332	0.228	0.260	0.0245
2007	0.338	0.236	0.257	0.0335

2008	0.325	0.235	0.295	0.0433
2009	0.325	0.232	0.305	0.0536
2010	0.340	0.234	0.265	0.0638
2011	0.327	0.230	0.297	0.0746
2012	0.320	0.227	0.316	0.0839
2013	0.320	0.223	0.320	0.0912
2014	0.325	0.218	0.314	0.0971
2015	0.339	0.212	0.291	0.101
2016	0.324	0.205	0.320	0.104
2017	0.332	0.199	0.300	0.104

Table 11: 2010 Benchmark calibration for Portugal

Description	Parameter	Value	Source
Labour Productivity			
Parameter 1 age profile of wages	y_1	0.0638	Authors' Calculations
Parameter 2 age profile of wages	y_2	0.0020	Authors' Calculations
Parameter 3 age profile of wages	y_3	$1.25e^{-4}$	Authors' Calculations
Variance of idiosyncratic shock	σ_u	0.196	Authors' Calculations
Persistence idiosyncratic risk	ρ_u	0.210	Authors' Calculations
Technology			
Employment share (headcount) Cognitive group	emp_c	0.472	Authors' Calculations
Government and Social Security			
Consumption tax rate	τ_c	0.215	Trabandt and Uhlig (2011)
SS tax employer	τ_{ss}	0.238	OECD Data
SS tax employee	$\tilde{\tau}_{ss}$	0.110	OECD Data
Capital income tax rate	τ_k	0.276	Trabandt and Uhlig (2011)
Tax scale parameter	θ_0	0.937	Implied value from $q1$
Tax progressivity parameter	θ_1	0.136	OECD Tax Data
Government debt to GDP	B/Y	0.447	IMF Data[17]
Government spending to GDP		0.37	OECD

Note: B/Y is the average of net public debt from 2008-12, IMF Data.

Heckman correction on returns to experiences and shocks processes

We use Heckman's selection model to control for selection bias only for PSID, as it contains information on non-workers, through a two-step statistical approach that will correct for the non-randomly selected sample. The first step consists in estimating the probability of entering the labor force through the selection equation:

$$\Phi(participation) = \Phi(Z'_{it}\epsilon + v_{it})$$

where Z includes education, age, marital status and number of children. As we are we are using rolling window to capture the dynamics in the income process, time dummies for the specific window are used together with an interaction term between education and age. From these estimates the inverse of the Mills ratio, λ_i, is stored for each observation ($\lambda_i = \dfrac{\phi(Z_i\epsilon_{it})}{\phi(Z_i\epsilon_{it})}$, with Φ being the normal density and Φ the normal CDF), and we use it to obtain consistent estimate of the conditional expectation of logwage:

$$E[ln(w_{it}) \mid X_{it}, workers = 1] = D'_t\xi + y_1 j + y_2 j^2 + y_3 j^3 + NRM_{it} + \rho\sigma_u\lambda(Z'_{it}\epsilon) + u_{i,t}$$

u_{it} is then modelled as an AR(1) with panel data to separate the individual fixed effect from the permanent and the idiosyncratic components,

$$u_{i,t} = \rho_u u_{i,t-1} + a_i + \epsilon_{i,t}.$$

Stationary Recursive Competitive Equilibrium

An agent with characteristics (j, h, β, a, u) has measure $\Phi(j, h, \beta, a, u)$. We define the recursive competitive equilibrium in the following way:

The household's optimization problem is solved dynamically through the value function $V(j, h, \beta, a, u)$ and the policy functions $c(j, h, \beta, a, u)$, $h'(j, h, \beta, a, u)$ and $n(j, h, \beta, a, u)$, given factor prices and initial conditions.

Markets clear:

$$\left[\xi + (r - \xi\delta)(1 - \tau_k)\right]\left(K + \frac{1}{\xi}B\right) = \int h + \Gamma d\phi$$

$$N^C = \int_{a > a*} n d\phi,$$

$$N^M = \int_{a \leq a*} n d\phi,$$

$$C + \xi X + G = Y$$

Assuming perfect competition, firms' factor prices equalize marginal products:

$$r = \left[A^{\sigma-1}Y\right]^{\frac{1}{\sigma}} \phi_1 Z^{\frac{\sigma-\rho}{\rho\sigma}} \phi_2 \left(\frac{1}{K}\right)^{\frac{1}{\rho}},$$

$$\mathrm{w}^C = \left[A^{\sigma-1}Y\right]^{\frac{1}{\rho}} \phi_1 Z^{\frac{\sigma-\rho}{\rho\sigma}} (1-\phi_2) \left(\frac{1}{N^C}\right)^{\frac{1}{\rho}},$$

$$\mathrm{w}^M = (1-\phi_1)\left(\frac{A^{\sigma-1}Y}{N^M}\right)^{\frac{1}{\sigma}}.$$

The government budget balances:

$$g\int d\Phi + G + RB = \int\left(\tau_k\left(\frac{r}{\xi}-\delta\right)\left(\frac{h+y}{\xi+(r-\xi\delta)(1-\tau_k)}\right) + \tau_c c + n\tau_l\left(\frac{nw(a,u,j)}{1+\tilde{\tau}_{ss}}\right)\right)d\Phi$$

The social security system balances:

$$\int_{j\geq 45} \Psi d\Phi = \frac{\tau_{ss}+\tilde{\tau}_{ss}}{1+\tilde{\tau}_{ss}}\left(\int_{j<45} nwd\Phi\right)$$

The assets of the deceased at the beginning of the period are uniformly distributed among the living:

$$\Gamma\int w(j)\,d\phi = \int (1-w(j))\,hd\phi.$$

APPENDIX B

Algorithm for matching occupations in Quadros de Pessoal

Following Fonseca et al. (2018), we use the same algorithm that they implemented which re-codes occupations based on the most frequent changes. The procedure is as follows: let $occupation_t^i$ be the occupation of worker i in year t, so we generate the matrix of $occupation_t^i$ and $occupation_{t+1}^i$, where the worker i is observed in both t and $t + 1$ and finally we aggregate the results by the mode of $occupation_{t+1}^i$. This algorithm was used for consolidating the matching already generated by the official crosswalks between *CPP 2010 → CNP 1994* between 2010 and 2009, *CNP 1994 4d → CNP 1994 3d* between 2007 and 2006 and *CNP1994 3d → CNP1985 3d* between 1995 and 1994. Our algorithm is matching with 4 digits precision when used between 2007-17 and 3 digits-precision between 1987-2007[15].

Matching Occupation from Census to Isco

To apply the Cortes et al. (2014) task-based occupations split, we started from Census 2010 Occupational Code and mapped them to ONET-SOC Code 2010[16]. The method is describe in details in Appendix A. that has an almost unique one-to-one match with Census;[17] the latter is better matched to the ISCO-08 (International Standard Classification of Occupations). ISCO-08 is already embedded into the Portuguese Classification of Occupations 2010 (CPP 2010), the latest occupational code used in Portugal. In this way it is possible to create a consistent correspondence between Census Code 2010 and CPP 2010. This method covers the period 2010-2017. In some cases, there is not a unique matching between Census-ISCO occupations and some codes have multiple values and each ISCO-08 is mapped to multiple Census Code 2010 values. After having created a full correspondence between the three codes, we defined a multiple dictionary that maps every ISCO-08 code to multiple Census values. The approach we followed here is based on Dingel and Neiman (2020) and occupations categories are defined by counting how many times ISCO-08 values fall in each category range, according to Cortes et al. (2014), in case of tie the occupation code is defined as 'Ambiguous'.[18]

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[15] Fonseca et al. (2018) matching is at 2 digits level.

[16] We use the official crosswalks documents from the Bureau of Labor Statics. Some Official Crosswalks have been used in combination with files available on David Author's website.

