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Optimal age-dependent taxation in emerging markets: A quantitative assessment

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This paper studies the design and welfare implications of an optimal age-dependent taxation scheme for an emerging economy. The setting is an overlapping generations economy with uninsured productivity risk, partially insured occupational risk (unemployment and informality by exclusion), stochastic retirement, and stochastic access to the pension fund. We calibrate this model for Ecuador and find that the optimal tax scheme provides a payroll tax exemption up to age 35, thereafter becoming hump-shaped with a maximum tax rate of 50% at age 50. The progressive tax levied on labor income implies an initial marginal tax rate of 5% that increases linearly to a top marginal tax rate of 35%. This tax scheme produces a welfare gain of 2.9% measured in compensated equivalent units and reduces wealth inequality by 5.8%. For comparison, in a model built and calibrated for the US economy (no informality, higher productivity and longevity risk, and full coverage of the social security system), the optimal payroll tax implies a zero tax rate up to age 27, becoming hump-shaped thereafter with a maximum tax rate of 56.2% at age 46.

KEYWORDS
Consumption and saving, fiscal policy, taxation, demographic trends and macroeconomic effects, occupational choice, informal labor markets, Latin America, Ecuador, United States.

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Impuestos óptimos que dependen de la edad aplicados en los mercados emergentes: Una evaluación cuantitativa

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Este artículo estudia las implicaciones de diseño y bienestar de un esquema de impuestos óptimo que depende de la edad para una economía emergente caracterizada por altos niveles de informalidad en el mercado laboral. El entorno es una economía de generaciones solapadas donde los hogares enfrentan riesgos de productividad no asegurados, riesgos laborales parcialmente asegurados, jubilación estocástica y acceso estocástico al fondo de pensiones. Calibramos este modelo para Ecuador y descubrimos que el esquema de impuestos óptimo proporciona una exención de impuestos sobre la nómina hasta los 35 años. A partir de allí se hace cóncavo con una tasa impositiva máxima del 50%, a los 50 años. El impuesto progresivo recaudado sobre el ingreso laboral implica un tasa impositiva marginal inicial de 5% que aumenta linealmente hasta alcanzar 35%. Este esquema impositivo produce una ganancia de bienestar de 2,9% medido en unidades equivalentes compensadas y reduce la desigualdad de la riqueza en 5,8%. A modo de comparación, en un modelo construido y calibrado para la economía de los EE.UU. (sin informalidad, mayor productividad y riesgo de longevidad, y cobertura total del sistema de seguridad social), el impuesto óptimo sobre la nómina implica una tasa impositiva de cero hasta los 27 años, haciéndose cóncavo a partir de allí con una tasa impositiva máxima del 56,2%, a los 46 años.

1 | INTRODUCTION

Demographic change and high levels of informality in developing countries put considerable and increasing pressure on health and pensions systems as well as on fiscal sustainability (Altamirano-Montoya et al., 2018). In the Latin American context, where inequality is always upfront on the economic and political debate, governments also grapple with the design of tax policy that is efficient and redistributive at the same time. As a consequence, although financing retirement and unemployment insurance is a key piece of the welfare state, designing reforms in line with the sustainability and modernization of the social security system is not trivial.

In this paper, we study the design and welfare implications of an optimal age-dependent taxation scheme for an emerging economy characterized by a labor market that exhibits high levels of informality and important productivity differentials between the formal and informal sectors. We also analyze how this optimal scheme would differ if the planner acts in the context of a developed country, where occupational risk is not an issue, and workers' productivity is significantly higher.

For this, we build a model that collects the main features that distinguish an emerging market and then adapt it to a developed economy. In the emerging market setting, we work with overlapping generations where households face uninsured idiosyncratic risk and partially insured occupational risk, stochastic retirement, stochastic access to the pensions fund, age-specific productivity with different age profiles for formal and informal sectors and fixed ability types determined at birth. Moreover, households are subject to progressive labor income taxation and flat tax rates over capital income and consumption. Firms hire formal and informal labor and face a flat tax rate on their profits, pay social security contributions on behalf of formal employees (on top of workers' own contributions) and pay monetary benefits to this group of workers.

Occupational risk refers to the possibility of workers being expelled from the formal sector either to the less productive informal sector or to unemployment. We understand informality as an occupational state where workers neither pay taxes nor contribute to the social security system (Perry et al., 2007) and are able to perform only low productivity activities. Moreover, informal workers do not have access to unemployment insurance and face reduced probabilities of benefiting from the pension fund driven by persistent informality. We calibrate this model for Ecuador, an emerging economy characterized by an aging population and high levels of labor informality.

In the context of a developed economy, the occupational risk is not an issue. This is why, in this setting, we assume full employment and calibrate age-specific productivity according to developed economy standards. Moreover, we assume deterministic retirement and access to the retirement fund, thus providing additional insurance against longevity risk (compared to the emerging economy benchmark). We calibrate this model for the United States.

To obtain the optimal tax scheme, we use a utilitarian welfare function where each individual's discounted utility is accounted for, weighted by the proportion that each age group represents in the overall population (we assume a stationary distribution). Under these assumptions, we find that the optimal contribution scheme is hump-shaped, provides a contribution exemption for workers aged up to 35, and reaches a maximum contribution rate of 50% at age 50. On average, workers end up contributing a nominal rate of 14.2%, which is 50% higher than the contribution rate in the status quo. Moreover, we find that the status quo marginal tax rates of the progressive labor tax scheme coincide with the ones chosen optimally by the planner. When subjecting the reform to a referendum where we assume that households with increased utility with respect to the status quo vote in favor of the reform, we find that 59.8% of the population would vote in favor, implying that the reform would win by a simple majority. Overall, the optimal tax scheme produces a welfare gain of 2.9% measured in compensating equivalent units and reduces wealth inequality by 5.8% (variation in the Gini coefficient).

These results might be sensible to one powerful assumption we are making about the production technology and two basic features that describe an emerging market. Regarding the production technology, we assume that the elasticity of substitution between formal and informal labor is 1 (Cobb-Douglas case). The reason why this might influence our results is that, if this elasticity were higher, then the firm could potentially shift all its labor demand towards the informal sector, reducing the leeway that the planner has to increase the contribution rates that affect formal workers. To see how much our results would change if we modify this assumption, in the sensitivity analysis, we present an alternative scenario where the elasticity of substitution between both types of labor is raised to 1.2. We find that our qualitative results do not change, but quantitatively the two scenarios are significantly different. However, we find that our benchmark economy provides more conservative results.

Something similar occurs to the productivity differential between formal and informal workers. In this case, productivity profiles have a direct effect on the shape and level of the optimal tax scheme. Thus, in a second alternative scenario, we eliminate this differential and calibrate the economy using an unconditional estimation of age-specific productivity. We find that this feature of emerging economies is key to our results because once we eliminate this difference, optimal contribution rates to the social security system suffer a severe contraction, as well as marginal tax rates in the progressive labor income tax scheme.

The second feature that concerns us is our assumption on stochastic retirement. We include this mechanism because pension systems in most emerging markets are on the verge of actuarial bankruptcy. This implies that there are high probabilities that current generations of workers might not have access to the retirement transfer. Thus, a third alternative scenario eliminates this feature and assumes, as for the case of the US economy, that retirement and access to the pensions fund are both deterministic. In this case, we find that our results show only small variations when stochastic retirement and stochastic access to the pensions fund are removed from the model.

When we look at how the planner would act in the case of the US economy, we find that the optimal contribution scheme is hump-shaped as well, but the exemption ends much earlier than in the emerging market (at 27 years old). The maximum tax rate of 56.2% is reached when workers become 46 years old, and the nominal average contribution rate is 30%, which is about 2.4 times the level in the status quo (12.4%). Regarding the design of the progressive labor income tax scheme, we find that the lowest and highest marginal tax rates drop to 0.1% and 14.6%, respectively, showing that within this economy, the planner performs a severe shift from funding the government to increase the size of the pensions fund. The political economy exercise results for the US show that 55.4% of the population would vote in favor of the reform, again implying that it would win by a simple majority.

Following the Mirrless tradition (Mirrlees, 1971), optimal tax reforms should aim at minimizing market distortions, especially those related to labor supply. Golosov et al. (2003) show that dynamic optimal fiscal policy is extremely hard to implement since the preferred tax scheme depends on households' detailed income history. However, Weinzierl (2011) shows that "tagging" (i.e. conditioning tax rates on individuals' observable characteristics, originally proposed in Akerlof, 1978) is very useful to capture most of the welfare gain of the full reform when average marginal rates of the labor income tax depend on age, which constitutes a partial reform since it does not make use of income history.

Our main contribution consists in analyzing the design and welfare effects, and providing key quantitative details of an age-dependent tax scheme in an economy where it is very likely for workers to become informal, informality is highly persistent, and there are productivity differentials between the formal and informal sectors.[1] The growing literature on age-dependent taxation focuses on studying optimal tax schedules on labor income for developed economies. Ndiaye (2017) is the closest to our paper. The author studies the effects of flexible retirement on optimal tax policy design. He finds that when retirement is exogenous (and fixed), the labor tax scheme is increasing in age (as in Farhi and Werning, 2013), but becomes concave once retirement is endogenous. The mechanism behind this result is that labor supply elasticities increase significantly as the individual ages.

The humped shape of the optimal age-dependent tax scheme is a general result in the literature. Erosa and Gervais (2002) find that age-dependent taxes arise as a natural implication of life-cycle behavior. The same result is obtained by Karabarbounis (2016), who analyzes optimal labor income tax designs in a very complex setting where the tax schedule is tagged to households' assets, age and filing status (one or two earners), Heathcote et al. (2019) who also allow for age-varying progressivity and Weinzierl (2011) who, following Mirrlees (1971), shows that tagging on age allows a partial reform to obtain most of the welfare gains of a full reform. In this paper, we embed enough complexity in our model so we can perform a quantitative assessment on *how high* (or low) age-specific tax rates should be for each age group in the economy.

We also find that the optimal tax scheme produces a significant increase in the average nominal payroll tax rate faced by workers and that this increase produces a major contraction in effective formal labor supply and an equally significant increase in informal labor supply. In the aggregate, labor supply falls even more than the supply of hours worked, implying that the reform causes a crowding-out effect among more productive formal workers and a crowding-in effect among less productive informal workers. In this literature, Antón (2014); Fernández and Villar (2017); Morales and Medina (2017) find that a tax cut in payroll taxes reduced labor market informality in Colombia, while Gruber (1997) finds that payroll tax reforms applied in Chile had no effects on employment, and most of the variation was concentrated on wages. Other research that follows this line include Bosch and Esteban-Pretel (2015, 2012); Ulyssea (2010); Margolis et al. (2014).

We depart from the literature in the way we model informality. In general, informality is modeled as the result of searching frictions (Zenou, 2008; Amaral and Quintin, 2006; Meghir et al., 2015; Alvarez-Parra and Toledo, 2016), or as optimal responses of firms and entrepreneurs (Maloney, 2004; Granda and Hamann, 2015; Ulyssea, 2018; Fortin et al., 1997; De Paula and Scheinkman, 2010). Instead, we model informality and unemployment as an exogenous source of partially insured risk to reflect that, especially among wage earners, informality is a result of exclusion from the labor market rather than a consequence of individual endogenous choices. In this regard, we contribute to the literature by studying how informality by exclusion affects optimal policy reform and households' choices over the life cycle (Perry et al., 2007; Bosch and Maloney, 2007; Kucera and Roncolato, 2008; Mondragon-Velez et al., 2010; Alloush et al., 2013; Williams and Youssef, 2015; Medvedev and Oviedo, 2016; Canelas, 2018).

Ecuador makes an interesting case study that can shed light on social security reforms for other emerging markets. Since 1970, its population has almost tripled and employed

[1] Analyzing how the payroll tax interacts with the progressive labor income tax scheme represents a marginal contribution to the extensive literature on progressive tax schemes (see e.g. Conesa and Krueger, 2006; Erosa and Koreshkova, 2007; Conesa et al., 2009; Krueger and Ludwig, 2013; Kindermann and Krueger, 2014; Krueger et al., 2015; Krueger and Ludwig, 2016; McGrattan and Prescott, 2017; Heathcote et al., 2019; Uribe-Terán, 2019).

informal population represented more than 60% for the 2008-2017 period.[2] In addition, laws approved in recent years have increased the financial pressure on pension systems due to additional coverage combined with lower revenue,[3] making a social security reform inevitable.

We organize this paper as follows. Section 2 describes the model. In section 3 we spend a considerable amount of space describing our calibration and estimation strategies, particularly because is the first time that this type of model is built for Ecuador; along the way we compare our estimation results with the ones obtained for the United States economy when deemed necessary. At the end of this section, we show how well our model matches some key moments of the data. In section 4 we provide a formal description of the optimization problem faced by the planner, while section 5 shows the effects of the application of the age-dependent optimal tax. Section 6 presents a sensitivity analysis of our main assumptions. In a similar vein, section 7 presents the main features of the model built for the US economy and shows the main differences in the results compared to what we obtained in the model calibrated for Ecuador. Finally, section 8 concludes.

2 | THE MODEL

We consider an overlapping generations economy where households work for a limited number of years and retire for the rest of their lives under a pay-as-you-go social security system. During their productive years, workers can move between formality, informality and unemployment. We assume that transitions across occupation status are exogenous, representing an additional source of risk for workers. Workers also face stochastic retirement and stochastic access to the retirement fund, implying that the social security system provides partial insurance for unemployment risk and retirement (longevity risk).

The typical period in our model is as follows. First, households receive an occupation shock, which determines the type of contract under which they provide labor. In the case of formal and informal workers, they receive an idiosyncratic productivity shock and decide how much labor to provide, and how much to consume and save. Unemployed and retired households decide how much to consume or save. Formal workers have access to unemployment insurance, while access to retirement insurance is stochastic conditional on households' labor history and occupational status at the moment of retirement.

The representative firm hires capital, formal and informal labor to produce the consumption good in the economy (numeraire) and maximize profits. Part of the costs that the firm faces besides the usual include a contribution to the social security fund and bonuses that are paid to formal workers. We assume no aggregate uncertainty.

2.1 | Households

The economy is populated by bachelor households with stochastic life spans, age-specific productivity, uninsured productivity shocks and partially insured occupational status. The latter are *partially insured* in the sense that only formal workers have access to unemployment insurance, while access to the retirement fund is more likely for workers with more history of formality during their active years. Moreover, households are born into two ability types (high or low) with equal probability, and into an specific occupation state. Each period they

[2]This share is higher than the 40% average officially reported. The reason is that we define informal workers as those that do not contribute to social security.

[3]In 2015, the Ecuadorian government stopped its 40% contribution to the pension system (in case of financing gaps). Likewise, it reduced the share allocated to the pension system from 9.74% to 6.06% of workers' contribution. Coverage was also extended to housemaids.

are endowed with one unit of time that has to be distributed between leisure and work.

2.1.1 | Demographics

There are J overlapping generations. Each period, a continuum of agents is born so the population grows at a constant rate n. Agents face stochastic life spans, where ψ_j is the conditional probability of being alive next year; all agents die with certainty at age J. Assets left by the dead are confiscated by the government, taxed at the current tax rate for capital income, and distributed among the living in a lump-sum transfer. This structure implies a stationary age distribution with ν_j denoting the proportion of households of age j at any point in time.

Workers face occupational risk, so they move exogenously between states $S = \{f, i, u\}$ where f is a formal contract, i an informal contract and u unemployment. We understand a formal contract as a labor relation where the worker contributes to the social security fund, pays taxes and receives monetary benefits from the employer. Moreover, a formal contract guarantees access to unemployment insurance and increases the probability of receiving pension transfers during retirement.

Transitions among occupation states are governed by a transition probability matrix **P**, where each entry $p(s_{j+1}, s_j) \equiv P(s_{j+1}|s_j)$ is the conditional probability of moving from state s_j to state s_{j+1} the following year. We also assume that $p(s_{j+1}, s_j) > 0$ for all possible transitions, so the Markov chain generated by **P** and S converges to a unique stationary distribution.

Workers also face stochastic retirement, where the probability of retirement is conditional on age p_j^r. Nonetheless, we assume that all agents retire with certainty at age j_r, so $p_j^r = 1$ for all $j \geqslant j_r$. During working age, agents face age-specific productivity levels that depend on occupational status ε_{js} where $\varepsilon_{js} = 0$ for $j > j_r$, $\varepsilon_{ju} = 0$ for all $j \geqslant 1$ and $\varepsilon_{jf} \geqslant \varepsilon_{ji}$ for all $j \geqslant 1$. The latter reflects that, on average, formal contracts are at least as productive as informal contracts within every age group.

2.1.2 | Income process

Income for each household comes from wages w_s that are determined in equilibrium with $w_u = 0$ since unemployed workers do not receive a wage. The income process is affected by an idiosyncratic productivity shock η, the age-specific and occupation-dependent productivity level ε_{js}, the workers' ability type determined at birth μ and the amount of hours supplied by workers in each occupation status ℓ_s (with $\ell_u = 0$). The fixed ability type defined at birth can take two values $\mu = \{\mu_l, \mu_h\}$ with variance σ_μ^2. Formally, labor income during period t at age j in occupation s is given by

$$y_{tjs} = \mu \varepsilon_{js} \eta_t w_{ts} \ell_{tjs}.$$

For the sake of notation, we avoid a household-specific subscript. The idiosyncratic productivity shock follows an $AR(1)$ process such that

$$\log \eta_{t+1} = \rho_\eta \log \eta_t + \epsilon_{t+1},$$

where ρ_η is the coefficient of autocorrelation and ϵ_t is assumed to be normally distributed with mean zero and standard deviation σ_η. Let $F_\eta(\eta_{t+1} \leqslant \eta|\eta_t)$ be the cumulative distribution function for η_{t+1} conditional on the value of η_t which we assume stationary.

2.1.3 | Recursive formulation

To describe the recursive formulation of the household problem we do not use the time period sub-index to avoid notation complications and use the age-specific sub-index only when deemed necessary. Moreover, we use prime notation to distinguish variables in the following period. With this in mind, households face different problems depending on their current occupation status, implying that we must use different state variables for each type.

For formal and informal workers we define the state variables $x_w = \{a, \eta, \mu, j\}$, where a are asset holdings, η the productivity shock, μ the fixed effect and j age. For unemployed households the state variables are $x_{us} = \{a, s_{-1}, j\}$ for $s = \{f, i, u\}$ where s_{-1} saves the occupation status during the last active period in the labor market. Let $b_u(s_{-1})$ denote the social security insurance transfer in case of unemployment; $b_u(i) = 0$ and $b_u(f) = \lambda_u$ implying that only workers with formal contracts before becoming unemployed are the ones with access to unemployment insurance.

The model also allows for the possibility of early retirement and current formality does not guarantee that the worker will have access to the pension fund transfer. In particular, access to retirement insurance is stochastic and conditional on age, labor history and the occupational status during the year before retirement. In this case, the state variables are $x_r = \{a, b_r, j\}$.

Let $p(\lambda_r, s_j, j)$ denote the probability of having access to the retirement fund for a worker of age j and occupation status s_j. With these considerations, we first work the case of a household that is hired with a formal contract. In this case, she decides how much to consume and work, and pays for her consumption, labor and capital income taxes besides her contribution to the social security fund. The problem for the formal worker can be written as

$$
\begin{aligned}
V_f(x_w) \quad &= \quad \max \Bigg\{ U(c_f, \ell_f) + \beta\psi_j \Bigg[(1 - p_j^r) \Bigg(\int \sum_{s'=i,f} p(s', f) V_{s'}(x'_w) F_\eta(d\eta'|\eta) + \\
&\quad + \; p(u, f) V_u(x'_{uf}) \Bigg) + p_j^r \sum_{b_r} p(b_r, s_j, j) V_r(x'_r) \Bigg] \Bigg\} \qquad (1) \\
\text{s. t.} \quad a'_f \quad &= \quad (1 + R)a + (1 - \tilde{\tau}_j) y_{jf} - T((1 - \tilde{\tau}_j) y_{jf}) + Tr + G - (1 + \tau_c)c, \\
&\quad a'_f \geqslant 0, \quad c_f > 0, \quad 0 \leqslant \ell_f \leqslant 1,
\end{aligned}
$$

where β is the discount rate, $R = (1 - \tau_k)r$ is the capital return net of taxes, $\tilde{\tau}_j$ is the payroll tax, $T(\cdot)$ is a progressive tax scheme that affects labor income, Tr is the lump-sum transfer that comes from the assets left by the dead, G is a government lump-sum transfer and τ_c is the tax rate for consumption.

Now consider the informal sector. The difference is that in this case the worker does not pay labor taxes and decides only how much to consume, save and work given the tax structures for consumption and capital income, and the equilibrium prices. In this case, the problem is

$$
\begin{aligned}
V_i(x_w) &= \max\left\{U(c_i,\ell_i)+\beta\psi_j\left[(1-p_j^r)\left(\int\sum_{s'=i,f}p(s',i)V_{s'}(x'_w)F_\eta(d\eta'|\eta)+\right.\right.\right.\\
&\quad\left.\left.\left.+\;p(u,i)V_u(x'_{ui})\right)+p_j^r\sum_{b_r}p(b_r,s_j,j)V_r(x'_r)\right]\right\} \qquad (2)\\
\text{s.t.}\quad a'_i &= (1+R)a+y_{ji}+Tr+G-(1+\tau_c)c_i,\\
&\quad a'_i\geqslant 0,\quad c_i>0,\quad 0\leqslant \ell_i\leqslant 1.
\end{aligned}
$$

If the household is unemployed she only decides how much to consume and save. The occupation status during the last active period in the labor market determines whether she has access to unemployment insurance or not. Moreover, when households leave unemployment they receive the average idiosyncratic productivity shock $\overline{\eta}$. With this in mind, the problem of an unemployed worker can be written as

$$
\begin{aligned}
V_u(a,s_{-1},j) &= \max\left\{u(c_u)+\beta\psi_j\left[(1-p_j^r)\left(\sum_{s'=i,f}p(s',u)V_{s'}(x'_w)+\right.\right.\right.\\
&\quad\left.\left.\left.+\;p(u,u)V_u(x'_{us})\right)+p_j^r\sum_{b_r}p(b_r,s_j,j)V_r(x'_r)\right]\right\} \qquad (3)\\
\text{s.t.}\quad a'_u &= (1+R)a+b_u(s_{-1})+Tr+G-(1+\tau_c)c_u,\\
&\quad a'_u\geqslant 0,\quad c_u>0.
\end{aligned}
$$

Finally, we need to consider the case of retired households. Contrary to occupational status, we assume that once a household retires it is impossible for her to get back to the labor market (so retirement is irreversible). Moreover, access to the retirement cash transfer is stochastic and depends on the workers' labor history and retirement age. Thus, the worker has access to retirement insurance with probability $p(b_r,s_j,j)$.

Taking this into consideration, retired households decide how much to consume and how much to save given their access status to retirement benefits, the tax schemes defined over capital income and consumption, and equilibrium prices. Formally,

$$
\begin{aligned}
V_r(x_r) &= \max\{u(c_r)+\beta\psi_j V_r(x'_r)\},\\
\text{s.t.}\quad a' &= (1+R)a+b_r+Tr+G-(1+\tau_c)c_r, \qquad (4)\\
&\quad a'_r\geqslant 0,\quad c_r>0.
\end{aligned}
$$

2.2 | Firms

We consider a representative firm that hires capital and labor to produce the consumption good in the Economy; labor can be hired in the formal or the informal sector. We assume a Cobb-Douglas production function with respect to capital and labor, and a CES aggregator for both types of labor. Formally,

$$
Q(K,L_f,L_i)=AK^{\alpha}\left[\alpha_f L_f^{\gamma}+(1-\alpha_f)L_i^{\gamma}\right]^{\frac{1-\alpha}{\gamma}},
$$

where α represents the share of output paid to capital, α_f is the proportion of formal labor required for production and γ is related to the elasticity of substitution between formal and informal labor, K is the available stock of capital in the economy, L_f is formal labor and L_i is informal labor. The purpose of using this production function is to have enough flexibility to study how the degree of substitution between the two types of labor can affect the optimal tax scheme.

The firm is required to pay taxes over its taxable profits, which are given by the firm's total income less labor and capital depreciation costs. Capital rental costs are not deductible, since households already pay taxes on this income source. Moreover, the firm contributes to the social security fund of its formal employees, and pays additional benefits that go beyond wages such as private health insurance, work-wear and bonuses. Taking this into consideration, the problem of the firm is

$$\max \Pi(K, L_f, L_i) = (1-\tau_\pi)\left[Q(K, L_f, L_i) - (1+\tilde{\tau}_f+\phi)w_f L_f - w_i L_i - \delta K\right] - rK,$$

where τ_π is the tax rate on the firm's profits, $\tilde{\tau}_f$ is the firm's contribution to its formal workers' social security fund, ϕ is the proportion of labor costs related to formal workers' additional benefits, and δ is the capital's depreciation rate.

We assume that firms can change the type of contracts (formal or informal) or end them without restriction (exclusion mechanism). The first order conditions for the firm's maximization problem define net returns in the economy and can be written as

$$r = (1-\tau_\pi)\alpha\frac{q}{k} - \delta, \tag{5}$$

$$w_f = \frac{(1-\alpha)\alpha_f}{1+\tilde{\tau}_f+\phi}\left(\frac{h_f}{h}\right)^{\gamma}\frac{q}{h_f}, \tag{6}$$

$$w_i = (1-\alpha)(1-\alpha_f)\left(\frac{h_i}{h}\right)^{\gamma}\frac{q}{h_i},, \tag{7}$$

where $q = Ak^{\alpha}\left[\alpha_f h_f^{\gamma} + (1-\alpha_f)h_i^{\gamma}\right]^{\frac{1-\alpha}{\gamma}}$ and k are output and capital per unit of effective labor, respectively, and h_f and h_i are the ratios of formal and informal labor hired by the firm, respectively.

2.3 | Social Security

The social security system manages a fund that is distributed between unemployment and retirement insurance. Formal workers contribute by means of an age-dependent payroll tax $\tilde{\tau}_j$ and firms through a tax levied on its hiring of formal workers $\tilde{\tau}_f$. The social security fund works as a pay-as-you-go system. In the benchmark economy we assume that $\tilde{\tau}_j = \tilde{\tau}$ for all $j < j_r$ to reflect the status quo in Ecuador's economy.

A proportion θ_t of the total revenue available in the fund is used to finance the retirement insurance transfer among those who have access, and the remaining $1-\theta_t$ of the fund is used for the unemployment insurance. We require the social security system to always run a balanced budget, so short or long-run deficits are not possible. Moreover, transfers λ_u and λ_r are determined in equilibrium.

2.4 | Government

The role of government is limited to collecting taxes and then redistributing its revenue among all living households through a lump-sum transfer. Capital income and consumption are taxed under flat schemes with rates τ_k and τ_c.

Labor income is taxed using a progressive tax scheme as in Kindermann and Krueger (2014). Taxable income corresponds to labor income from formal workers net of the payroll tax:

$$\hat{y}_{jf} = (1 - \tilde{\tau}_j) y_{jf}.$$

The marginal tax rate for labor income is computed as

$$T'(\hat{y}_{jf}) = \begin{cases} \tau_l + \tau_m(\hat{y}_{jf} - y_l) & \text{if } y_l \leqslant \hat{y}_{jf} < y_h, \\ \tau_h & \text{if } \hat{y}_{jf} > y_h, \end{cases}$$

where $\tau_h \geqslant \tau_l$ are the maximum and minimum marginal tax rates respectively, y_l is the amount of income that is exempt, y_h is an income threshold after which the marginal tax rate becomes flat and $\tau_m = (\tau_l - \tau_h)/(y_h - y_l)$ corresponds to the linear increase in the marginal tax rate for income levels that lie within y_l and y_h.

The government uses tax revenue to finance a lump-sum transfer to all the living households in the economy. We assume that this expenditure is a fixed proportion of GDP, so the lump-sum transfer is simply $G = gQ$, where $0 \leqslant g \leqslant 1$.