[17] For multiple matching, we used the first occurrence in the list manually checking their consistency.

[18] These cases represent only a small portion of the workers in the data, on the file sample, this group is made of , representing the of the whole sample.

Matching Occupation across years

To recover previous years mapping in Portugal we then use the crosswalk CPP 2010 to CNP 1994.[19] To create a unique correspondence between occupations we implemented a specific algorithm that work as follows: starting from CPP 2010 values, if it has a unique correspondence, then the dictionary is updated with a one-to-one key to value object, otherwise when there are multiple values, the correct matching is recovered empirically, so the algorithm searches for the most common value in the panel containing common workers between 2009 and 2010, and assign the CNP 1994 code that is more recurrent, at the condition that it is above a certain recurrence threshold.[20] Crosswalks used for the analysis can be found in Appendix B. In doing that, we took into account also the changes that were made in Cortes et al. (2014) when passing from Census 2010 to Census 2002, in order to have a consistent mapping between US and Portugal. With method we covered the period 2010-1995. In 2007 the Occupational Code reduces to 3 digits only and for the majority of them a one-to-one matching is feasible, when there is multiple matching the same algorithm described before is used.

Teleworking and Susceptibility to Covid-19 by earnings percentiles

Table 12: Employment share per percentile group – Portugal

Occupation Categories	Bottom 10%	10-25%	25-50%	50-75%	75-90%	Top 10%
Non-Routine Cognitive	0.91%	1.09%	1.58%	3.9%	6.05%	6.38%
Non-Routine Manual	4.08%	5.6%	6.46%	3.67%	0.62%	0.14%
Routine Cognitive	2.06%	2.85%	6.45%	8.19%	4.65%	2.47%
Routine Manual	2.74%	5.3%	10.09%	9.2%	4%	1.33%

Table 13: Employment share per percentile group - United States

Occupation Categories	Bottom 10%	10-25%	25-50%	50-75%	75-90%	Top 10%
Non-Routine Cognitive	1.48%	2.5%	5.1%	11.2%	10.63%	10.13%
Non-Routine Manual	2.4%	4.06%	4.17%	2.52%	1.2%	0.68%
Routine Cognitive	1.92%	3.38%	6.5%	5.9%	2.37%	1.82%
Routine Manual	1.5%	2.87%	4.77%	6.67%	3.8%	1.4%

[19] Source: Official Crosswalk CPP 2010 → CNP 1994 Istituto Nacional de Estatistica.

[20] If the match is lower than the occupation is defined as "Ambiguous".

Table 14: Teleworking Index per percentile group - Portugal

Occupation Categories	Bottom 10%	10-25%	25-50%	50-75%	75-90%	Top 10%
Non-Routine Cognitive	68.27	68.08	63.54	61.61	62.08	77.42
Non-Routine Manual	4.202	7.691	10.31	8.316	10.43	12.76
Routine Cognitive	33.61	34.18	36.07	48.01	59.93	71.15
Routine Manual	1.177	1.079	1.111	1.475	1.756	2.923

Table 15: Teleworking Index per percentile group – United States

Occupation Categories	Bottom 10%	10-25%	25-50%	50-75%	75-90%	Top 10%
Non-Routine Cognitive	66.15	76.78	70.67	66.58	62.72	54.46
Non-Routine Manual	6.482	12.29	13.54	16.18	10.20	7.075
Routine Cognitive	35.71	29.69	36.11	25.92	13.33	7.461
Routine Manual	7.873	6.448	8.110	6.718	6.422	3.138

Table 16: Susceptibility Index per percentile group – Portugal

Occupation Categories	Bottom 10%	10-25%	25-50%	50-75%	75-90%	Top 10%
Non-Routine Cognitive	56.49	55.18	54.86	56.38	58.41	51.11
Non-Routine Manual	59.70	61.95	65.56	64.73	63.99	64.54
Routine Cognitive	58.13	58.66	58.50	57.31	55.72	53.94
Routine Manual	50.21	48.25	49.19	49.72	50.27	52.59

Table 17: Susceptibility Index per percentile group – United States

Occupation Categories	Bottom 10%	10-25%	25-50%	50-75%	75-90%	Top 10%
Non-Routine Cognitive	48.11	47.40	51.71	51.14	51.13	52.28
Non-Routine Manual	80.82	77.60	77.46	76.18	81.60	82.45
Routine Cognitive	55.58	57.71	56.69	55.73	58.51	63.22
Routine Manual	48.02	48.54	50.33	50.79	51.30	51.98

Tax Function

Given the tax function

$$ya = \theta_1 y^{1-\theta_1}$$

which we employ, the average tax rate is defined as

$$ya = (1 - \tau(y))y$$

thus,

$$\theta_0 y^{1-\theta_1} = (1 - \tau(y))y$$

which implies:

$$(1 - \tau(y)) = \theta_0 y^{-\theta_1}$$

$$\tau(y) = 1 - \theta_0 y^{-\theta_1}$$

$$T(y) = \tau(y)y = y - \theta_0 y^{1-\theta_1}$$

$$T'(y) = 1 - (1 - \theta_1)\theta_0 y^{-\theta_1}$$

In this way, the tax wedge for any two incomes $(y_1; y_2)$ is given by:

$$1 - \frac{1 - \tau(y_2)}{1 - \tau(y_1)} = 1 - \left(\frac{y_2}{y_1}\right)^{-\theta_1}$$

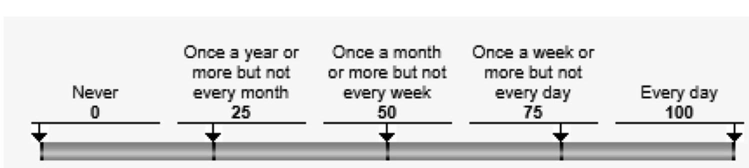
and therefore independent of the scaling parameter θ_0. In this manner, one can raise average taxes by lowering θ_0 and not the progressivity of the tax code, since the progressivity is uniquely determined by the parameter θ_1.

Information on O-NET Surveys

Exposition to diseases or infections

This survey is based on the question "How often does this job require exposure to disease/infections?" and it is calculated as follows:

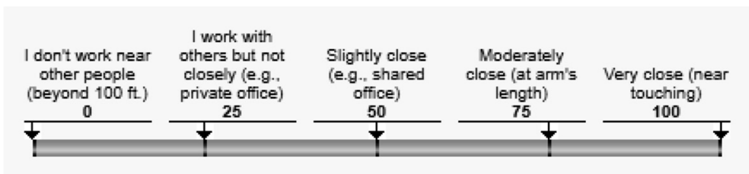
Figure 8: Source: O-NET online



Physical Proximity

This survey is based on the question "To what extent does this job require the worker to perform job tasks in close physical proximity to other people?" and it is calculated as follows:

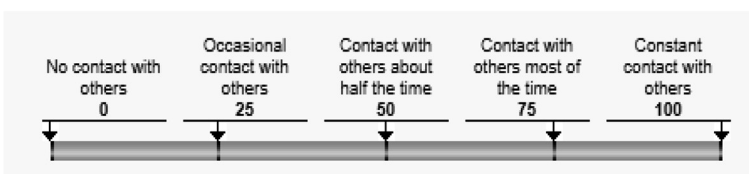
Figure 9: Source: O-NET online



Contact with others

This survey is based on the question "How much does this job require the worker to be in contact with others (face-to-face, by telephone, or otherwise) in order to perform it?" and it is calculated as follows:

Figure 10: Source: O-NET online



Mapping indexes from O-NET surveys to Quadros de Pessoal

As previously underlined, between 4-digits ISCO and 6-digits SOCs there is not a one-to-one mapping and when it is the case the value from the O-NET index it is directly mapped to ISCO. The problem before was solved by maintaining the multiple matching and counted the occurrence of every occupation category within the same ISCO code. That solution was needed as the division is on a discrete scale. For O-NET surveys scores, the scale is continuous[21] so that when there are multiple matching we can "smooth" the division.