2.5 | Equilibrium

We next define the competitive equilibrium and the stationary equilibrium of the economy depicted in the previous section. From the partition we performed over the state space in the recursive formulation of the workers' optimization problem, we have the state variables for active workers defined as $x_w = \{a, \eta, \mu, j\}$ where $a, \eta \in \mathbb{R}_+$, $\mu \in \mathcal{U} = \{\mu_l, \mu_h\}$ and $j \in \mathcal{J} = \{1, \ldots, J\}$. Thus, the state space for workers is given by $\mathcal{X}_w = \mathbb{R}_+ \times \mathbb{R}_+ \times \mathcal{U} \times \mathcal{J}$. For unemployed households the state variables are $x_{us} = \{a, s_{-1}, j\}$ where $s_{-1} \in S = \{f, i, u\}$, so the state space is $\mathcal{X}_u = \mathbb{R}_+ \times S \times \mathcal{J}$. In the case of retired workers, the corresponding set is given by $x_r = \{a, b_r, j\}$ where $b_r \in \mathcal{B} = \{0, \lambda_r\}$ and the state space is $\mathcal{X}_r = \mathbb{R}_+ \times \mathcal{B} \times \mathcal{J}$. The full set of state variables in the economy is given by $x = \{a, \eta, \mu, s_{-1}, s, b_r, j\}$, so the state space for the economy is $\mathcal{X} = \mathbb{R}_+ \times \mathbb{R}_+ \times \mathcal{U} \times S \times \mathcal{S} \times \mathcal{J}$, where we have accounted for the distribution of households over different occupational states and $\mathcal{S} = S \cup \{r\}$.

Let $\mathscr{B}(\mathbb{R}_+)$ be the Borel σ-algebra of $\mathbb{R}_+$ and $\mathscr{P}(\cdot)$ the power set for $\mathcal{U}$, $\mathcal{J}$, S, $\mathcal{B}$ and $\mathcal{S}$. Then, we can define the different sets of all finite measures defined over the state space and the sub state spaces defined by the different occupation states. Let $\mathcal{M}_w$ be the set of all finite measures over $(\mathcal{X}_w, \mathscr{B}(\mathbb{R}_+) \times \mathscr{B}(\mathbb{R}_+) \times \mathscr{P}(\mathcal{U}) \times \mathscr{P}(\mathcal{J}))$, $\mathcal{M}_u$ the set defined over $(\mathcal{X}_u, \mathscr{B}(\mathbb{R}_+) \times \mathscr{P}(S) \times \mathscr{P}(\mathcal{J}))$, $\mathcal{M}_r$ the set defined over $(\mathcal{X}_r, \mathscr{B}(\mathbb{R}_+) \times \mathscr{P}(\mathcal{B}) \times \mathscr{P}(\mathcal{J}))$ and $\mathcal{M}$ the set defined over the entire state space $(\mathcal{X}, \mathscr{B}(\mathbb{R}_+) \times \mathscr{B}(\mathbb{R}_+) \times \mathscr{P}(S) \times \mathscr{P}(\mathcal{S}) \times \mathscr{P}(\mathcal{B}) \times \mathscr{P}(\mathcal{J}))$.

Additionally, let $\mathbf{1}_s$ be indicator functions that take the value of 1 if the household belongs to group $s \in \mathcal{S}$. The purpose of these functions is to locate policy functions in the correct section of the complete state space. Definition 2.1 deals with the competitive equilibrium and Definition 2.2 with the stationary equilibrium.

Definition 2.1 (Competitive Equilibrium) *Given sequences of capital income and consumption tax rates $\{\tau_{ct}, \tau_{kt}\}_{t=1}^{\infty}$, the progressive labor income tax scheme $T_t(\tau_l, \tau_h, y_{lt}, y_{ht})$ age-specific payroll tax rates $\{\tilde{\tau}_{jt}\}_{t=1}^{\infty}$, firm's profits tax rate $\{\tau_{\pi t}\}_{t=1}^{\infty}$, firm's contribution rates for formal employment $\{\tilde{\tau}_{ft}\}_{t=1}^{\infty}$, bonuses paid to formal employees $\{\phi_t\}_{t=1}^{\infty}$, proportions that define how the social security fund is distributed $\{\theta_t\}_{t=1}^{\infty}$ and initial conditions K_1, Φ_{f1}, Φ_{i1}, Φ_{u1}, Φ_{r1} and Φ_1, a* *competitive equilibrium is a sequence of functions for working households* $\{V_{st}, c_{st}, a'_{st}, \ell_{st}\}_{t=1}^{\infty}$ *for* $s \in S - u$ *and for unemployed and retired households* $\{V_{st}, c_{st}, a'_{st}\}_{t=1}^{\infty}$ *for* $s \in \mathcal{S} - \{f, i\}$*, production plans for the firm* $\{K_t, L_{ft}, L_{it}\}_{t=1}^{\infty}$*, progressive tax schemes for labor income* $\{T_t : \mathbf{R}_+ \to \mathbf{R}_+\}_{t=1}^{\infty}$*, pension and unemployment insurance benefits* $\{\lambda_{rt}, \lambda_{ut}\}_{t=1}^{\infty}$*, prices* $\{w_t, r_t\}_{t=1}^{\infty}$*, transfers derived from accidental bequests* $\{Tr_t\}_{t=1}^{\infty}$ *and measures* $\{\Phi_{ft}\}_{t=1}^{\infty}, \{\Phi_{it}\}_{t=1}^{\infty}, \{\Phi_{ut}\}_{t=1}^{\infty}, \{\Phi_{rt}\}_{t=1}^{\infty}, \{\Phi_t\}_{t=1}^{\infty}$ *with* $\Phi_{ft} \in \mathcal{M}_f$*,* $\Phi_{it} \in \mathcal{M}_i$*,* $\Phi_{ut} \in \mathcal{M}_u$*,* $\Phi_{rt} \in \mathcal{M}_r$ *and* $\Phi_t \in \mathcal{M}$ *such that:*

(i) *households maximize their life-time expected utility, so* $\{V_{st}, c_{st}, a'_{st}, \ell_{st}\}_{t=1}^{\infty}$ *for* $s \in S - u$ *and* $\{V_{st}, c_{st}, a'_{st}\}_{t=1}^{\infty}$ *for* $s \in \mathcal{S} - \{f, i\}$ *solve problems (1), (2) and (3).*

(ii) *Production plans* $\{K_t, L_{ft}, L_{it}\}_{t=1}^{\infty}$ *maximize the profits of the firm, and prices* $\{w_t, r_t\}_{t=1}^{\infty}$ *satisfy*

$$
\begin{aligned}
r &= (1-\tau_\pi)\alpha\frac{q}{k} - \delta, \\
w_f &= \frac{(1-\alpha)\alpha_f}{1+\tilde{\tau}_f+\phi}\left(\frac{h_f}{h}\right)^{\gamma}\frac{q}{h_f}, \\
w_i &= (1-\alpha)(1-\alpha_f)\left(\frac{h_i}{h}\right)^{\gamma}\frac{q}{h_i},
\end{aligned}
$$

(iii) *The social security system budget constraints are satisfied so, given* $\{\theta_t\}_{t=1}^{\infty}$

$$
\lambda_{rt}\int \Phi_{rt}(da, \lambda_r, dj) = \theta_t \int \tilde{\tau}_{jt}\mu\varepsilon_j\eta w_{ft}\ell_{ft}\Phi_{ft}(da, d\eta, d\mu, dj), \tag{8}
$$

$$
\lambda_{ut}\int \Phi_{ut}(da, f, dj) = (1-\theta_t)\int \tilde{\tau}_{jt}\mu\varepsilon_j\eta w_{ft}\ell_{ft}\Phi_{ft}(da, d\eta, d\mu, dj). \tag{9}
$$

(iv) *The accidental bequest aggregated lump-sum transfer is given by*

$$
Tr_{t+1} = \int (1-\psi_j)\left(\mathbf{1}_f a'_{ft} + \mathbf{1}_i a'_{it} + \mathbf{1}_u a'_{ut} + \mathbf{1}_r a'_{rt}\right)\Phi(da, d\eta, d\mu, ds_{-1}, ds, db_r, dj), \tag{10}
$$

(v) *Markets clear:*

$$
C_t = \int \left(\mathbf{1}_f c_{ft} + \mathbf{1}_i c_{it} + \mathbf{1}_u c_{ut} + \mathbf{1}_r c_{rt}\right)\Phi(da, d\eta, d\mu, ds_{-1}, ds, db_r, dj), \tag{11}
$$

$$
K_t = \int \left(\mathbf{1}_f a + \mathbf{1}_i a + \mathbf{1}_u a + \mathbf{1}_r a\right)\Phi(da, d\eta, d\mu, ds_{-1}, ds, db_r, dj), \tag{12}
$$

$$
L_{ft} = \int \mu\varepsilon_j\eta\ell_{ft}\Phi_{ft}(da, d\eta, d\mu, dj), \tag{13}
$$

$$
L_{it} = \int \mu\varepsilon_j\eta\ell_{it}\Phi_{it}(da, d\eta, d\mu, dj), \tag{14}
$$

$$
K_{t+1} + C_t = AK^{\alpha}\left[\alpha_f L_f^{\gamma} + (1-\alpha_f)L_i^{\gamma}\right]^{\frac{1-\alpha}{\gamma}} + (1-\delta)K_t. \tag{15}
$$

(vi) *The government budget is balanced,*

$$
T_{yt} = \int T_t((1-\tilde{\tau}_{jt})\mu\varepsilon_j\eta w_{ft}\ell_{ft})\Phi_{ft}(da, d\eta, d\mu, dj), \tag{16}
$$

$$
G_t = \tau_{ct}C_t + \tau_{kt}K_t + T_{yt} + \tau_{\pi t}\tilde{\Pi}_t, \tag{17}
$$

where $\tilde{\Pi}_t = AK^{\alpha}\left[\alpha_f L_f^{\gamma} + (1-\alpha_f)L_i^{\gamma}\right]^{\frac{1-\alpha}{\gamma}} - (1+\tilde{\tau}_f+\phi)w_f L_f - w_i L_i - \delta K$ *are taxable* *profits.*

(vii) *Laws of Motion: let* $\tilde{\mathcal{X}}_w = \mathcal{A} \times \mathcal{E} \times \mathcal{U} \times \mathcal{J}$, $\tilde{\mathcal{X}}_u = \mathcal{A} \times S \times \mathcal{J}$, $\tilde{\mathcal{X}}_r = \mathcal{A} \times \mathcal{B} \times \mathcal{J}$, $f_\eta(\eta)$ *the unconditional probability distribution function of* η, $f_\eta(\eta'|\eta)$ *the probability of* η' *conditional on* η *and* p_s *the unconditional probability of being born into an occupational state* $s \in S$. *Then*

$$\Phi_{ft+1} = H_{ft}(\Phi_{ft}), \quad \Phi_{it+1} = H_{it}(\Phi_{it}), \quad \Phi_{ut+1} = H_{ut}(\Phi_{ut}), \\ \Phi_{rt+1} = H_{rt}(\Phi_{rt}), \quad \Phi_{t+1} = H_t(\Phi_t), \tag{18}$$

where

a. $H_{ft} : \mathcal{M}_f \to \mathcal{M}_f$ *is given by*

For all $j \in \mathcal{J} - 1$,

$$\Phi_{ft+1}(\tilde{\mathcal{X}}_w) = \int P_{ft}((a, \eta, \mu, j); \tilde{\mathcal{X}}_w)\Phi_{ft}(da, d\eta, d\mu, dj),$$

where

$$P_{ft}((a, \eta, \mu, j); \tilde{\mathcal{X}}_w) = \begin{cases} (1 - p_j^r)\psi_j p(f, s) f_\eta(\eta'|\eta) & \textit{if } a'_{ft} \in A, \mu \in \mathcal{U}, j+1 \in \mathcal{J}, \\ 0 & \textit{otherwise.} \end{cases}$$

For $1 \in \mathcal{J}$:

$$\Phi_{ft+1}(\tilde{\mathcal{X}}_w) = (1+n)^t \begin{cases} p_f(1 - p_j^r) f_\eta(\eta) \sum_{\mu \in \mathcal{U}} p_\mu & \textit{if } Tr_t \in A, \\ 0 & \textit{otherwise.} \end{cases}$$

b. $H_{it} : \mathcal{M}_i \to \mathcal{M}_i$ *is given by*

For all $j \in \mathcal{J} - 1$,

$$\Phi_{it+1}(\mathcal{X}_w) = \int P_{it}((a, \eta, \mu, j); \tilde{\mathcal{X}}_w)\Phi_{it}(da, d\eta, d\mu, dj),$$

where

$$P_{ft}((a, \eta, \mu, j); \tilde{\mathcal{X}}_w) = \begin{cases} (1 - p_j^r)\psi_j p(i, s) f_\eta(\eta'|\eta) & \textit{if } a'_{it} \in A, \mu \in \mathcal{U}, j+1 \in \mathcal{J}, \\ 0 & \textit{otherwise.} \end{cases}$$

For $1 \in \mathcal{J}$:

$$\Phi_{it+1}(\tilde{\mathcal{X}}_w) = (1+n)^t \begin{cases} p_i(1 - p_j^r) f_\eta(\eta) \sum_{\mu \in \mathcal{U}} p_\mu & \textit{if } Tr_t \in A, \\ 0 & \textit{otherwise.} \end{cases}$$

c. $H_{ut} : \mathcal{M}_u \to \mathcal{M}_u$ *is given by*

For all $j \in \mathcal{J} - 1$,

$$\Phi_{ut+1}(\tilde{\mathcal{X}}_u) = \int P_{ut}((a, s_{-1}, j); \tilde{\mathcal{X}}_u)\Phi_{ut}(da, ds_{-1}, dj),$$

where

$$P_{ut}((a,s_{-1},j);\tilde{\mathcal{X}}_u) = \begin{cases} (1-p_j^r)\psi_j p(u,s) & \text{if } a'_{ut} \in A, \mu \in \mathcal{U}, j+1 \in \mathcal{J}, \\ 0 & \text{otherwise.} \end{cases}$$

For $1 \in \mathcal{J}$:

$$\Phi_{ut+1}(\tilde{\mathcal{X}}_u) = (1+n)^t \begin{cases} p_u(1-p_j^r)\sum_{\mu\in\mathcal{U}} p_\mu & \text{if } Tr_t \in A, \\ 0 & \text{otherwise.} \end{cases}$$

d. $H_{rt} : \mathcal{M}_r \to \mathcal{M}_r$ *is given by*
For all $j \in \mathcal{J} - 1$,

$$\Phi_{rt+1}(\tilde{\mathcal{X}}_r) = \int P_{rt}((a,b_r,j);\tilde{\mathcal{X}}_r)\Phi_{rt}(da,db_r,dj),$$

where

$$P_{rt}((a,b_r,j);\tilde{\mathcal{X}}_r) = \begin{cases} p_j^r p(br,s_j,j)\psi_j & \text{if } s \in S, a'_{rt} \in A, j+1 \in \mathcal{J}, \\ \psi_j & \text{if already retired,} \\ 0 & \text{otherwise.} \end{cases}$$

e. $H_t : \mathcal{M} \to \mathcal{M}$ *reflects the laws of motion previously described.*

Definition 2.2 (Stationary Equilibrium) *A stationary equilibrium is a competitive equilibrium in which per capita variables, policy functions, prices and policies, are constant; distributions are invariant, and aggregate variables grow at the constant growth rate of the population.*

3 | MATCHING THE MODEL TO THE DATA

To discipline the model we estimate most of the parameters that are required, and we leave for calibration those that cannot be fully identified with our data. To accomplish this task we use official population forecasts, household surveys and time series of macroeconomic aggregates. We provide detailed information about each source in the following sections.