Following Dingel and Neiman (2020) and using U.S. employment data[22] we allocate the SOC's U.S. employment weight across the ISCOs according to the ISCO's employment share in Quadros de Pessoal. For example, if a particular SOC has 1000 U.S. employees and

[21] Originally on a scale [0,100] or [0,1]. We scaled everything to [0,100].

[22] Occupational Employment Statistics.

is associated with two ISCOs that count respectively 6000 and 2000 workers in Portugal, we allocate 3/4 of the employees (750) to the larger ISCO and 1/4 (250) to the smaller one with their respective scores. Once the process is done for whole SOCs we compute the weighted mean for each ISCO code using the U.S. employees share for each occupation.

Table 18: Transition matrix PSID U.S. 1969–2017

From ↓ To →	Non-Routine Cognitive	Non-Routine Manual	Routine Cognitive	Routine Manual
Non-Routine Cognitive	85.70	2.78	7.95	3.55
Non-Routine Manual	7.28	80.72	5.40	6.58
Routine Cognitive	13.25	3.50	78.64	4.59
Routine Manual	5.21	3.84	4.33	86.59

Table 19: Transition matrix (headcount) PSID U.S. 1969–2017

From To	Non-Routine Cognitive	Non-Routine Manual	Routine Cognitive	Routine Manual
Non-Routine Cognitive	54.991	1.784	5.107	2.284
Non-Routine Manual	2.018	22.368	1.498	1.825
Routine Cognitive	5.654	1.495	33.545	1.962
Routine Manual	2.525	1.863	2.100	41.905

Table 20: Transition matrix Quadros de Pessoal 1987–2017

From To	Non-Routine Cognitive	Non-Routine Manual	Routine Cognitive	Routine Manual
Non-Routine Cognitive	89.32	1.60	6.28	2.78
Non-Routine Manual	1.89	86.98	3.49	7.61
Routine Cognitive	4.63	2.23	90.44	2.67
Routine Manual	1.39	3.08	1.81	93.70

Table 21: Transition matrix (headcount) Quadros de Pessoal 1987-2017

From To	Non-Routine Cognitive	Non-Routine Manual	Routine Cognitive	Routine Manual
Non-Routine Cognitive	6,427,630	115,666	452,182	200,577
Non-Routine Manual	114,958	5,279,883	212,411	462,381
Routine Cognitive	469,993	226,660	9,162,156	270,846
Routine Manual	235,839	519,792	306,187	15,793,224

Table 22: Sector coding

Key	NACE Sector
A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D	Electricity, gas, steam and air conditioning supply
E	Water supply; sewerage, waste management and remediation activities
F	Construction
G	Wholesale and retail trade; repair of motor vehicles
H	Transportation and storage
I	Accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defence; compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other service activities
U	Activities of extraterritorial organisations and bodies

Figure 11: Portugal

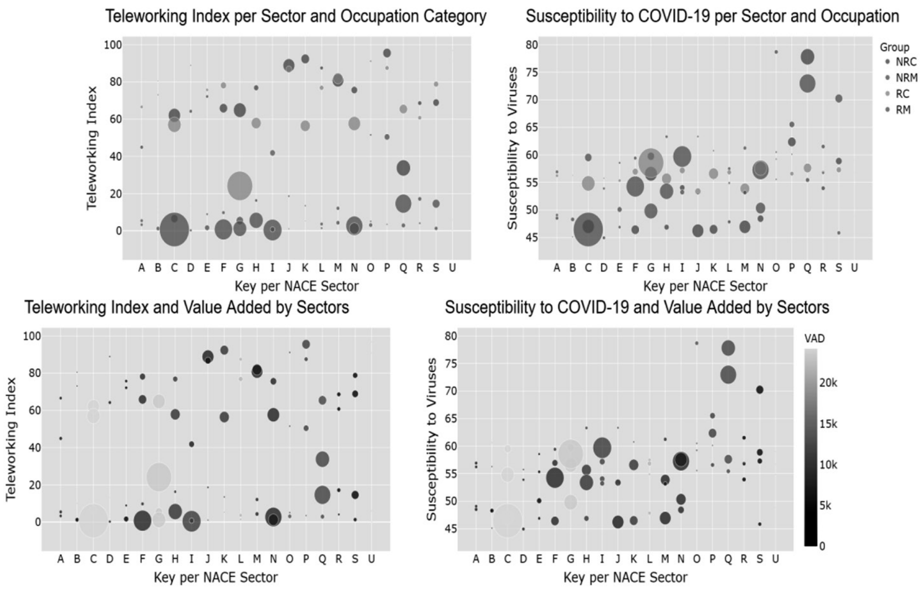
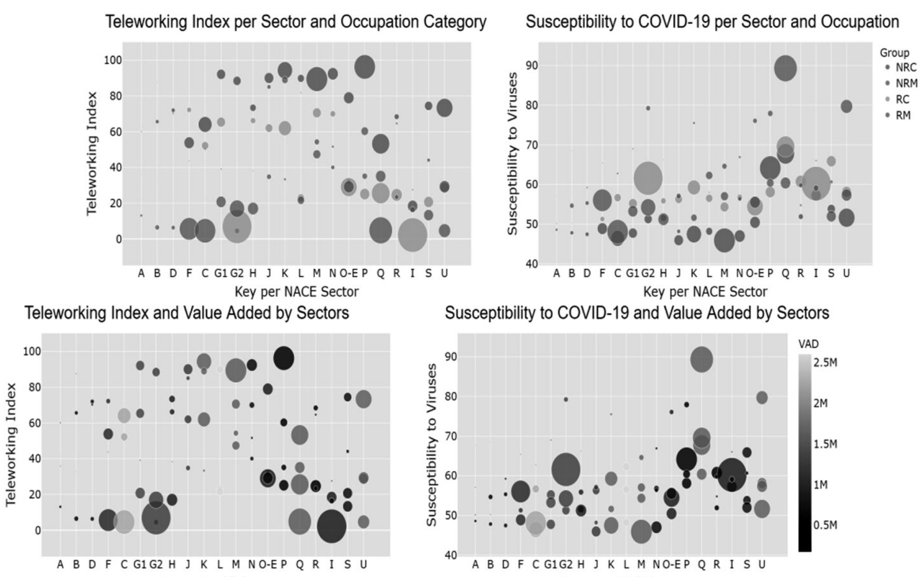


Figure 12: United States



Characteristics of PSID

"Head" and "Spouse"

For each family, the head component represents the person with the most financial responsibility in the household unit and has at least 16 years old. The head can also be female, and it is the case when she is married and her husband is present in the financial unit, also if she has a boyfriend and they are living together for at least one year. When the head of a family die, become incapacitated, or simply move out a new head is selected for the next surveys. Also, if the family splits then a new head is chosen and a new family unit is created, with the respective new head.

Heads are defined in the panel by using the sequence number 1, meaning that they represent the reference person in the household, in combination with the variable "Relation to Head" equal to 1 before the survey wave of 1983 and 10 after. Spouses have sequence number 2, and relation to head 2 before 1983 and 20 or 22 after (The latter indicates female cohabitors who have lived with Head for 12 months or more or who was mover-out nonresponse by the time of the interview)

File structure and data quality of the PSID

Data have been retrieved from PSID website, where both family-level series and individual--level series have been used to import or generate time consistent series for different variables. Information from household variables have been disentangled to match only the relative individual to which they were referred to, and mainly all the variables used are from this source. The only variables imported from individual-level data were "Relation to Head" and "Interview Number 1968". By setting panel observations at individual level we did not have to create a matching between family unit and person ID, as frequently done in the literature.

Variables to be imported are designed with two different format, VRxxxx and ERxxxxx, where the former represent *final release* variables, the latter *early release* variables. Anyway, in the most recent years, all the variables have been updated and PSID decided to keep using ER format even if the variables where in final version. Moreover, the different files that contains all the information about household income that before were contained the *Hours of Work and Wage Files* have been unified in the family-level data (source: PSID Help center personal email).

Latino Sample

This sample comprises approximately 2000 Latino households that have been added to the PSID In 1990, and they represented families from Mexico, Puerto Rico and Cuba. However, after 1995 it was dropped because missing of an important part of the after 1968 immigrants, as Asians for example, and lack of sufficient funding. Many observations of this sample are miscoded in important characteristics, as wages and salaries, for this reason we decided to drop them from our panel.

Variable Definitions

Most of the series contained in the family-level data are consistent and can be directly used, however some of them have been changed over the years, in these cases specific amendments have to be done. A specific description of all the variables modified follows here:

- Education: Total grades completed by the individual at the moment of the interview, before 1984 a unique variable included all type of education independently of whether it was college or high-school, after that the series has missing years and restarts only after 10 years, to overcome this issue we used the combination of two other series specifying respectively the years of education before college and years of college achieved.
- Wage and Income from Labor – Head: Total income from wages and salaries plus overtime, bonuses, commissions and other job-related income, which are unified till 1993, after that all extra-wages source of income are split in different series.
- Wage and Income from Labor – Spouse: Total income from labor, in 1984 any income from farming, business, market gardening, or roomers and boarders, labor-asset has been added to the series. The respective series with these amount have been used to clear and obtain only income from labor.
- Sex of Spouse: This variable has been imputed using combination of Sex of Head, Relation to Head and sequence number.

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Optimal Taxation and Investment-Specific Technological Change

Taxação ótima e progresso tecnológico específico do investimento

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ABSTRACT
In this paper, we look at the relationship between Investment Specific Technological Change (ISTC) and optimal level of labor income progressivity. We develop an incomplete markets overlapping generations model that matches relevant features of the US economy and find that the observed drop in the relative price of investment since the 1980's leads optimal progressivity to increase. This result hinges on ISTC increasing the wage premium through an increase in the variance of the permanent component of labor income. This result is supported by recent findings in the literature that highlight the increasing role of the permanent component of labor income in the observed increase in income inequality.
Keywords: Optimal taxation; technological change; income inequality.

JEL Classification: E24; E62; H21.

RESUMO
Neste artigo examinamos a relação entre *Investment Specific Technological Change* (ISTC) e o nível ótimo de progressividade dos impostos sobre rendimentos do trabalho. Desenvolvemos um modelo de gerações sobrepostas de mercados incompletos que reproduz características relevantes da economia dos EUA e apurou-se que a queda observada no preço relativo do investimento desde a década de 1980 leva a um aumento da progressividade ótima. Este resultado decorre da ISTC aumentar o prémio salarial através do aumento da variância da componente permanente do rendimento do trabalho. Este efeito é confirmado por resultados recentes na literatura que destacam o papel crescente do componente permanente do rendimento do trabalho no aumento observado da desigualdade de rendimento.
Palavras-chave: Taxação ótima; progresso tecnológico; desigualdade de rendimento.

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1. Introduction

Optimal taxation theory tries to explain how a government can maximize the social welfare function using a fiscal system that considers consumption and saving allocations from households. The government may want to use taxation in order to correct efficiency or inequality problems in the society. For instance, it might want to use progressivity in order to reduce income inequality and insure low-income households from possible idiosyncratic productivity shocks. Nevertheless, it must consider the fact that this policy tool may also affect efficiency in the economy, and the result might not be coincident with its initial purpose.

It is true however that income inequality and progressivity have had different trends since 1980. Income inequality has sharply increased, and inversely, the relative price of investment decreased due to technological improvements. Investment-Specific Technological change theory suggests that these two phenomena are connected because capital is a substitute for routine jobs and a complement for non-routine jobs. The labor share has also declined due to the reduction of investment prices and therefore the wage premium has grown. Inequality started when relative demand for non-routine workers tended to increase, leading to unemployment in routine workers.

This thesis tries to connect the influence of Taxation in shaping welfare with the increase in inequality due to Investment Specific Technological Change. It intends to simulate the influence of a drop on the relative investment price on the optimal taxation in 1980. This thesis uses a model with incomplete markets, overlapping generations, heterogeneous agents and partial uninsurable idiosyncratic risk. The distinguish factor of this model is the fact that it incorporates two different types of tasks as in Autor et al. (2003): routine jobs and non-routine jobs. The model is calibrated to match the data of US economy in 1980 and subsequently the relative price of investment is changed to match the observed drop in the data between 1980 and 2010.

The model captures some important aspects of Optimal Taxation and Investment Specific Technological Change Theory: (i) optimal progressivity increases with the dispersion of permanent ability; (ii) skill heterogeneity always implies positive progressivity; (iii) higher wage premium and post-tax income Gini is associated with the drop on investment prices; (iv) routine labor share decreases due to its substitutability with capital, which is now less expensive.

The rest of the dissertation is as follows: in Section 2 we discuss some related literature; in Section 3, we describe the model and the calibration method and in Section 4 the results; section 5 concludes.

2. Literature Review

Ramsey (1927) was the first paper that contributed to analyze of Optimal Taxation, lacking, however, to incorporate heterogeneity across the population. This is a key feature for this thesis, taking for instance the findings of Huggett et al. (2011) according to which heterogeneity in initial conditions accounts for about 61.5% of the variation in lifetime earnings for the United States.

Mirrlees (1971) introduced a way to mathematically analyze the problem of unobserved heterogeneity in which agents only differ in their abilities. In the Mirrlees' approach, the government faces an imperfect information problem due to the trade-off created by unobserved heterogeneity, diminishing marginal utility of consumption and incentive effects. Thus, when government increases redistribution, it has to guarantee that the highest qualified workers continue to produce in the level corresponding to their capacity. According to this approach the government faces an imperfect information problem due to the trade-off created by unobserved heterogeneity, diminishing marginal utility of consumption and incentive effects. Thus, when government increases redistribution, it must guarantee that the highest productive workers continue to produce in the level corresponding to their capacity.

There are two very important results introduced by Mirrlees (1971) that are fundamentals in this paper. First, that Optimal Taxation depends on the distribution of ability. It is, in fact, the schedule of marginal tax rates and how they are tailored to the shape of the ability distribution that defines the balance between equality and efficiency. One of his conclusions is that it would be optimal to have a zero marginal tax rate at the top, however several other studies differ in this point. For instance, Saez (2001) concluded that marginal tax rates should rise between middle-and high-income earners, and that rates at high incomes should "not be lower than 50% and may be as high as 80%". Other authors have different conclusions, these diverse results are consequences of different theories of what makes a worker reach the top of the income scale.

The second important result from Mirrlees (1971) is that the optimal marginal tax rate rises with wage inequality due to a change in the distribution of ability, increasing the benevolent effects of redistribution. More recently other authors also connected the increase in inequality with a more redistributive tax system. Heathcote et al (2017) showed that tax progressivity increases with appropriate measures of inequality. Moreover, they show that it is the permanent component of the income process that is responsible for most of the increase in income inequality since the 1980s. Krueger et al. (2009) stated that household heterogeneity and idiosyncratic earnings risk are key determinants of the progressivity of labor income taxes. Using a model with idiosyncratic uninsurable income shocks and permanent productivity differences across households they concluded that, since redistribution is insurance against low ability (the value function characterizing lifetime utility is strictly concave in the ability to generate income), such insurance is possible by using progressive labor income taxes or taxation of capital income, or both. This relation between wage inequality and the optimal tax system is the key element of this dissertation, connecting Optimal Taxation Theory with Investment-Specific Technological Change which tries to relate the increase in wage inequality through the decline of investment price goods.