3.1 | Calibration

We assume a utility function that is additively separable between consumption and leisure, and over time. Formally,

$$U(c,\ell) = \frac{c^{1-\sigma_1}-1}{1-\sigma_1} + \chi\frac{(1-\ell)^{1-\sigma_2}}{1-\sigma_2},$$

where σ_1 and σ_2 correspond to the coefficients of risk aversion associated with each good. We calibrate σ_1 and σ_2 following previous literature and χ to reproduce the average hours worked that we observe in the data. To compute this target we use annualized hours worked by wage-earners obtained from Ecuador's labor surveys for the period 2001-2017.[4]

[4] In particular, throughout this paper we use the Tax Dataset for Ecuador covering the period 2001-2017 constructed by Gachet et al. (2018). This dataset combines tax and social security legislation with official labor

We calibrate the discount factor β to replicate the capital-output ratio in steady state. We obtain Ecuador's series of capital stock and output from the Federal Reserve of St. Louis dataset (FRED Economic Data) for the period 1965-2014.

The calibration of the idiosyncratic shock and the ability fixed effect allows the model to replicate income inequality along the life-cycle. In this line, we assume equal probability of belonging to the low or high ability groups and the standard deviation of the fixed effect σ_μ is set to replicate the variance of the logarithm of labor income at age 22.

The standard deviation of the error term in the $AR(1)$ process of the productivity idiosyncratic shock σ_η is calibrated to generate the variance of the logarithm of labor income at age 60. The autocorrelation coefficient of the $AR(1)$ process is set to replicate the linear increase in the variance of the logarithm of labor income from age 22 to 60 that we observe in the data. This calibration is summarized in Table 1.

TABLE 1 Households' preferences calibrated parameters

Parameter	Target	Value
σ_1	Literature	2.0000
σ_2	Literature	3.0000
χ	Average hours worked	0.4398
β	Steady-state capital-output ratio	1.0310
σ_μ	Variance of log income at age 22	0.4295
σ_η	Variance of log income at age 60	0.0524
ρ_η	Linear increase in variance of log income	0.9900

We calibrate the depreciation rate δ so that the model matches the investment-capital ratio in steady-state. Non-wage cost ϕ corresponds to 55.55% of firm's total wage bill and includes benefits in the form of two additional wages that are paid before the start of the school-year and in December, 15% workers' share of firm's profits, in-kind payments (e.g. uniforms, transportation), reserve funds (annual payment made to the Social Security System by employers for all workers after the first year of employment), severance payment and family subsidy. Social security contributions are excluded from labor costs because they are introduced separately in our model.[5] Table 2 presents the values for these parameters.

TABLE 2 Firm's calibrated parameters

Parameter	Target	Value
δ	Steady-state investment-capital ratio	0.0774
ϕ	Prop. of workers' benefits respect to wage bill	0.5555

The revenue side of the fiscal budget in our economy is complex because the government runs a progressive tax scheme on labor income and flat tax rates on capital income, consumption and firms' profits. Moreover, the social security system collects contributions from workers and firms. The parameters of the progressive tax scheme are both estimated

surveys published by The National Institute of Statistics and Census (INEC).

[5]Non- wage costs were computed using industry surveys from 2000-2015 published by INEC. These surveys are a representative sample of firms with more than 10 employees in three sectors of the economy: Manufacture, Commerce and Services. We estimate each labor cost as the share of firms' total wages and then compute the average for the economy for 2014, which is the year prior to the decline in oil prices.

(see section below) and determined in equilibrium. Except for the consumption tax rate that is used to balance the government budget constraint, flat tax rates are set according to current legislation. The capital income tax rate corresponds to a simple average of the applicable marginal tax rates. We present these tax rates in Table 3.

TABLE 3 Government and Social Security calibrated parameters

Parameter	Target	Value
τ_k	Capital income tax rate	0.2500
$\tilde{\tau}_j$	Payroll tax rate	0.0945
τ_π	Firm's profit tax rate	0.2500
$\tilde{\tau}_f$	Firm's contribution to social security fund	0.1115

3.2 | Estimation

In this section we describe the strategy used to estimate the parameters that we can identify with our data. This is a particularly challenging task, since it is the first time that this type of model is built for Ecuador. To our surprise, however, household surveys and publicly available data provide enough information to estimate the rest of parameters required to discipline the model.

3.2.1 | Population dynamics

By population dynamics we refer to the growth rate of population and the conditional survival probability. In this regard, INEC publishes official population forecasts for Ecuador in a very detailed fashion, including population growth by age and gender.[6]

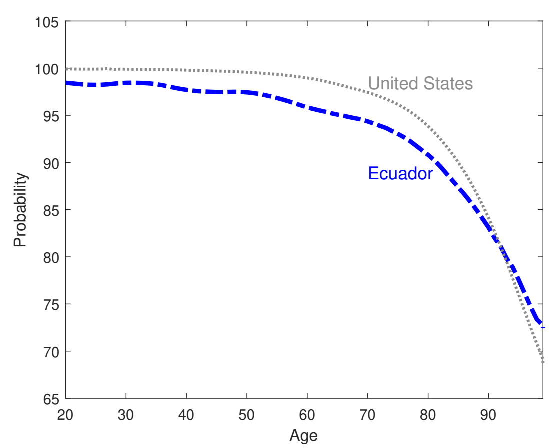


FIGURE 1 Conditional survival probability from age 1 to 99 (ψ_j)

We set the population growth rate to $n = 1.55\%$, that corresponds to the average population growth rate between 1990 and 2020. Regarding conditional survival probabilities, we use the population distribution by age for 2017 and compute $\psi_j = \text{pop}_{j+1}/\text{pop}_j$ for $j = 2, \ldots, 99$, where pop_j is the population of age j. We present these probabilities in Figure

[6]This information is available at `http://www.ecuadorencifras.gob.ec/proyecciones-poblacionales/`.

1 and compare them to the ones obtained for the United States (Conesa et al., 2009; Uribe-Terán, 2019). As this figure shows, survival probabilities in Ecuador are significantly lower than in the US, implying that the longevity savings motive is weaker in Ecuador.

3.2.2 | Age-specific productivity

To estimate age-specific productivity we follow Hansen (1993). For this we use a repeated cross section labor dataset from 2001 to 2017 concentrating on wage earners (Gachet et al., 2018). We compute real wages using the CPI and then calculate effective hours worked for each household conditional on whether the worker is formal or informal as

$$\tilde{h}_{its} = \frac{w_{its}}{w_{ts}} h_{it}, \tag{19}$$

where w_{its} is hourly wage reported by worker i in year t within sector s, w_{ts} is the average hourly wage in sector s at time t and h_{it} are normalized yearly hours worked for each worker in a given year.

Then we perform a pooled non-parametric regression to capture how much of the variation in $\tilde{h}_{its}$ can be explained by the age of individuals. Specifically, within each sector, we estimate

$$\hat{h}_{is} = m_s(j_i) + \epsilon_{is}, \tag{20}$$

where j_i is the age of each individual within each sector in our sample. We interpret $\hat{m}_s(j_i)$ as the part of effective labor that can be explained by age, and $\hat{\epsilon}_{is}$ as the part that is explained by other factors such as idiosyncratic productivity shocks, ability, etc. To estimate $\hat{m}(\cdot)$ we follow

$$\hat{m}_s(j_i) = \frac{1}{N_s} \sum_{i=1}^{N} {}_s \frac{K_h(j - j_i)}{\sum_{i=1}^{N_s} K_h(j - j_i)} h_{is}, \tag{21}$$

where K_h is the Epanechnikov kernel for a given bandwidth h (Epanechnikov, 1969) and N_s is the total number of observations within sector s in our pooled sample. Then, given our age grid $j_g = \{20, 21, \ldots, 64, 65\}$ we compute age-specific productivity as

$$\varepsilon_{js} = \hat{m}_s(j), \tag{22}$$

where $j \in j_g$. Since the grid over which $\hat{m}_s(\cdot)$ is defined is not j_g necessarily, we use piece wise cubic interpolation to obtain ε_{js} (Fritsch and Carlson, 1980).

We perform an additional adjustment. The reason for this is that our initial estimates show a significant gap in magnitudes between age-specific productivity for formal and informal workers along the life cycle. However, not all this gap can be explained by productivity differentials only. The reason for this is that formal workers are more likely to receive the minimum wage, while informal workers are not. Since we are not modeling a minimum wage policy explicitly, we adjust this gap in order to match the formality wage premium that we observe in the data and set $\zeta = 1.3965$ implying that, on average, adjusted informal productivity $\tilde{\varepsilon}_{js}$ is about 40% higher than estimated productivity.[7] The estimated

[7] The way we perform this adjustment is as follows. Given ε_{js}, we first normalize productivity levels so $\varepsilon_{1s} = 1$. Then we restrict the adjustment so everyone at age 1 starts with an age-specific productivity of 1. Since the adjustment is made only for informal workers, we compute $\tilde{\varepsilon}_{ji} = (\varepsilon_{ji} - 1)\zeta + 1$.

(adjusted) age-profile of labor productivity is presented in Figure 2 and, again, we compare our estimation to the US results.

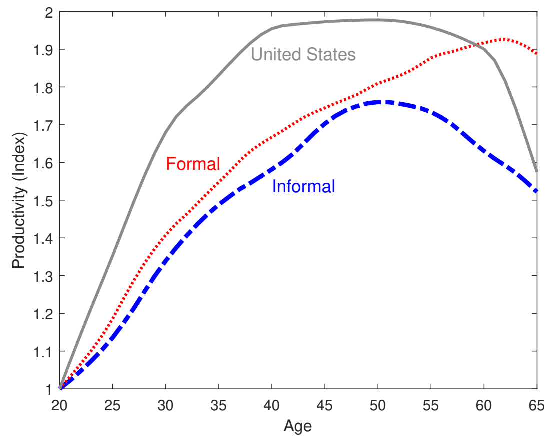


FIGURE 2 Age-specific productivity from age 20 to 65 (ε_j)

Our results show that, on average, the peak of productivity for Ecuadorian formal workers occurs very late in the life cycle, past age 60. On the contrary the peak of productivity for informal workers occur at 50 years old.

Notice that productivity dynamics along the cycle are significantly different from what is observed in the US. For the latter the peak in productivity occurs at age 50, but it stays almost at the same level from age 40 up to age 60. Moreover, while the peak in productivity for Ecuador is about 1.7 times the productivity at age 20, in the US productivity almost doubles. These stylized facts are consistent with broader findings about the behavior of wages along the life cycle. In particular, Lagakos et al. (2018) recently documented the life-cycle dynamics for developed and emerging economies and found that, on average, experience-wage profiles in developed economies are twice as steep as for developing countries. These differences can have significant impact on the numerical solution of the model and over the results of the optimal taxation exercises. In particular, we expect to have steeper life cycle profiles for hours worked and lower optimal tax rates on average compared to what could be obtained in a model calibrated for the US.

3.2.3 | Occupation transitions

One of the main challenges we face is that our model needs to generate a realistic life cycle profile of occupational risk. For this, we opt for estimating occupation transitions directly, which is equivalent to assume that occupation status is exogenous and responds to the embedded structure of the labor market.

We use labor surveys to compute these transitions. For this, we exploit a special feature of these surveys: By design, samples are mobile panels that maintain the same dwellings for two consecutive years every two years. This implies that, for example, surveys for 2015 and 2016 can be considered as a panel at the dwelling level, but although the previous pair 2013-2014 is a panel as well, it is not compatible with the one for 2015-2016.

Therefore, we concentrate in the available panels between 2011-2015 and match individuals that live in the same dwelling using age and gender focusing only on wage earners. We estimate the transition matrix **P** of a Markov chain with states $S = \{f, i, u\}$. To estimate **P** we rely on the frequency of observed transitions between states for all available panels using the surveys' sample weights. Let n_s be the number of individuals in year t whose current occupational status is s. Then, the joint probability of being in given status s and s' in two consecutive years is simply

$$P(s, s') = n_{s,s'} \left(\sum_{s} \sum_{s'} n_s n_{s'} \right)^{-1}, \tag{23}$$

while the marginal probability for each state s in year t is

$$P(s) = \left(\sum_{s} n_{s,s'} \right) \left(\sum_{s} \sum_{s'} n_s n_{s'} \right)^{-1}. \tag{24}$$

Combining (23) and (24) using Bayes theorem we obtain

$$p(s', s) = P(s'|s) = \frac{P(s, s')}{P(s)}. \tag{25}$$

To capture the drop (rise) in informality (formality) from age 20 to 25 that we observe in the data, we also estimate initial conditions for the Markov chain corresponding to the share of formal, informal and unemployed workers at age 20. However, these computations are not enough for the model to replicate the life-cycle dynamics that we observe in the data, since our environment features stochastic retirement and survival, and these two ingredients interact with the share of workers alive in each cohort. Thus we adjust the estimated transition probabilities from formal to formal, formal to informal, informal to formal and informal to informal using a calibrating procedure until the model exactly replicates the aggregate shares of formal, informal and unemployed workers that we observe in the data. Table 4 shows the results.

TABLE 4 Estimated transition probabilities for occupation status and initial conditions

Current State	**Initial Condition**	**Future State**		
		Informal	**Formal**	**Unemployed**
Informal	53.79	0.7685	0.1857	0.0458
Formal	33.22	0.0643	0.9102	0.0254
Unemployed	12.99	0.4909	0.2812	0.2279

Notes: Initial conditions are percentages, transitions are probabilities.