For instance, the drop on investment prices can be partially explained by the improvement in computer performance: since manual computing, performance increased by a factor between 1.7 trillion and 76 trillion (Nordhaus 2007). Thus, during this period of automation improvement labor share also declined as showed in Karabarbounis and Neiman (2014) that, using a general equilibrium model to obtain an expression for the labor share as a function of the price of investment goods, concluded that this mechanism is able to explain half of the observed decline in the labor share.

There are many shreds of evidences that a positive correlation between the computerization of the workplace and skilled labor in production exists. Autor et al (2003) found out that computerization is associated with the reduction of routine labor and with the increase in non-routine jobs. They state that because of the decline of investment price, capital should have substantially substituted for workers performing routine unskilled tasks. Computer capital is then a substitute for cognitive and manual tasks that can be concluded following explicit rules and complements non-routine jobs characterized by problem-solving and complex communications tasks. Their model represents 60% of the change in the relative demand estimated in the last quarter of the twentieth's century. Task changes within nominally identical occupations account for almost half of this impact. This thesis uses the same description of tasks as in Autor et al. (2003), that is, tasks are divided in routine (can be accomplished by machines following explicit programming rules) and non-routine (tasks for which the rules are not sufficiently well understood to be specified in computer code and executed by machines).

Even though this dissertation uses a task framework as in Autor et al (2003), tasks and skills might be correlated: while investment price has declined, firms tended to substitute expensive labor for machines and it created significant advantages for workers whose skills become increasingly productive (Acemoglu and Autor, 2011). Acemoglu (2002) concluded that technical change has been skill-biased during the last century resulting from the rapid increase in the supply of skilled workers and the recent increase in inequality is probably a consequence of the acceleration in skill bias. Acemoglu and Autor (2011) also concluded that, after analyzing the effects of technology on the relative demand for skills, those effects are related with technology and in special to the skill bias of technical change. They also stated that automation creates negative effects on the real wages of the group that has been replaced.

Inequality is then created (i) when unemployment rates increase to unskilled workers due to the demand for clerical and information-processing tasks (non-routine) and (ii) when routine households' wages decrease. These two consequences of SBTC result from capital--skill complementarity and are explained by Krussel et al. (2000). Automation increases the aggregate welfare by raising productivity and changing factor prices (Acemoglu and Restrepo, 2018), therefore if the stock of capital increases, marginal productivity of skilled labor increases but the opposite occurs for non-skilled workers. When adding the reduction of investment prices to this mechanism, the result is that firms will substitute away from labor towards capital. Krussel et al. (2000) estimated that the capital-skill complementarity effect increased the skill premium about 60 percent over the sample and the effect after 1980 is about 2.1 percent per year.

This dissertation will then be centered in the idea that the increase in income inequality is a consequence of a drop in investment prices and, due to SBTC, it increased the relative demand for non-routine workers and amplified the importance of the permanent component in the income process of the population by increasing the wage premium. Guerreiro et al. (2017) analyzed the impact of a fall in the automation price that could lead to a massive income inequality. They concluded that income inequality could be reduced by making the tax system more progressive. Ferreira (2019) also concluded that the effects from SBTC account for 42% of the overall increase in income inequality.

However, tax progressivity with the aim of mitigating income inequality might create a loss in efficiency and in its initial purpose. Government must trade-off this concern against the standard distortions that this policy tool imposes on labor supply and capital accumulation decisions. In one hand, progressivity offers both social insurance against labor market insurance and redistribution concerning initial conditions. First, it leads to more equality and more equal distribution of income, wealth, consumption and welfare. Second, in the absence of formal or informal private insurance markets against idiosyncratic uncertainty, progressivity provides a partial substitute for these missing markets and therefore may lead to less volatile household consumption over time (Conesa et al., 2006). But on the other hand, progressivity creates distortions in the labor supply and skill investment. A tax schedule with increasing marginal rates reduces both the returns to working more hours and the returns to acquiring human capital. Moreover, if the equilibrium skill premium responds to skill scarcity, a more progressive tax system, by depressing skill investment, may exacerbate inequality in pretax wages and undermine the original redistribution intent (Heathcote et al., 2017).

3. **Model**

This modelling framework builds on Bewley (1980) and incorporates also the assumptions from Aiyagari (1994) and Hugget (1993): an incomplete markets economy with overlapping generations of heterogeneous agents and partial uninsurable idiosyncratic risk that generates both income and wealth distributions. This approach is based on Brinca et al. (2016) and includes a bequest motive in the same philosophy as Brinca et al. (2019). The model strongly builds on the features of the model 2 introduced in the introduction. However, the model features are more extensive technology sector, which is explained in detail, below.

This different methodology includes two types of workers: non-routine (NR) and routine (R); and three final goods sectors in the economy: consumption goods, non-ICT capital, and an ICT capital sector (Eden and Gaggl 2018). One main assumption in this model is to use the capital-skill complementarity from Krussel et al. (2000), but with these two types of workers.

Labor Income

In this framework, households differ across different factors such as permanent ability a, asset holdings, persistent idiosyncratic productivity shocks and four discount factors $\beta \in \{\beta_1, \beta_2, \beta_3, \beta_4\}$. The idiosyncratic productivity shock u is assumed to follow an AR (1) process in the form of:

$$u_{i,t} = \rho_u u_{i,t-1} + \epsilon_{i,t}, \qquad \epsilon_{i,t} \sim N(0,\sigma_\epsilon^2). \tag{1}$$

Hence, the defining equation of household 's wage is given by:

$$w_{it}(j,a_i,u_{it}) = w_t^s e^{y_1 j + y_2 j^2 + y_3 j^3 + a_i + u_{it}}, \tag{2}$$

where y_1, y_2 and y_3 try to capture the age profile of wages which are calibrated directly from data (1980 or 2010) and w_t^s, $s \in S \equiv \{NR,R\}$, is the wage per efficiency unit of labor.

Moreover, there is a wage differential between the two types of workers that tries to capture the share of between-group inequality which does not result from the value of the wage premium as determined by relative productivities. The within-group earnings inequality is modelled by constructing a wage distribution within each group in order to match the inequality in the data.

Technology

Using the Brinca et al. (2019) approach, there are three competitive final goods sectors: consumption, non-ICT capital and ICT capital. In this model, a representative intermediate goods firm produces $Z_t^c + Z_t^s + Z_t^e$ using a constant returns to scale technology in capital and labor inputs; it rents non-ICT capital at rate r_t^s, ICT capital at r_t^e and each labor variety at w_t^s, $s \in S$; it chooses in each period capital and labor to maximize the its profits:

$$\Pi_t^z = p_t^z y_t - r_t^s K_{st} - r_t^e K_{et} - \Sigma_{s \in S} w_t^s N_{st}, \tag{3}$$

subject to:

$$y_t = Z_t^c + Z_t^s + Z_t^e = C_t + G_t + X_{st} + \xi_t X_{et} = Y_t \tag{4}$$

where Z_t is the quantity of input z used in the production of the final (consumption (c), non-ICT capital (s) or ICT capital (e)) good, p_t^z is the price of intermediate goods (which is equal to the marginal cost of production due to perfect competition), X_{et} is the ICT capital good and ξ_t is the relative price of the equipment good and $\xi_t = p_t^e / p_t^c$.

Hence, assuming that the production function of intermediate goods is Cobb-Douglas over non-ICT capital and CES (Eden and Gaggl, 2018) over the remaining inputs, the aggregate demand measured in terms of the consumption good is given by:

$$Y_t = F(.) = A_t G(.) = A_t K_{st}^{\alpha} \left[\sum_{i=1}^{3} \varphi Z_t^{\frac{\sigma-1}{\sigma}} + \left(1 - \sum_{i=1}^{3} \varphi\right) N_{Rt}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma(1-\alpha)}{\sigma-1}}, \tag{5}$$

$$Z_t = \left[\phi K_{et}^{\frac{\rho-1}{\rho}} + (1-\phi_1) N_{NRt}^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}},$$

where A_t is total factor productivity, φ is the share of the composite factor, Φ is the share of the ICT capital in the composite, ρ is the elasticity of substitution between ICT capital and the non-routine labor and σ represents the elasticity of substitution between the composite Z_t and routine labor. In order to ensure that there is complementarity between the two inputs in the composite, it is necessary that $\rho < \sigma$. Moreover, the reason why the production function is CES over ICT capital is that this restriction allows non-routine labor to interact with "routine inputs", which can be produced by either routine labor or ICT capital (Eden and Gaggl, 2018).

As a result, the capital laws of motion in this model are:

$$K_{st+1} = (1 - \delta_s)K_{st} + X_{st}, \tag{6}$$

$$K_{et+1} = (1 - \delta_e)K_{et} + X_{et}, \tag{7}$$

in which δ_s and δ_e are the non-ICT capital and ICT capital depreciation rates, respectively.

Labor Income

There are three assets in the economy: ICT capital, k_e, non-ICT capital, k_s, and government bonds, b. In order to guarantee the non-arbitrage condition, investing in ICT capital must have the same return as investing in bonds. Moreover, in this market there is no investment-specific technological change, then in the steady-state, the relative price of the equipment good is constant. Thus, equation (8) represents the return rate on the bond, equation (9) denotes the return rate on non-ICT capital, and equation (10) defines the state variable for the consumer:

$$\frac{1}{\xi}\left[1 + (r_e - \xi\delta_e)(1 - \tau_k)\right] = 1 + (1 - \tau_k), \tag{8}$$

$$\frac{1}{\xi}\left[1 + (r_e - \xi\delta_e)(1 - \tau_k)\right] = 1 + (r_s - \delta_s)(1 - \tau_k), \tag{9}$$

$$h \equiv \xi ke + b + ks. \tag{10}$$

Competitive Equilibrium

In a perfect competition economy, firm's profit maximization implies that factor prices have to be equal to their marginal products.

$$w_t^{NRC} = \Xi_t \varphi \left[\phi\left(\frac{K_{et}}{N_{NRt}}\right)^{\frac{\rho-1}{\rho}} + (1-\phi)\right]^{\frac{\sigma-\rho}{(\rho-1)\sigma}} \left[1-\phi\right], \tag{11}$$

$$w_t^{RM} = \Xi_t (1-\varphi)\left(\frac{N_{Rt}}{N_{NRt}}\right)^{-\frac{1}{\sigma}}, \tag{12}$$

$$r_t^s = A_t \alpha \left[\frac{K_{et}}{N_{NRt}}\right]^{\alpha-1} \left[\varphi\left(\phi\left(\frac{K_{et}}{N_{NRt}}\right)^{\frac{\rho-1}{\rho}} + (1-\phi)\right)^{\frac{(\sigma-1)\rho}{(\rho-1)\sigma}} + (1-\varphi)\left(\frac{N_{Rt}}{N_{NRt}}\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma(1-\alpha)}{\sigma-1}}, \quad (13)$$

$$r_t^e = \Xi_t \left[\varphi\left(\phi\left(\frac{K_{et}}{N_{NRt}}\right)^{\frac{\rho-1}{\rho}} + (1-\phi)\right)^{\frac{\sigma-\rho}{(\rho-1)\sigma}} + \phi_1\left[\frac{K_{et}}{N_{NRt}}\right]^{-\frac{1}{\rho}}\right], \quad (14)$$

where:

$$\Xi_t = A_t\left[\frac{K_{et}}{N_{NRCt}}\right]^{\alpha}\left[1-\alpha\right]\left[\varphi\left(\phi\left(\frac{K_{et}}{N_{NRt}}\right)^{\frac{\rho-1}{\rho}} + (1-\phi)\right)^{\frac{(\sigma-1)\rho}{(\rho-1)\sigma}} + (1-\varphi)\left(\frac{N_{Rt}}{N_{NRt}}\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1-\sigma\alpha}{\sigma-1}} \cdot \quad (15)$$

For certain given prices, policies, transfers, and initial conditions, a household with age j, asset position h, discount factors β, permanent ability a, and a persistent idiosyncratic productivity shock u, maximizes his utility on any given period by choosing consumption c, work hours n, and future asset holding h'. His problem can be formulated recursively as:

$$V(j,h,\beta,a,u) = \max_{c,n,h'}\left[U(c,n) + \beta E_{u'}\left[V(j+1,h',\beta,a,u')\right]\right]$$

s.t.:

$$c(1+\tau_c) + qh' = h + \Gamma + g + Y^N$$
$$Y^N = \frac{nw(j,a,u)}{1+\tilde{\tau}_{ss}}\left(1 - \tau_{ss} - \tau_l\left[\frac{nw(j,a,u)}{1+\tilde{\tau}_{ss}}\right]\right) \quad (16)$$

$$n \in [0,1], \qquad h' \geq -\underline{h}, \qquad h_0 = 0, \qquad c > 0.$$

The retired households face the same problem apart from having three different characteristics: age-dependent probability of dying $\pi(j)$, constant retirement benefits and the bequest motive $D(h')$ as in Brinca et al. (2019). Thus, their problem is defined as

$$V(j,h,\beta,a,u) = \max_{c,h'}\left[U(c,n) + \beta(1-\pi(j))\left[V(j+1,h',\beta) + \pi(j)D(h')\right]\right] \quad (17)$$

s.t.:

$$c(1+\tau_c)+qh'=h+\Gamma+g+\Psi$$

$$h'\geq -\underline{h},\quad c>0.$$

The equilibrium in this framework is obtained by a stationary recursive approach, in which $\phi(j,h,\beta,a,u)$ is the measure of agents that correspond to the characteristics (j,h,β,a,u). Hence, the stationary recursive competitive equilibrium is defined as in Brinca et al. (2019):

Taking factor prices and initial conditions as given, the value function $V(j,h,\beta,a,u)$ and the policy functions, $c(j,h,\beta,a,u)$, $h'(j,h,\beta,a,u)$, and $n(j,h,\beta,a,u)$ solve the household's optimization problem;

Markets clear:

$$\left[\xi+(r_e-\xi\delta_e)(1-\tau_k)\right]\left(K_e+\frac{B}{\xi}+\frac{K_s}{\xi}\right)=\int h+\Gamma d\phi,$$

$$N_R=\int_{a<p_R} nd\phi,\qquad N_{NR}=Q_{NR}\int_{p_{NRS}\leq a} nd\phi, \tag{18}$$

$$C+G+\delta_sK_s+\xi\delta_eK_e=F(K_s,K_e,N_{NR},N_R);$$

Equations 11-14 hold.