The conditional transition probabilities show that movement from formality and informality to other occupational states are rather persistent. In fact, conditional on being informal, the probability of continuing in informality the following period is 77%, and the probability of formality continuation is 91%. We also find that it is more likely for an informal worker to become unemployed (5% probability vs 3% for a formal worker) and that unemployed workers are almost twice more likely to find an informal job than a formal one (49% probability vs. 28%).

3.2.4 | Stochastic retirement

As described above, our model features stochastic access to the retirement fund. In this case we are interested in estimating the probability that a worker that retires at age j in occupational status s_j was able to complete the sufficient number of contributions to social security and, in this way, gain access to the transfer during retirement. Table 5 shows the requisites that have to be fulfilled for a worker to gain access to the pension fund according to the current Ecuadorian legislation.

TABLE 5 Age and contributions requisites for workers in Ecuador to gain access to the pension fund

Age	No. of Contributions	Years of contributions
No age limit	480 or more	40 or more
60 – 64	360 or more	30 or more
65 – 69	180 or more	15 or more
70 or older	120 or more	10 or more

We concentrate in the third column (years of contributions), since the modeled period is a year. Let j_c denote the minimum number of years that the worker is required to contribute to social security (i.e. j_c years as a formal worker). Then, we compute the probability of complying with the required number of contributions conditional on current occupational status just before retirement, age and labor history. Formally we define

$$p(\lambda_r, s_j, j) \equiv P(b_r = \lambda_r | s_j, j) = \frac{P\left(\sum_{t=1}^{j} \mathbf{1}(s_t = f) \geqslant j_c, s_j\right)}{P(s_j)}, \tag{26}$$

where $b_r = \{0, \lambda_r\}$ is the social security transfer to retirees, $\mathbf{1}(s_t = f)$ is an indicator function that takes the value of one when a given state is formal, so $P\left(\sum_{t=1}^{j} \mathbf{1}(s_t = f) \geqslant j_c, s_j\right)$ is the joint probability of having accumulated at least j_c periods of formality up to age j and finishing working life in occupational status s_j, and $P(s_j)$ is the probability of being in occupational status s_j at age j. Thus, $p(\lambda_r, s_j, j)$ is the result of a simple application of Bayes Theorem. Notice that, since occupational status follows an exogenous process, then $p(\lambda_r, s_j, j)$ is also exogenous. Additionally, we have that $P(b_r = 0|s_j, j) = 1 - p(\lambda_r, s_j, j)$.

We compute these probabilities using the transition matrix between occupational status that we computed in the previous section. In particular, we simulate occupational transitions, survival and retirement for 3500 households at birth during 46 years and apply equation (26) to the simulated data. In figure 3 we present these probabilities, which become relevant from age 58 onward, for formal, informal and unemployed workers. Our calculations show that a formal worker retiring at age 60 faces a 48% probability of having access to the pension fund compared to 39% for unemployed workers and only 23% for informal workers.

For formal and informal workers these probabilities increase linearly until age 65 (64% and 47% respectively), while for unemployed it remains constant. The reason for these dynamics –something that is also behind the reason for why an unemployed worker is more likely to have the pension fund compared to an informal worker– is that formality and informality are very persistent, while unemployment is quite unstable. Under these conditions, only 45% of the retired population at 65 has access to the pension fund, which implies an average replacement rate of 28%.

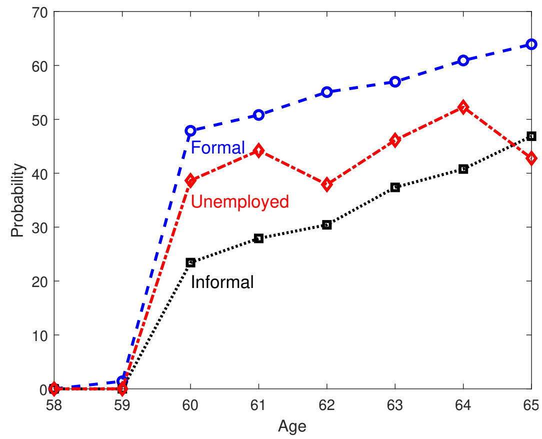


FIGURE 3 Probability of gaining access to the pension fund conditional on age, occupational status at age of retirement and labor history

3.2.5 | Other parameters

Our modeled economy features stochastic retirement. To estimate the probability of retirement we use the same idea that we used to compute the age-specific transition matrices between occupational status and compute the transition between economic activity and retirement. For this we use a question in official labor surveys that reads as follows: *Have you received retirement transfer or pensions?* As opposed to transitions between occupational status, we assume that transitions to retirement are permanent.

Since the survey question we are using includes pensions other than retirement (such as transfers to dependents of deceased contributors), there are probabilities different from zero for young households. Since we are concerned only with retirement transfers, we set the retirement probability to zero from age 20 to 54, and then to one from 65 onward. This implies that, effectively, we are using the estimated probabilities for ages 55-64 (see Figure 4). Again, we use only wage-earners and probabilities are computed after simulating the model with 3500 households at birth. For completeness, Figure 4 shows the estimated and simulated retirement probabilities. The difference between the two is that the latter is affected by the probability of survival.

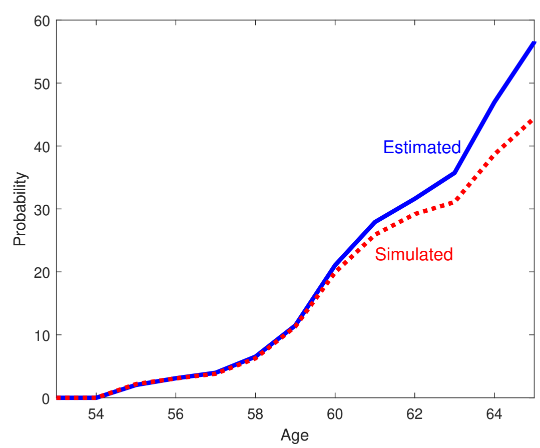


FIGURE 4 Age-specific retirement probability, from age 53 to 65 (p_j^r)

The representative firm in the economy follows a Cobb-Douglas specification with respect to capital and labor, with a CES aggregator for formal and informal labor. However, the benchmark economy is calibrated so the CES part of the function behaves as a Cobb-Douglas.[8] Thus, we identify the parameters related to this function using administrative firm level data from Ecuador's Internal Revenue Service. In particular we use a non-balanced panel with around 8,500 observations per year for the period 2014-2017 (25,342 in total) to estimate the following equation

$$\log Q_{it} = \beta_0 + \alpha_0 \log K_{it} + \alpha_1 \log L_{it} + \log Q_{it-1} + \beta' \mathbf{X}_i + \delta' \mathbf{dt}_t + \eta' \mathbf{di}_i + \mu_{it}, \tag{27}$$

where Q is production measured as total value added, K is the amount of registered assets, L the number of workers and $\mathbf{X}_i$ a matrix of controls at the firm level, $\mathbf{dt}_t$ are time fixed effects and $\mathbf{di}_i$ are firm-level fixed effects. We estimate (27) by a two-step Arellano Bond estimator and set $\alpha = \hat{\alpha}_0$.

Since we are assuming constant returns to scale, each parameter in our production function can be interpreted as the proportion of output that is paid to each input. Thus, the proportion of output paid to formal workers is $\alpha_f(1-\alpha)$, where α_f is the share of labor income paid to formal workers. We estimate α_f from labor surveys. The resulting parameters are presented in Table 6.

TABLE 6 Production function parameters

Parameter	Description	Value
α	Prop. of output paid to capital	0.4230
α_f	Prop. of income paid to formal	0.7126
γ	Related to elasticity of substitution	1e-10

The social security system in our economy manages two transfers targeted to provide partial unemployment and retirement insurance. We assume that both transfers are fully funded by firms' and formal workers' contributions. To setup the proportion of this fund that is directed to the retirement transfer θ we use information from the Ecuadorian Institute of Social Security (IESS). This information is contained in statistical bulletins were we have data on monthly evolution of beneficiaries and average payments of the different benefits that are managed by IESS.

Based on this data we assume that the only benefits provided by IESS are severance payments (retirement transfers) and unemployment insurance. Then, to compute θ we simply add the total amount used in these transfers and then divide the sum of severance payments by the total of both benefits. We do this using data for 2016 aggregated for the full year and find that $\theta = 0.9223$; that is, 92% of the fund is used to cover severance payments.

We also assume that government expenditure is determined as a fixed proportion of total output g. To estimate this parameter, we use annual time series of national accounts for Ecuador from 1965 to 2014. We compute g as the long-term average of the proportion of total Government consumption with respect to GDP and find $g = 0.1358$. Keep in mind that we are only considering current consumption of the General Government in order to compute this ratio.

Finally, the progressive tax scheme applied to labor income requires us to calculate the ratios of the extreme values of the tax scheme y_l and y_h with respect to average income

[8] We are aware that this particular choice for the calibration of the production function might impact our results substantially. For this reason, in section 6 we assume an alternative calibration in which formal and informal labor are perfect substitutes.

in the economy.[9] Let $\omega_1 \equiv y_l/\overline{y}$ and $\omega_2 \equiv y_h/\overline{y}$ where $\overline{y}$ is the average of pre-tax labor income. For 2017 the progressive tax scheme in Ecuador set (in current USD) $y_l = 11,290$ and $y_h = 115,140$ which, given the average labor income that we observe in the household surveys for that year imply $\omega_1 = 1.2202$ and $\omega_2 = 12.4437$. A summary of these parameters is presented in Table 7.[10]

TABLE 7 Summary of other estimated parameters

Parameter	Description	Value
θ	Prop. of SS fund used for severance transfers	0.9223
g	% of GDP dedicated to Government consumption	0.1358
ω_1	Lower bound of tax scheme with respect to average income	1.2202
ω_2	Upper bound of tax scheme with respect to average income	12.4437

3.3 | Numerical solution

We solve the model over a discretized state space using an equidistant grid for assets with 41 grid points. The idiosyncratic productivity shock is discretized using a 21-state Markov Chain where grid points and the transition matrix are computed following Tauchen and Hussey (1991). The households' optimization problem is solved using the Endogenous Grid Method to gain efficiency. We solve the equilibrium by a simple bisection method.

The solution to the Simulated Method of Moments minimization problem is obtained by applying the Generalized Pattern Search (GPS) algorithm (Audet and Dennis Jr, 2002). All functions involved in the model are evaluated using piece-wise cubic hermite interpolating polynomials (PCHIP) (Fritsch and Carlson, 1980). We use Montecarlo simulations to simulate the model. Instead of simulating the Markov chain for the idiosyncratic productivity shock, we opt for simulating the $AR(1)$ process directly and then use PCHIP interpolation to gain accuracy.

3.4 | The benchmark economy

Before turning to the policy experiments, we end this section by assessing the fit of our model to the data and describing the benchmark economy. Table 8 compares the model and the data for the targets we chose for calibration and the percentage of informality and shows that we have been successful in the calibration procedure.

The model also performs well in matching the distributions that we can compare to the data. Figure 5 shows the results of three key exercises given the optimal policy exercises that we have in mind. Panel 5a shows the model-generated cross-section distribution of labor income compared to its empirical distribution. The model performs well in generating enough variation in labor income, although it is not able to replicate the behavior observed in the tails of the empirical distribution, which is a usual shortcoming of this type of models. Moreover, the bimodality of the modeled distribution occurs because of the two possible values of the fixed ability shock.

Panel 5b, on the other hand, shows the age-profile of the variance of the logarithm of labor income. The model replicates quite closely these dynamics, something that is of

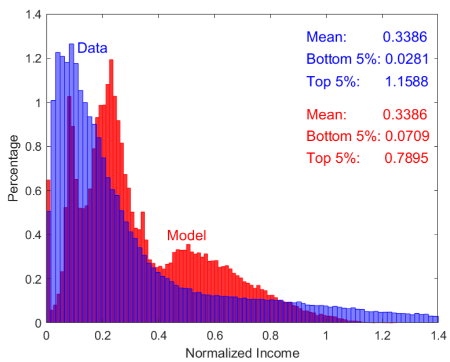
[9]We do this for simplicity. However, Kindermann and Krueger (2014) relate y_l to the median of the income distribution and y_h to the mean.

[10]The estimated values of all age-specific parameters are available from the authors upon request.

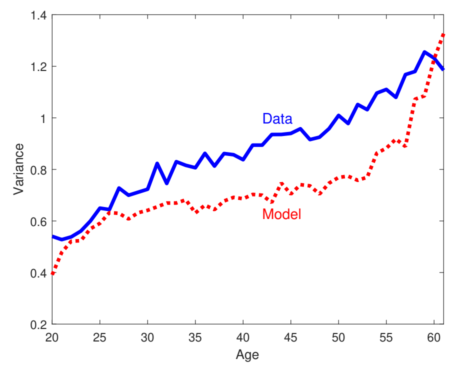
TABLE 8 Calibration targets

Target	Model	Data
Capital-output ratio	3.245	3.245
Hours worked	0.340	0.340
Variance of log income at 22	0.522	0.521
Variance of log income at 60	1.228	1.228
Informality	29.6%	29.6%
Formality wage premium	2.479	2.479

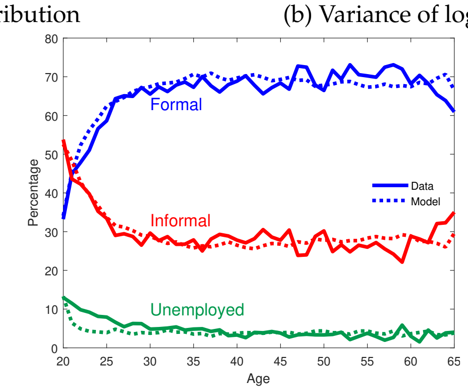
particular importance considering that our goal is to compute an age-dependent optimal tax scheme.



(a) Cross-section distribution



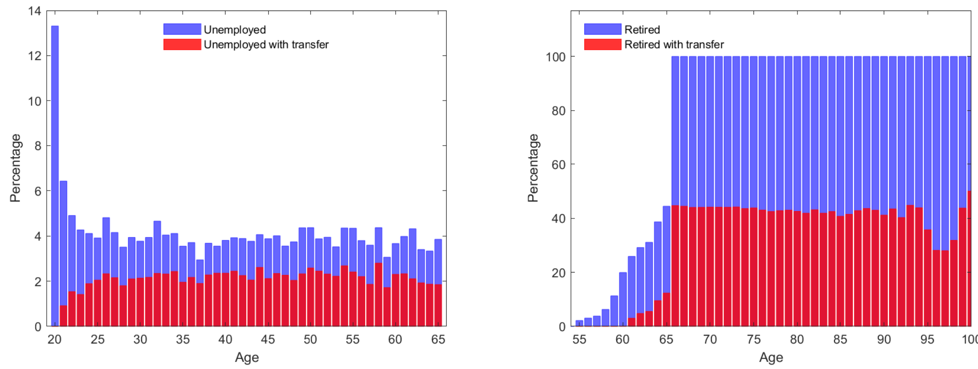
(b) Variance of log income by age



(c) Occupation status by age

FIGURE 5 Labor income distribution and percentage of workers in each occupation status through the life cycle

Panel 5c shows the percentage of formal, informal and unemployed workers along the life cycle generated by the estimated Markov chain that is fed to the model. Our estimations allow the model to replicate a fitted version of what we observe in the data. In particular, the model correctly generates the significant increase in the proportion of formal workers that occurs between ages 20 and early 30s. The model also produces the significant drop in informality during the early years in the labor force and the observed unemployment dynamics at the end of the life cycle; yet, it generates a rapid drop at the beginning of the life cycle –something that does not occur in the data– implying that unemployment persistence may vary with age.



(a) Unemployed (b) Retired

FIGURE 6 Social security transfers coverage by age

An important aspect of our model is that not all workers are insured against unemployment and retirement, and this shapes savings behavior specially during formality spells. On average, 54% of unemployed workers and 34% of retirees are covered by social security. Figure 6 shows social security coverage over the life cycle for unemployed workers (6a) and retirees (6b). Coverage for unemployed workers follows the same dynamics as the share of formality, since the only requisite that we are imposing for a worker to have access to this fund is to have had a formal contract before being hit by the unemployment shock. On the other hand, coverage for retirees is much more restricted and stable from 65 years old onward, when it covers about 40% of retired population.

4 | OPTIMAL TAX SCHEME

We use this economy to perform an optimal policy analysis assuming that a general decision is to stay within the family of pay-as-you-go social security systems. We allow the planner to choose payroll tax rates conditional on the age of individuals and the minimum and maximum marginal tax rates for the labor income tax scheme. Formally, the decision set is $\mathbf{t}^* = \{\{\tilde{\tau}_j\}_{j=1}^{j_r}, \tau_l, \tau_h\}$. We approximate the set of age-dependent tax rates using 7 equidistant points spread over the range $\mathcal{J}_r = [1, \ldots, 46]$ and then use shape-preserving cubic splines interpolation to obtain optimal rates on points outside the grid.

The planner chooses $\mathbf{t}^*$ to maximize the weighted average of discounted utility for each age group in the steady state determined by the policy. The social welfare function is similar to the one used by Heathcote et al. (2019) and has the property that the planner values improvements in redistribution, particularly along the life cycle. Formally, the planner solves

$$W(\mathbf{t}^*) = \int (\mathbf{1}_f V_{ft} + \mathbf{1}_i V_{it} + \mathbf{1}_u V_{ut} + \mathbf{1}_r V_{rt})\, \Phi_{\mathbf{t}^*}(da, d\eta, d\mu, ds, j),$$

where $\Phi_{\mathbf{t}^*}$ is the invariant distribution in a steady state defined by $\mathbf{t}^*$. Given the timing of the model, we assume that workers are born into formality, informality or unemployment, and that they inherit the lump-sum transfer left by the dead. We also assume that unemployed workers are born without access to unemployment insurance.

5 | RESULTS

Before we describe the optimal tax scheme in detail, it is important to keep in mind the response mechanisms and trade-offs that the planner faces in determining the optimal tax and social security contributions schemes. The main reason for this is that, contrary to what is done in previous literature on age-dependent taxation, we consider the two taxing schemes defined over labor income separately, keeping in mind that they interact with each other.

Previous contributions such as Erosa and Gervais (2002), Weinzierl (2011) and Heathcote et al. (2019) consider labor income taxation under a unified scheme. One might think that our problem and theirs are equivalent, but we argue otherwise because personal labor income taxation and social security contribution schemes pursue very different policy goals that can trigger different trade-offs for the planner.

On the one hand, the optimal social security contribution scheme collects resources only from formal workers and funds an inter-generational transfer focused on the retired population. The usual practice in previous literature is to allow the planner to set positive (tax) or negative (subsidy) rates along the life cycle, without restricting negative rates only for the elderly. This feature of the optimization exercise is related to the longevity and retirement insurance motives specifically.

On the other hand, under most tax legislation in emerging and developed economies, the contribution to the social security fund is deducted from the tax base of the labor income tax, which tends to be progressive (this is the case in Ecuador and in the US). This particular feature triggers a trade-off for the planner: When setting the optimal tax scheme, increasing the size of the social security fund through higher marginal contributions can reduce inter-generational inequality and improve the well-being of the retired population at the expense of reducing the redistributive capabilities of the labor income tax scheme, thus increasing cross-section inequality among workers.

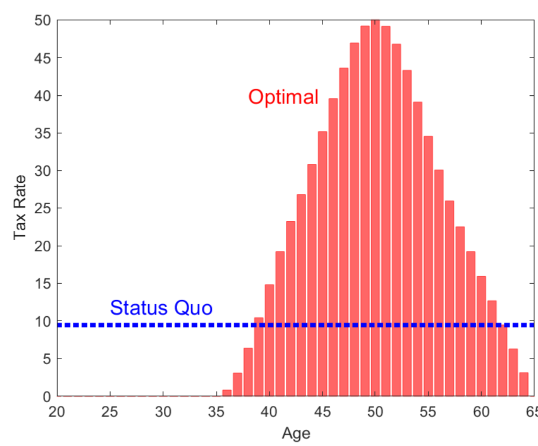


FIGURE 7 Optimal social security contribution rates

The optimal social security contributions scheme provides an exemption until the workers become 35 years old. After this age, the contribution rate is concave on age, reaching its maximum of 50% at age 50 (see Figure 7). This result confirms previous findings regarding the optimal age profile of the labor income tax scheme (Erosa and Gervais, 2002; Weinzierl, 2011; Heathcote et al., 2019), and shows that these results persist even when the planner considers payroll and personal income tax schemes separately.

Regarding the progressive tax scheme levied over post-payroll tax labor income, we find that the initial marginal tax rate is 5% and the maximum tax rate is 35% with an exempt income level that is 4.9% higher than the status quo, and a maximum income level (after which the scheme becomes flat) that is 3.3% higher. Thus, surprisingly, the optimal scheme basically replicates current legislation in Ecuador.

What the planner is obtaining through the application of this tax scheme is to provide young workers with some leeway at their entry to the labor market, so they can insure themselves against the idiosyncratic risk that is present in the economy. In particular notice that, because of the profile of age-specific productivity, young workers are relatively poorer than older workers, so most of them will benefit from the exempt income level provided by the progressive labor income tax scheme and will be exempt from the payroll contribution to the social security system.

5.1 | Aggregate results

In this section we study how the economy is affected by the reform. The changes in the labor income tax and social security contributions schemes produce a welfare gain of 2.9% measured in compensated equivalent units. This welfare gain comes in spite of a contraction of 0.97% in aggregate consumption. When we look at how consumption varies conditional on occupational status, we find that consumption for formal workers fall 3.12%, for informal workers 0.71%, for unemployed 1.16% and for retired workers without access to the retirement transfer 0.77%. However, retired workers covered by the social security system are able to increase consumption by 2%, which comes together with an expansion of the social security fund of 10.63%.

Since the optimal tax reform consists of a segment of ages in which formal workers face significantly higher payroll contributions than in the status quo, there are severe effects on both the level and composition of the labor supply. In particular, hours worked fall by 2.66%, which translates in a labor supply overall contraction of 3.47%. Since the labor supply contraction is higher than the reduction in hours worked, we have that the optimal tax reform produces a crowding out effect over the time dedicated to work by more productive workers.

There are two sources for this fall in productivity. First, that formal workers reduce hours worked by 5.78% while informal workers increase their time devoted to the firm's production by 6.71%. This shift from formal to informal hours produces a fall in productivity because, *ceteris paribus*, formal workers are more productive than informal workers.

But, second, formal labor supply falls by 6.52% while informal labor supply increases by 5.89%, which means that the fall in formal labor supply is deeper than the contraction in hours worked, and the increase in informal supply is weaker than the increase in hours worked. This translates into more productive formal workers reducing more hours (since they face a higher effective tax rate), and less productive informal workers choosing to work more.

Regarding other aggregates, besides the significant increase in the size of the social security fund, which alleviates the longevity and unemployment insurance motives, there is a severe contraction of 25.96% in the amount collected by the progressive labor tax scheme and a shallow increase of 3.62% in capital income tax revenue. These results imply that the planner is more worried about life-cycle triggered inequality than by cross-section labor income inequality. The reason for this is that it is willing to sacrifice labor income tax revenue, which reduces the redistributive capacity of the progressive tax scheme, to increase the ability of the social security system to alleviate, mainly, the longevity risk savings motive.

The result on savings comes from two opposing forces triggered by the tax reform. On

TABLE 9 Compensated Equivalent Variation (*CEV*) and Aggregate Variations

Variable	% Variation
CEV	+2.92
Consumption	–0.97
Formal	–3.12
Informal	–0.71
Unemployed	–1.16
Retired with transfer	+2.01
Retired w/o transfer	–0.77
Hours Worked	–2.66
Formal	–5.78
Informal	+6.71
Labor Supply	–3.47
Formal	–6.52
Informal	+5.89
Output	–1.11
Capital Stock	+1.69
Social Security Fund	+10.63
Labor tax revenue	–25.96
Capital tax revenue	+3.62

one hand, the increase in the social security transfer that workers receive at the end of their working lives pushes for a reduction in savings, since longevity risk is partially covered. On the other hand, workers know that if they work under formal contracts at mature ages, they will face very high contribution rates, and will choose to reduce their labor supply with the corresponding fall in labor income. The only way to achieve this without sacrificing consumption, is to increase savings during early years. Overall, the second effect is stronger and we observe an increase of 1.69% in the capital stock of the economy.

Regarding the effect on production, again is the result of two opposing outcomes: The sensible fall in labor supply and the weak increase in the capital stock. All in all, output falls in 1.11% with respect to its level in the status quo.

5.2 | Welfare Decomposition and Life Cycle Effects

To pin-down the sources of the welfare gain, we follow Conesa et al. (2009), and decompose the welfare gain into each of its sources and whether it comes from a variation in levels or an improvement in the distributions of consumption and leisure. Given our choice for the utility function, the compensated equivalent variation is given by

$$\text{CEV} = \left\{ \frac{(1-\sigma_1)\left[W(c_0,\ell_0) - \chi/(1-\sigma_2)(1-\ell_0)^{1-\sigma_2}\right]+1}{(1-\sigma_1)\left[W(c^*,\ell^*) - \chi/(1-\sigma_2)(1-\ell^*)^{1-\sigma_2}\right]+1} \right\}^{\frac{1}{1-\sigma_2}} - 1,$$

where $W(c, \ell)$ is total welfare given by a specific choice of consumption c and leisure $(1-\ell)$. In general terms, this expression measures the percentage variation in consumption needed to maintain welfare constant in its pre-reform level. From here, consumption CEV_c and leisure CEV_l compensated equivalent variations are defined as

$$\begin{aligned} W(c^*, \ell_0) &= W(c_0(1+CEV_c), \ell_0), \\ W(c^*, \ell^*) &= W(c^*(1+CEV_l), \ell_0), \end{aligned}$$

where $CEV \approx CEV_c + CEV_l$. To see the intuition behind this result, notice that CEV_c measures the variation in consumption needed to compensate consumers for the tax reform *keeping leisure constant*, while CEV_l does the same but starting from the level of welfare obtained by the optimal consumption level c^*, thus measuring only the welfare compensation explained by changes in leisure.

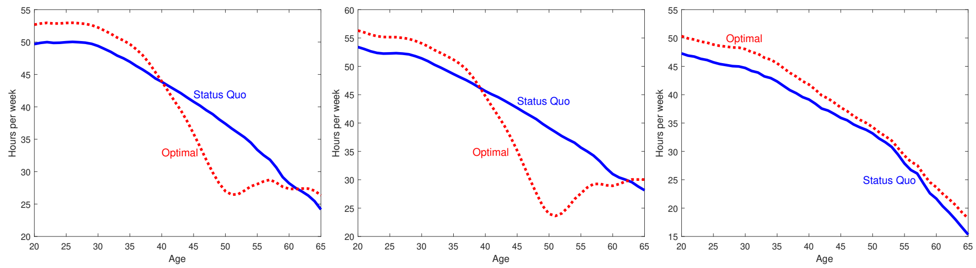
Moreover, within each specific equivalent variation it is possible to pin down the level and distributional effects of the tax reform. In particular, the level effect for the consumption-specific compensated equivalent variation is given by the growth rate of aggregate consumption $CEV_{c\gamma} = C^*/C_0 - 1$, so the distribution effect is the residual $CEV_{cd} = CEV_c - CEV_{c\gamma}$. A similar decomposition can be applied to leisure and we further expand these computations to condition equivalent variations on the workers' occupational status. The results of these calculations are presented in Table 10.

TABLE 10 Welfare decomposition

	% Variation			
	Aggregate	**Formal**	**Informal**	**Unemployed**
CEV	+2.92	+2.16	+4.28	–1.14
Consumption	–0.98	–3.18	–0.96	–1.14
Level	–0.97	–3.12	–0.71	–1.16
Distribution	–0.01	–0.06	–0.25	+0.01
Leisure	+3.90	+5.34	+5.24	–
Level	+1.37	+3.23	–2.84	–
Distribution	+2.53	+2.11	+8.08	–

The compensated equivalent variation explained by leisure implies a welfare improvement of 3.9%, of which 2.5% is due to a better distribution (particularly along the life cycle), and 1.4% because of an increase in its level. This welfare gain is triggered by a rearrangement of the consumption of leisure along the life cycle due to the contribution exemptions granted at the entry to the labor market, and the high contribution rates that are postponed to ages 39 to 63, range at which the optimal payroll tax rate is above the status quo. This design concentrates more working hours in ages 20 to 39, and produces a severe contraction from ages 39 to 63 (see panel 8a in figure 8). Of course, the aggregate behavior is a reflection of what occurs with formal workers. In this case, the welfare improvement explained by leisure is 5.3%: 3.23 explained by better distribution and 2.11% for higher level (panel 8b in figure 8).