The government budget balances:

$$g\int d\phi+G+RB=$$

$$\int\left(\tau_k(r_e/\xi-\delta_e)\left(\frac{h+\Gamma}{\xi+(r_e/\xi-\delta_e)(1-\tau_k)}\right)+\tau_cc+n\tau_l\left(\frac{nw(a,u,j)}{1+\tilde{\tau}_{ss}}\right)d\phi. \tag{19}$$

The social security system balances:

$$\int_{j\geq 45}\psi d\phi=\frac{\tilde{\tau}_{ss}+\tau_{ss}}{1+\tilde{\tau}_{ss}}\left(\int_{j\geq 45} nwd\phi\right). \tag{20}$$

The assets of the deceased at the beginning of the period are uniformly distributed among the living:

$$\Gamma \int w(j)\, d\phi = \int (1 - w(j))\, h d\phi. \tag{21}$$

The wage premia is endogenous and it can be expressed relative to routine wages as:

$$\frac{w^{NRC}}{w^{RM}} = \frac{[1-\phi]\varphi}{1-\varphi}\left[\phi\left(\frac{K_e}{N_{NR}}\right)^{\frac{\rho-1}{\rho}} + (1-\phi)\right]^{\frac{\sigma-\rho}{(\rho-1)\sigma}}\left[\frac{hR}{hNR}\right]^{\frac{1}{\sigma}}. \tag{22}$$

4. Calibration

The calibration of the model is made to match the U.S. economy in 1980 as in Brinca et al. (2019). The parameters that are exogeneous are set directly to match the data. The endogenous parameters are estimated by using the simulated method of moments (SMM). Table 3 in the Appendix lists all values and sources of exogeneous parameters.

Preferences

Even though there has been a debate in the literature considering the parameter of Frisch elasticity, it is set to 1.0 as in Brinca et al. (2016). The parameter of risk aversion is also set to the same level.

Labor productivity

The wage profile that is defined in equation (2) is calibrated directly from the data. Equation (23) is run using data from the panel of Study of Income Dynamics (PSID):

$$\ln(w_1) = \ln(w) + y_1 j + y_2 j^2 + y_3 j^3 + \epsilon_i, \tag{23}$$

where j is the age of individual i. The residuals of equation (28) are used to estimate the parameters governing the idiosyncratic shock ρ_u and σ_ϵ. The wage differential between non-routine and routine groups is calibrated to match the log difference in average wages between groups in 1980. In order to see the employment level of the two groups, their values are set to equal their observed weight in total employment in 1980.

Technology

In this framework, both relative price of investment and total factor productivity are set to 1.0 in 1980. The production function parameters are the same as in Eden and Gaggl (2018).

Government Budget and Social Security

The tax function used in this thesis is the same as in Gouveia and Strauss (1994) and Benabou (2002). The estimates of θ_1 and θ_2 in 1980 are from Ferriere and Navarro (2018). There is no progressivity for the social security rates, and both are set to 0.06, the average in 1980. Finally, the capital taxation τ_k and consumption tax τ_c are set to 0.47 and 0.05 respectively, in order to match the values obtained in Mendonza et al. (1994) for 1980.

Parameters calibrated using SMM

Given that there are several parameters that do not have any empirical counterpart, this framework uses the simulated method of moments so that the following loss function is minimized:

$$L(\psi, \beta_1, \beta_2, \beta_3, \beta_4, \underline{h}, \chi, \sigma_{NR}, \sigma_R) = || M_m - M_d ||, \tag{24}$$

Since there are nine parameters, the model needs to have nine data moments to have an exactly identified system. Table 1 and Table 2 display the target data moments and the nine parameters, respectively.

Table 1: Calibration Fit

Data moment	Description	Source	Target	Model value
75-100/all	Average wealth of households 75 and over	US Census Bureau	1.31	1.30
$\bar{n}$	Fraction of hours worked	PWT	0.33	0.33
K/Y	Ratio between capital and output	BEA	3.0	3.0
var *ln w* NR; R	Variance of the log wages	CPS	0.23; 0.21	0.23; 0.21

Table 2: Parameters Calibrated Endogenously

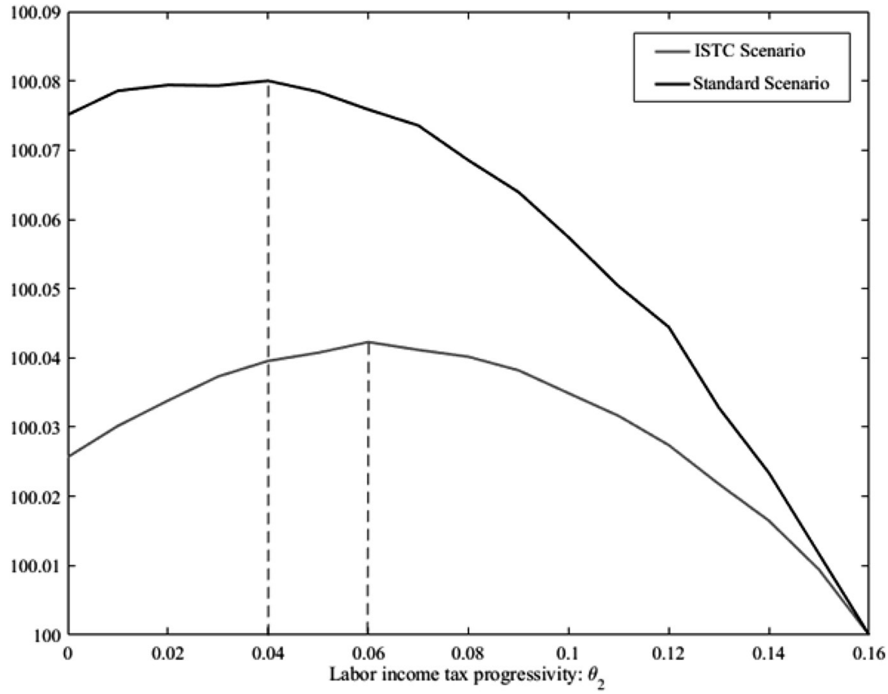
Parameters	Description	Value
ψ	Bequest utility	7.30
$\beta_1, \beta_2, \beta_3, \beta_4$	Discount factors	0.93; 0.99; 0.976; 0.93
$\underline{h}$	Borrowing limit	0.02
χ	Disutility from work	7.0
σ_{NR}, σ_R	Standard Deviations of ability	0.24; 0.43

5. **Results**

The most important mechanism of this thesis is from the drop of relative investment price. It is expected that with the decrease in investment prices, workers whose tasks are complementary to capital see their relative demand increase and therefore a higher equilibrium wage. Since workers get allocated to tasks at market entry depending on their ability level, the rise in the wage premium will increase the importance of the permanent component in their income process. Heathcote et al. (2017) show that this permanent component of the income process that is responsible for most of the increase in income inequality. If permanent component explains more of income dispersion, then optimal progressivity increases because it reduces consumption dispersion between different skills/tasks and increases insurance against low ability (Heathcote et al., 2017; Krueger et al., 2009). Hence, because this research changes the relative investment price, *ceteris paribus*, it is expected that the marginal benefits of progressivity are higher than their costs and optimal labor income progressivity will increase with respect to the benchmark economy in 1980.

Figure 1 displays the levels of progressivity as a function of the Expected Social Welfare of an Unborn Individual. This is the parameter used to measure the changes in the social welfare because the social planner is utilitarian and, thus, he cares equally about the utility from consumption of all agents within a cohort. Then, according to Heatchote et al. (2017), the contribution to social welfare from any given cohort is the within-cohort average value for remaining expected lifetime utility. The *Standard Scenario* represents the benchmark model of 1980, and the *ISTC Scenario* is the same calibration, with the exception of the relative investment price which dropped from 1.0 to 0.586 in order to match the values in Brinca et al. (2019).