Since occupational status are connected through occupational mobility, the optimal tax reform produces a generalized increase of informal hours worked along the life cycle, particularly at the entry to the labor market (panel 8c in figure 8). Since we do not observe



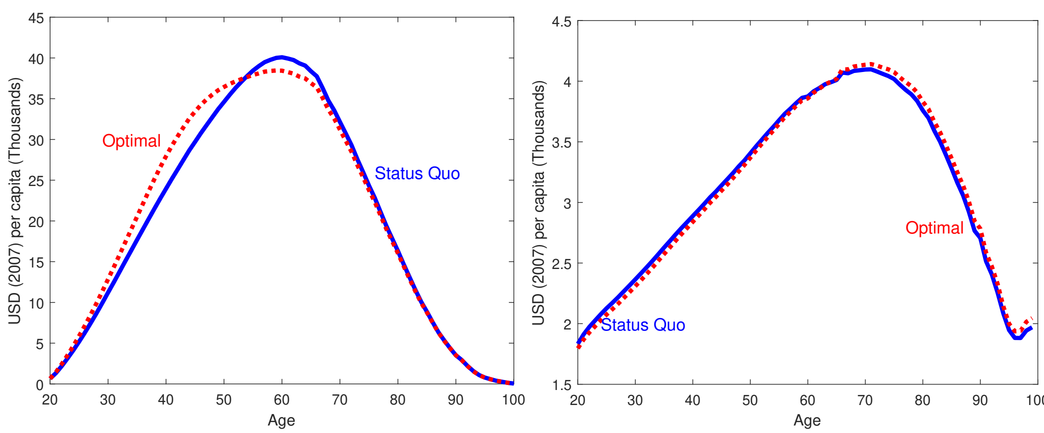
(a) Aggregate (b) Formal (c) Informal

FIGURE 8 Life cycle profiles of hours worked: Aggregate and by occupational status

any age range in which informal workers increase their consumption of leisure, the welfare gain of 5.2% explained by leisure of informal workers is mainly explained by a 8.1% gain due to a better distribution of leisure, countered by a welfare loss of 2.8% due to the fall in the level.

Consumption, on the other hand, triggers weak welfare variations, and most of the welfare loss in entirely explained by a fall in its level. In the aggregate, the welfare loss explained by consumption keeping the level of leisure constant is 1.0%. The weak variation in welfare is consistent with the optimal life cycle profile of consumption presented in panel 9b in figure 9. In particular, this figure shows a small increase in consumption during retirement years and an equally modest fall in consumption during working ages. Overall, since more weight is given to current consumption, the welfare gain of retirees is offset by the welfare loss of working-age population.

However, contrary to what happens with leisure, welfare variations are very heterogeneous among occupational groups. In this sense, the most severe welfare reduction is concentrated in formal workers, where the overall loss explained by consumption is 3.2%, again, based purely on the fall in the level of consumption (see table 10). The second most affected group are the unemployed (1.1% fall in welfare), with a similar outcome for informal workers.



(a) Assets (b) Consumption

FIGURE 9 Life cycle profiles of savings and consumption

The dynamics of consumption and leisure over the life cycle produce a direct effect on how workers accumulate assets (panel 9a in figure 9). Under the optimal tax scheme, workers under 50 accumulate more assets compared to the status quo. One of the reasons for this is, of course, that there is an overall decrease in consumption for working age population; nonetheless, as we discussed in the previous paragraph, this decrease is rather small.

The bulk of the increase in assets is actually related to the dynamics of leisure. Recall from our previous discussion that formal workers increase labor supply for the first 19 years in the labor market and then there is a severe contraction triggered by the high contribution rates to social security. Given the consumption smoothing motive, workers will accumulate more assets during periods of high labor supply, so they can use them to maintain consumption once they reduce labor. In fact, figure in panel 9a shows that, under the optimal tax scheme, the stock of assets for workers over 50 years old is lower for the rest of the life cycle. This occurs in spite of the increase in the size of the retirement fund and the fact that the probability of having access to the retirement transfer remains constant.

But who actually benefits from the optimal tax reform? To answer this question we compute discounted utility up to their corresponding age for each individual in our simulation and then identify those that register an increase after the tax reform. Then, we compute the percentage of individuals that register a welfare improvement within each age group. The results of this computation are shown in Figure 10 for the aggregate, formal, informal, unemployed and retired households.

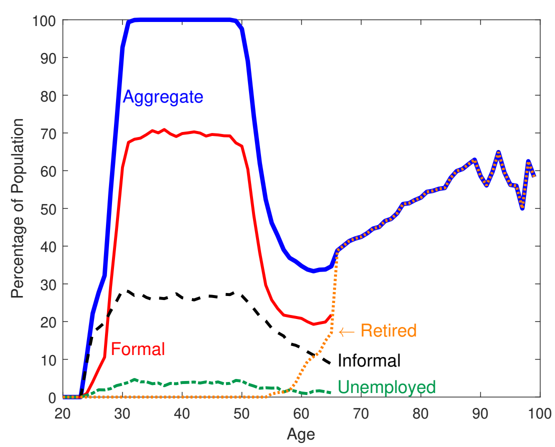


FIGURE 10 Percentage of population with welfare gains by age

The increase in working hours and the fall in consumption affects primarily to very young workers: virtually none of the workers between 20 and 23 years old register a welfare improvement. However, all workers between 30 and 50 years old enjoy a welfare gain that is mainly explained by the increase in leisure time induced by the optimal tax scheme. Then, 40% of retired population at 65 enjoy a welfare gain, and this propotion increases as individuals grow old. However, part of these dynamics can be explained by the dead of retirees.

These results have an important political economy implication. Overall, 59.8% of the population benefits from the reform, so if the policy change is subject to a referendum that requires simple majority for implementation, and assuming that households vote rationally, then the proposal would win the vote. Moreover, if we look at how heterogeneous groups would vote in such referendum, we find that 42.5% of formal workers, 19.8% of informal workers, 2.6% of unemployed and 52.7% of retirees would vote in favor of the reform.

5.3 | Distributive Effects

The optimal tax scheme produces differentiated mandatory contributions to the pay-as-you go social security system for different age groups and comes together with a progressive income tax that is basically the current scheme according to Ecuadorian tax laws. However, the main difference compared to the status quo, is that the optimal tax scheme shifts tax revenue from the government to the pension fund, reducing the redistributive capacity of the labor income progressive tax scheme. With this in mind, in this section we study how the implementation of the optimal tax reform affects the distribution of wealth, consumption and after tax labor income. Table 11 presents the percentage variation in the the Gini coefficients of this distributions.

TABLE 11 Variations in the Gini coefficients

Variable	% Variation
Wealth	–5.79
Consumption	+2.09
Disposable Income	+15.51

What we find is that the optimal tax system is very effective at reducing wealth inequality, producing a fall in the Gini coefficient of 5.8%. The driver of this result relies on the intergenerational transfers produced by the form of the age-dependent contributions scheme and the increase of the size of the pensions fund. However, the cost of this reduction are increases in both after-tax labor income (15.5%) and consumption (2.1%), which comes in hand with the severe reduction in taxable income for formal workers during their most productive years, thus affecting the progressiveness of the tax system in general.

6 | SENSITIVITY ANALYSIS

As any quantitative assessment based on general equilibrium modelling, our results depend on some specific assumptions we have made, particularly on the structure of the labor market and access to the retirement fund. In this section we want to analyze how three of our most salient assumptions affect the optimal design and how they affect our comparative statics exercise.

TABLE 12 Calibrated parameters for sensitivity analysis scenarios

Parameter	Substitutes	Simple Productivity	Deterministic Retirement
χ	0.2502	0.4196	0.4409
β	1.0310	1.0280	1.0313
σ_μ	0.4461	0.4849	0.4257
σ_η	0.0835	0.0663	0.0603
ζ	1.2329	–	1.4140

We propose three alternative scenarios in which we ask the planner to recompute the optimal tax scheme using the equivalent version of the aggregate welfare function applicable to each alternative setting. The calibrated parameters for each alternative are presented in Table 12.

One of our main concerns is how much our results could be affected if we increase the elasticity of substitution between formal and informal labor in the production function. The reason for this is that if the production technology allows the firm to substitute both type of workers more easily, the firm could potentially shift all its labor demand towards the informal sector, reducing the leeway that the planner has to increase the contribution rates. Thus, in the first scenario we increase the elasticity of substation, so instead of having $\gamma \to 0$ we set $\gamma = 0.2$, which implies an elasticity of substitution between formal and informal labor of 1.25.[11]

Second, we want to assess how differentiated age-specific productivity contributes to the results. The reason why this is important is that this productivity profile affects average productivity along the life cycle, thus having a direct effect on the shape and level of the optimal contributions scheme. To make this assessment, we estimate age-specific productivity using labor surveys *without* conditioning the estimation on occupational status, so we end up with a unique age-specific productivity profile. This assumption will also affect equilibrium wages, so we are giving up the possibility to calibrate the model to match the formality premium that we observe in the data.

Third, in the benchmark model we are assuming that retirement is stochastic and only a fraction of retired population has access to the retirement fund. These assumptions straighten the longevity savings motive, and the planner tends to increase contribution rates in order to increase the size of the pensions fund and reduce attenuate overall risk perceived by the household. Thus, in the third scenario we assume that retirement is deterministic and that all retirees have access to the pensions fund.

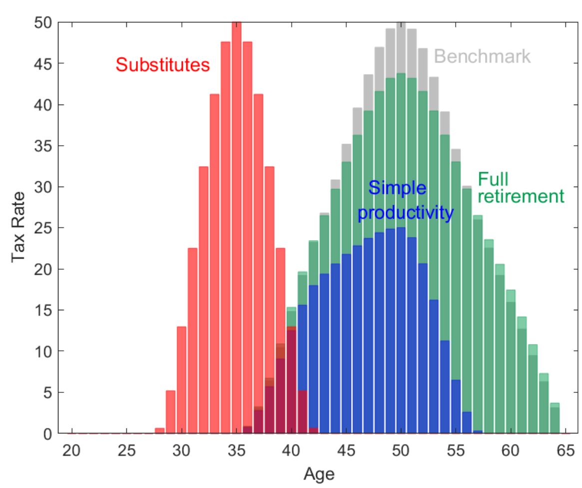


FIGURE 11 Alternative optimal schemes against benchmark economy

As it can be seen in Figure 11, the hump-shaped profile of contribution rates along the life cycle persists in all scenarios. However, relaxing each of the proposed assumptions brings significant quantitative changes in the optimal tax reform. In this regard, we when increase substitution between formal and informal labor, strictly positive tax rates concentrate between 28 and 42 years old (compared to 36 to 64 years old in the status quo), and the top contribution rate of 50% occurs at 35. Within this age-range the productivity difference

[11] We are thankful to Lian Allub for making us think about this possibility.

between formal and informal labor is small compared to the growing gap that occurs after age 46. In spite of this sensible change in the contribution rates profile, the progressive labor income tax scheme is slightly modified from the benchmark optimal, with a small reduction in the top marginal tax rate from 35% to 33.6%. All these changes are the response of the system to an increase in the labor demand elasticity.

Differentiated productivity levels for the formal and informal sectors is key for our quantitative results. If we do not take this difference into account, as we do in the second scenario, then the age range with strictly positive contribution rates lies between 36 and 57 years old (i.e. 7 years shorter than the benchmark span), with a maximum contribution rate of about 25% that occurs when agents reach 50 years old (same as benchmark, with a tax rate that is cut in half). There is also a major contraction in the top marginal tax rate applied to formal workers from 35% to only 8%. Most of these differences are because, under a unique age-specific productivity profile, average overall productivity falls considerably, reducing the payment capabilities of most formal households.

These results, however, deserve further analysis. In particular, notice that the difference in age-specific productivity present in the benchmark economy allows formal households to insure themselves against the shocks that are present in the economy. On the other hand, when age-specific productivity is the same in both sectors, formal households only benefit from the wage differential that occurs in equilibrium (much higher in the sensitivity scenario than in the benchmark), but see increased opportunity costs the moment that the planner chooses to increase labor income tax rates and contributions. Thus, at very high contribution and tax rates, households cut back in their labor supply, making the planner to be shy on the maximum levels.

Stochastic retirement, on the other hand, is the most innocuous assumption with respect to the optimal contribution rates profile. Specifically, it only affects the maximum tax rate, which is 45%. The reduction in the optimal labor income tax scheme is shallow as well, moving to a maximum marginal tax rate of 34.1%. In this sense, since all the elderly is covered by the social security system, the transfer can be set lower than in the benchmark economy to cover the reduced longevity risk.

To have a sense of the changes triggered by the optimal policy schemes in each counterfactual we present variations in main aggregates and the welfare decomposition in Table 13. Variations in aggregates are consistent with the differences found in the optimal tax schemes. Specifically, the results hardly change when stochastic retirement is removed from the model but have significant discrepancies when looking at the other two scenarios.

We first look at changes in the composition of the labor supply. Recall from the previous section that in our benchmark model, hours worked contracted 2.7%, producing a deeper reduction of 3.5% in labor supply. Both contractions are entirely driven by a 5.8% and 6.5% in formal hours worked and labor supply respectively, and in spite of increases of 6.7% and 5.9% in informal hours worked and labor supply, respectively. These results showed the significant productivity drop triggered by the reform, and mainly explained by the difference by sector in age-specific productivity.

In fact, in the model with a single age-specific productivity profile for both sectors, the fall in hours worked and labor supply is quite moderate (less than 1% in both cases). But, what is surprising, is that the dynamics within the structure of labor supply changes: in this scenario informal labor is the most affected, with contractions of 3.7% and 3.9% in hours worked and effective labor supply, respectively. Thus, without considering the inherent productivity differentials between the formal and informal sector, the model actually predicts that the optimal tax scheme would reduce informality despite the higher average tax rate faced by formal workers over their life cycle.

The assumption on the degree of sustainability between formal and informal labor on

TABLE 13 Sensitivity analysis: Aggregate results and Welfare Decomposition

Variable	% Variation			
	Optimal	**Substitutes**	**Simple Productivity**	**Deterministic Retirement**
Hours worked	-2.66	-1.41	-0.66	-2.72
Formal	-5.78	-0.93	0.78	-5.2
Informal	6.71	-2.18	-3.72	4.92
Labor Supply	-3.47	-1.08	-0.85	-3.42
Formal	-6.52	-0.65	0.56	-5.89
Informal	5.89	-1.92	-3.92	4.23
Consumption	-0.97	1.49	1.32	-0.55
Output	-1.11	-0.1	1.46	-0.84
Capital Stock	1.69	1.16	4.54	2.32
SS Fund	10.63	-10.67	-8.47	10.12
CEV	2.92	4.48	4.21	4.13
Consumption	-0.98	1.42	1.23	-0.47
Level	-0.97	1.49	1.32	-0.55
Distribution	-0.01	-0.06	-0.08	0.08
Leisure	3.9	3.05	2.98	4.6
Level	1.37	0.9	0.33	1.39
Distribution	2.53	2.16	2.64	3.21

the demand side also produces a contraction in both hours worked and labor supply (1.4% and 1.1% respectively). Again, this assumption also produces changes in the composition of labor supply: the optimal reform produces a reduction of 0.9% and 2.2% in formal and informal hours worked, that translates into contractions of 0.7% and 1.9% in effective labor supply. Since the fall in labor supply is more shallow than the reduction in hours worked, we see that the reform displaces less productive workers in both sectors.

The optimal tax reform also triggers different responses depending on the specific assumptions of these two scenarios. While consumption falls in 1.0% in the benchmark economy, it increases in 1.5% and 1.3% in the increased substitution and simple productivity scenarios, respectively. Something similar occurs with the capital stock, which increases in 1.2% and 4.5% in each scenario.

In the case of the increased substitution scenario, the increase in the capital stock is not enough to overcome the contraction in effective labor supply and, as a result, output falls in 0.1%. When looking at the simple productivity setting, on the other hand, the increase in the capital stock is much stronger than the fall in effective labor, so output increases in 1.5%. It is worth emphasizing that this scenario is the only setting in which the optimal tax scheme does not have a contractionary effect on output.

Another point that is relevant for our discussion is that the increase in the size of the social security fund that we obtain in the benchmark (10.6%) is very sensible to assumptions made over the degree of substitution between both types of labor and the behavior of age-specific productivity. In both scenarios we observe shrinking of the social security fund triggered by the optimal tax reform of 10.7% and 8.5% respectively.

How do these aggregate responses translate into welfare variations? The bottom panel of Table 13 provides an answer to this question. The first thing to notice is that the benchmark economy produces the most moderate welfare gain compared to all the alternatives (less than 3% versus welfare gains higher than 4% in all cases). Moreover, the economy with deterministic retirement is very similar to the benchmark, only that the welfare contraction produced by consumption is weaker (0.5%) while the welfare gain produced by higher level and better distribution of leisure is stronger (4.6%).

On the contrary, in the scenarios with increased substitution and single productivity profile for both sectors the welfare gain triggered by the reform can be decomposed in positive contributions of consumption and labor. In fact, in both cases the welfare gain explained by consumption is about 30% of the total welfare gain. Moreover, there are only incipient negative contributions to welfare produced by worsening of the distribution of consumption, with negative contributions of 0.1% in both scenarios.

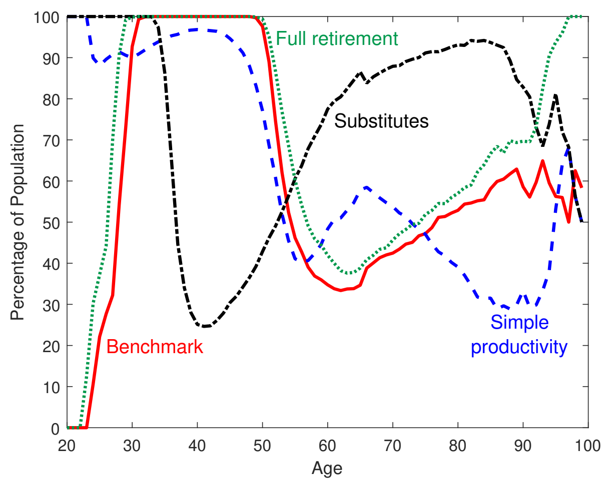


FIGURE 12 Welfare gain by age for alternative optimal schemes

We end this section by computing the proportion of the population that observes positive variations in their discounted flow of remaining utility conditional on their age (Figure 12). The profile of welfare gain generated by the economy with deterministic retirement follows the same dynamics as the benchmark economy, with an increased proportion of workers that exhibit utility gains at all ages. However, the intriguing result in this analysis is that, contrary to the benchmark and the economy with deterministic retirement, the optimal reform generates welfare gains in most of very young workers in the scenarios with increased substitution and single productivity profile.

Moreover, only by looking at the age profiles of welfare gains, is very difficult to analyze which scenario generates the highest proportion of population with increased utility. This is important because of its political economy implications. Thus, to provide this ranking, we compute the proportion of the population that registers utility gains, and assume that each agent with increased utility would vote in favor of the reform, if subject to a referendum. As in the benchmark economy, it turns out that the optimal tax reform would win a simple majority referendum in all the scenarios. Moreover, in the scenarios with deterministic retirement and increased substitution between formal and informal labor, the reform would win with 68.7% and 75.1% of the votes, implying that the reform would win with absolute majority (two thirds of valid votes). These results show, again, that the benchmark economy provides the most conservative results in every respect.

7 | COMPARISON TO A DEVELOPED ECONOMY

One of the most important contributions of this paper is to provide a quantitative assessment of the theory of age-dependent taxation in an emerging market context. In this section we ask how our results would change if we perform the policy optimization in a model designed and calibrated for a developed economy, in particular, the United States. The reasons to choose the United States as our example of a developed economy should be obvious, since most of the literature on age-dependent taxation is based on this economy.

Adapting the model to a developed economy implies a simplification of the model along several directions. The most salient modification is the structure of the labor market, since informality is not usually seen as a feature that characterizes developed economies. In this line, we simplify the labor market and assume full employment, which implies that the production function in this setting is a simple Cobb-Douglas.

Another modification in the design of the model is related to retirement and the structure of the social security system. In particular, we assume deterministic retirement (everyone retires at 65, everyone has access to the retirement fund) and the entire fund is distributed among retirees.

Finally, we need to recalibrate the entire model, adapting all the parameters to the case of the United States. The most important modifications are related to survival risk and age-specific productivity profiles, which we already discussed in the estimation section of the paper. Other major changes include: a reduction in the capital share (0.36 for the US), an increase in the ratio of total government consumption with respect to GDP (17%), and changes in capital income tax rate (28.3%), the minimum and maximum marginal tax rates of the labor income tax scheme (10% and 39.6% respectively) and the payroll tax rate (12.4%). In general, the specifics of this alternative calibration follow Conesa et al. (2009) and Krueger and Ludwig (2016) closely. In table 14 we present the results for the calibrated parameters that we obtain from the Simulated Method of Moments, and compare the results to Ecuador's calibration for completeness.[12]

TABLE 14 Households' preferences calibrated parameters for the United States

Parameter	Target	Value ECU	Value USA
σ_1	Literature	2.0000	2.0000
σ_2	Literature	3.0000	3.0000
χ	Average hours worked	0.4398	0.7127
β	Steady-state capital-output ratio	1.0310	0.9988
σ_μ	Variance of log income at age 22	0.4295	0.4133
σ_η	Variance of log income at age 60	0.0524	0.1646
ρ_η	Linear inc. in variance of log income	0.9900	0.9900

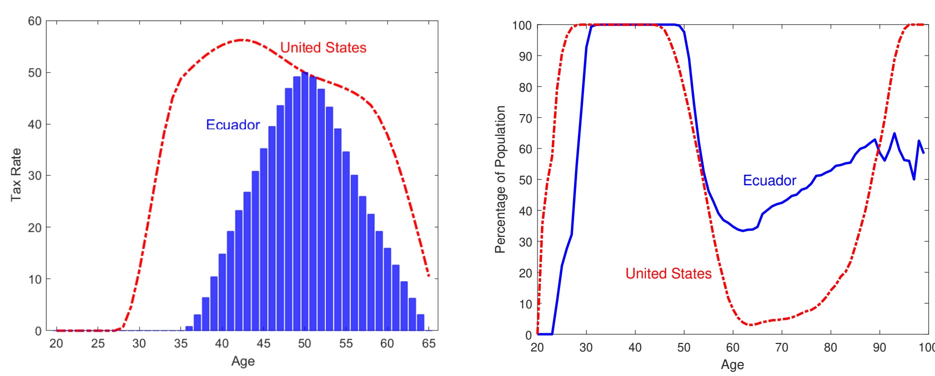
The values of the calibrated parameters show additional structural differences between the two economies. One of the main differences between the two is the level of age-specific productivity, which is much higher in the United States. Since average hours worked is about the same in the two economies, the calibration for χ (the relative weight of leisure in the utility function, needs to be much higher in the US calibration (0.44 in Ecuador versus 0.71 for the United States). Something similar occurs for the steady state capital-output ratio and the calibration of β, which needs to be very high in Ecuador's calibration.

[12] A detailed description of the model and its calibration is available from the authors upon request.

The calibration of the standard deviation of the innovation in the $AR(1)$ process followed by the productivity shock is about the same in the two settings. However, the value for the standard deviation of the fixed effect is much higher for the US (0.16 versus 0.05 for Ecuador). The reason for this is that most of the variance of log income during young ages in Ecuador is explained by occupational status and the difference in age-specific productivity for formal and informal workers. Since this mechanism is absent in the model for the US, we need to generate income variation at early stages of the life cycle through the (exogenous) ability fixed effect.

Given the changes in the structure and calibration of the model, it is expected for results to vary significantly for a developed country. We present the optimal tax schedule in panel 13a of Figure 13. Given that productivity is much higher in the US and the absence of occupational risk, workers are able to sustain contribution rates that are much higher compared to Ecuador, and significantly higher (on average) compared to the status quo in that Economy. In particular, US workers start contributing to the social security system at age 27 and keep contributing until they retire.

But the difference is not only qualitative, but also quantitative. While in Ecuador the average contribution rate in the optimal reform is 14.2% (50% higher than in the status quo), in the United States this average rises to 30.0%, which is 2.4 times the level in the status quo. However, in spite of having a huge increase in social security contributions, the optimal labor income tax scheme implies that the lowest marginal tax rate should be about 0.1%, while the top marginal tax rate is 14.6% (a severe cut from the 39.6% rate in the status quo). This implies that in the United States the shift from funding government expenditure to funding the retirement fund is stronger than in the case of Ecuador.



(a) Optimal Contributions Scheme

(b) Welfare Gain Age Profile

FIGURE 13 Optimal Social Security Contributions Scheme and Welfare Gains Age Profile: Ecuador versus United States

Regarding the utility increase profile over the life cycle, we observe that in the case of the United States there is more concentration of workers with welfare gains early in the life cycle, a severe drop for workers older than 50 years old, and then a reversal for the last 10 years alive. Thus, the reform in the US mostly benefits young workers, since they face lower effective tax rates on their labor income and reduced longevity risk which is partially insured by higher contributions to the retirement fund.

To finish, we perform again the political economy exercise of asking whether the optimal policy would win a referendum where each household votes in favor in the have a utility increase and the policy is implemented if the election is won by simple majority. We see that in the US economy 55.4% of the population would vote for the reform, which is enough to win the referendum. However, this proportion is lower compared to the 59.8% vote in favor of the reform that would be obtained in Ecuador.

8 | CONCLUSION

The purpose of this paper was to study the design and welfare implications of an optimal age-dependent taxation scheme for an emerging economy characterized by a labor market that exhibits high levels of informality and lower productivity compared to developed economies. In particular, we allowed the planner to set age-dependent contribution rates to the social security fund, and the marginal tax rates of a progressive tax scheme levied over labor income. Since both schemes were treated as separate policy instruments, we were able to understand how they interact and how the planner prioritizes alleviating intergenerational vs. cross-sectional inequality. Moreover, to have a clear perspective on how the characteristics of an emerging market might influence the design of the optimal tax scheme, we allow the planner to repeat the optimization within the context of a developed economy.

The model for the emerging market, calibrated for Ecuador, consisted on an overlapping generations economy where households faced uninsured idiosyncratic risk and partially insured occupational risk, stochastic retirement, stochastic access to the pensions fund, age-specific productivity differentiated for the formal and informal sectors and fixed ability types determined at birth. Occupational risk refers to the possibility that formal workers endure moving to the less productive and uninsured informal sector or unemployment.

The context of the developed economy was simpler. In particular, we eliminated occupational risk and set deterministic retirement and access to the pension fund. Moreover, the model was calibrated for the United States, so one of the main differences with respect to the model calibrated for Ecuador was that the average worker in the US is (significantly) more productive than the average worker in Ecuador, within comparable age groups.

To design the optimal tax scheme, we used a utilitarian welfare function where the discounted utility of each individual was accounted for, weighted by the proportion that each age group represents within the overall population. We found that the optimal contribution scheme is hump-shaped, provides a contribution exemption for workers up to age 35, and reaches a maximum contribution rate of 50% at age 50. On average, workers end up contributing a nominal rate of 14.2%, which is 50% higher than the contribution rate in the status quo. Moreover, to our surprise, we found that the status quo marginal tax rates of the progressive labor tax scheme coincide with the ones chosen optimally by the planner. When subjecting the reform to a referendum where we assume that households with increased utility with respect to the status quo vote in favor of the reform, we found that 59.8% of the population would vote in favor, implying that the reform would win by a simple majority.

When we looked at how the planner would act in the case of the US economy, we found that the optimal contribution scheme is hump-shaped as well, but the exemption ends much earlier than in the emerging market (at 27 years). The maximum tax rate of 56.2% is reached when workers are 46 years old, and, overall, the nominal average contribution rate is 30%, which is about 2.4 times the level in the status quo (12.4%). Regarding the design of the progressive labor income tax scheme, we find that the lowest and highest marginal tax rates drop to 0.1% and 14.6%, respectively, showing that within this economy, the planner performs a severe shift from funding the government to increase the size of the pensions fund. We repeated the political economy exercise for the US and found that 55.4% of the population would vote in favor of the reform, again implying that it would win by a simple majority.

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