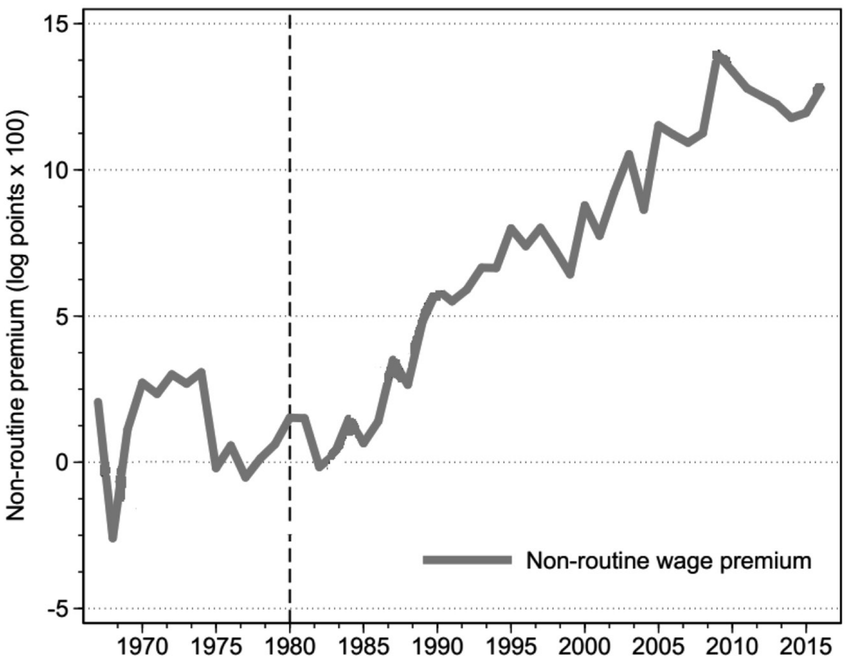
Figure 1: Welfare vs. Progressivity



Note: Horizontal axis: labor income tax function progressivity. Vertical axis: normalization of the changes of "Expected Social Welfare of an Unborn Individual" where the benchmark is $\theta_2 = 0.16$.

The first result that can be understood when analyzing Figure 1 is that, in both cases, optimal labor tax progressivity is positive. Thus, this model captures the assumption from Heathcote et al. (2017): skill heterogeneity always implies positive progressivity. Moreover, ISTC increases the importance of redistribution, increasing optimal progressivity. The ISTC Scenario represents that mechanism: the drop on the relative investment price is responsible for an increase of 24% in the wage premium. This is a consequence of the observed change in the routine labor share that fell 23% due to the substitution effect between routine jobs and ICT capital that increased the capital share by 27%. These results are corroborated by Figure 2 from Brinca et al. (2019) where it is showed that the wage premium has increased since 1980.

Figure 2: The rise of non-routine wage premium (Brinca et al., 2019)



The rise in the wage premium will increase the importance of the permanent component in the income process of workers and thus, the optimal labor tax progressivity increased from 0.04 to 0.06. The comparative analysis is displayed in Table 4. In order to see an empirical example, using the tax function as in Ferreira (2019), if the average salary were 1000$, and it increased 50%, the average tax rate would change from $\tau(y) = 0{,}365$ if $\theta_2^* = 0{,}04$ to $\tau(y) = 0{,}452$ if $\theta_2^* = 0{,}06$.

6. **Conclusions**

Optimal taxation is one of the classic trade-offs in economy between efficiency and equality. It is helpful when a government wants to face inequality with fiscal policy, but it might be ineffective if the loss in productivity is higher than the gains of redistribution. Nevertheless, it may be a valuable fiscal tool to face a problem such as income inequality, which has increased in the last thirty years. This thesis uses a model with incomplete markets, overlapping generations, heterogeneous agents and partial uninsurable idiosyncratic risk, adding the fact that in the technological environment there are two types of tasks that increase the dispersion of ability. Moreover, routine jobs are made substitute of capital in this model and conversely, the non-routine jobs are complement of capital.

The model is calibrated to match the data of US from 1980 and we try to capture the effects of the drop on the relative investment price in optimal progressivity, connecting Investment Specific Technological Change with Optimal Taxation. The most important result is the fact that optimal labor tax progressivity is not only positive but also increases with Investment Specific Technological Change. This experiment was also able to capture the increase in wage premium as well as the drop on the routine labor share, which are the main drivers to the increase in the optimal progressivity. This dissertation is able to demonstrate the link between the fall on relative investment price and the levels of optimal progressivity in the economy. All these effects are created in a model with different types of workers that respond differently to capital. These mechanisms may be important to predict future effects of automation that can start to become a substitute not only of routine but also of non-routine jobs through artificial intelligence, as in Acemoglu and Restrepo (2018).

A further study following this framework could examine how Investment Specific Technological Change accounts for the change in the optimal labor tax progressivity. Moreover, it would be interesting to study not only the impacts of the dispersion of ability, but also the effects of idiosyncratic productivity shocks that were eliminated in this model, adding this same analysis for the capital income tax and follow the works of Krueger et al. (2009).

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APPENDIX

Table 3: 1980 Calibration Summary

Description	Parameter	Value	Source
Preferences			
Inverse Frisch elasticity	η	1,010	Brinca et al. (2016)
Risk aversion parameter	σ	1,001	Brinca et al. (2016)
Labour productivity			
Depreciation rate equipment	θ_e	0,105	BEA
Depreciation rate structures	θ_s	0,033	BEA
Parameter 1 age profile of wages	y_1	0,265	Brinca et al. (2016)
Parameter 2 age profile of wages	y_2	-0,005	Brinca et al. (2016)
Parameter 3 age profile of wages	y_3	0,000	Brinca et al. (2016)
Hours worked for SS purposes	h_{ss}	0,330	Assumption
Variance of idiosyncratic risk	σ_u	0,013	Assumption
Persistence idiosyncratic risk	ρ_u	0,013	Assumption
Technology			
Share of income which goes to structures	α	0,151	Authors' calculations
Share of the ICT cap/NR composite	φ	0,469	Eden and Gaggl (2018)
Share of the ICT cap in the ICT cap/NR composite	ϕ	0,300[1]	Eden and Gaggl (2018)
Elasticity of substitution of the ICT cap/NR composite	ρ	1,558	Eden and Gaggl (2018)
Elasticity of substitution between composites and RM labor	l	8,307	Eden and Gaggl (2018)
TFP	A	1,000	Normalization
Relative price of investment	I_p	1,000	Normalization
NR wage differential	NR_{wrat}	1,097	CPS

[1] This value is different from the original reference. However, because this is related to the scale used in Eden and Gaggl (2018), the only difference is exactly the scale.

Description	Parameter	Value	Source
Employment share (headcount) of the NR group	emp_{nr}	0,403	CPS
Government and SS			
Consumption tax rate	τ_c	0,054	Mendoza et al (1994)
SS tax employer	τ_{ss}	0,061	Social Security Bulletin, July 1981
SS tax employee	τ_{ss}	0,061	Social Security Bulletin, July 1981
Capital income tax rate	$\tilde{\tau}_k$	0,469	Mendoza et al (1994)
Tax scale parameter	θ_1	0,850	Implied value from
Tax progressivity parameter	θ_2	0,160	Ferriere and Navarro (2018)
Government debt to GDP	B/Y	0,320	(FRED) – average 1978-1982
Military spending to GDP	G/Y	0,053	World Bank (average 1978-1982)

Table 4: Results across scenarios

Parameters	Standard Scenario	ISTC Scenario
GDP/capita	0,53	0,83
Var ln (w)	0,26	0,32
R Var ln (w)	0,21	0,21
NR Var ln (w)	0,23	0,41
Wage premium	0,55	0,38
Hours	0,36	0,39
K/Y	3,00	7,26
Capital share	0,30	0,38
Labor share	0,70	0,62
R Labor share	0,33	0,26
NR Labor share	0,37	0,36

Average Tax Function

Using the same method as in Ferreira (2019), the average tax function $\tau(y)$ is obtained by:

$$y_a = 1 - \theta_1 y^{-\theta_2}$$

$$y_a = (1 - \tau(y))y$$

$$\tau(y) = 1 - \theta_1 y^{-\theta_2}$$

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